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# INFLUENCE OF BACKPACK LOAD ON POSTURE AND GAIT BIOMECHANICS IN SCHOOL-AGED CHILDREN

*Original Research*

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## ABSTRACT

**Background:** School-aged children frequently carry backpacks that exceed safe weight limits, placing them at risk of postural deviations and altered gait mechanics. International guidelines recommend that backpacks should not exceed 10–15% of a child's body weight, yet students in Pakistan, particularly in urban areas like Lahore, often carry loads beyond this range. This can lead to forward trunk inclination, spinal misalignment, shoulder asymmetry, and compromised gait, ultimately affecting musculoskeletal development and physical wellbeing.

**Objective:** To evaluate the impact of varying backpack weights on postural alignment and gait biomechanics in school-going children using the Posture and Postural Ability Scale (PPAS).

**Methods:** A cross-sectional study was conducted from August 2024 to January 2025 across five public and private schools in Lahore. A total of 200 children aged 8–14 years were selected using stratified random sampling. Participants were divided into three groups based on backpack weight as a percentage of body weight: Light Load (<10%), Moderate Load (10–15%), and Heavy Load (>15%). Postural assessments were performed using the PPAS, which scores from 1 (normal) to 7 (severe deviation). Gait parameters, including stride length (cm), walking speed (m/s), and step frequency (steps/min), were recorded. Data were analyzed using SPSS v25, with significance set at $p < 0.05$.

**Results:** Students in the Heavy Load group demonstrated significantly higher forward trunk lean (5.2 ± 1.1), shoulder asymmetry (6.1 ± 1.4), and postural instability (5.6 ± 1.3) compared to the Light Load group (1.8 ± 0.9, 2.1 ± 0.7, and 1.9 ± 0.8, respectively; $p = 0.000$). Stride length decreased from 55.3 ± 4.2 cm to 45.8 ± 6.0 cm, walking speed reduced from 1.2 ± 0.2 m/s to 0.8 ± 0.1 m/s, and step frequency dropped from 110 ± 5 to 98 ± 6 steps/min in Heavy Load group ($p = 0.000$).

**Conclusion:** Excessive backpack weight significantly affects postural control and gait biomechanics in children, increasing the risk of long-term musculoskeletal complications. The PPAS proved effective in detecting postural deviations. School-based interventions and ergonomic guidelines are critical to mitigate these risks.

**Keywords:** Backpack weight, Biomechanics, Gait, Musculoskeletal health, Postural balance, Posture, School children.

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## INTRODUCTION

Backpacks are an essential part of daily life for school-aged children, serving as a practical means to carry books and educational supplies. While their use is nearly universal, concerns have emerged regarding the physical strain imposed by excessive backpack loads. Research consistently demonstrates that carrying a backpack exceeding 10–15% of a child's body weight can adversely affect spinal posture and gait mechanics, potentially leading to musculoskeletal discomfort, chronic pain, and postural deformities (1,2). Alterations such as increased trunk inclination, forward head posture, and asymmetrical weight distribution have been documented, suggesting long-term implications for musculoskeletal health if these conditions persist (3,4). In the context of Pakistan, particularly urban areas like Lahore, this issue is exacerbated by academic pressures, institutional requirements to carry multiple textbooks, and limited access to digital or locker-based alternatives (5). Consequently, many schoolchildren are burdened with disproportionately heavy backpacks for extended periods. Despite mounting anecdotal evidence and parental concerns, the issue remains under-researched locally, leaving a critical gap in understanding how these biomechanical stressors influence the physical development of Pakistani schoolchildren (6).

International studies conducted in countries such as the United States, Australia, and the United Kingdom have shown that carrying heavy backpacks negatively affects dynamic balance and gait patterns. Observed changes include shorter stride length, reduced walking speed, and increased double support time, all indicative of compensatory movement adaptations aimed at coping with abnormal spinal loading (7,8). These biomechanical alterations not only impair functional mobility but also contribute to fatigue and inefficient energy expenditure, potentially discouraging physical activity in young children (9,10). Postural stability and gait integrity are fundamental to healthy child development. Efficient musculoskeletal function ensures proper coordination, minimizes injury risk, and supports academic participation through physical readiness (11). When exposed to continuous mechanical stress due to excessive backpack weight, children often exhibit compensatory strategies, including increased forward flexion of the trunk, pelvic tilting, and curvature of the spine—all of which may predispose them to chronic pain syndromes and postural anomalies over time (11,12).

Assessment tools such as the Posture and Postural Ability Scale (PPAS) offer a standardized and quantifiable approach to evaluating posture under varying physical loads. Unlike traditional visual assessments, the PPAS allows clinicians and researchers to objectively score postural deviations, improving the reliability of outcomes in research settings (13). Evidence suggests that children carrying backpacks heavier than 15% of their body weight score higher on PPAS, indicating more pronounced postural instability and misalignment (14). Given the lack of regional data and the observable increase in backpack-related musculoskeletal complaints among students in Lahore, there is a pressing need to investigate this issue using validated biomechanical and postural assessment tools. This study aims to evaluate the effects of varying backpack loads on postural alignment and gait biomechanics among schoolchildren using the Posture and Postural Ability Scale (PPAS). The objective is to provide evidence-based recommendations that can inform ergonomic interventions, parental guidance, and school-level policies aimed at minimizing the physical burden of backpack use and preventing long-term musculoskeletal consequences.

## METHODS

A cross-sectional study was carried out between August 2024 and January 2025 in five public and private schools located in Lahore, Pakistan. Schools were purposefully selected to ensure representation from a variety of socioeconomic backgrounds, enhancing the generalizability of findings across different student populations. Ethical approval for the study was obtained from the Institutional Review Board (IRB). Prior to data collection, informed written consent was obtained from the parents or legal guardians of all participating students, in accordance with ethical research standards. The study involved a total of 200 school-going children aged 8 to 14 years, selected through stratified random sampling to ensure balanced representation across age, gender, and school type. Children were eligible for inclusion if they were in good general health, had no history of musculoskeletal or neurological disorders, and regularly carried backpacks to school. Participants with a history of spinal deformities, orthopedic trauma, or those using assistive walking devices were excluded from the study to minimize confounding influences on gait and posture. Participants were stratified into three groups based on their backpack load as a percentage of body weight: Light Load (<10%), Moderate Load (10–15%), and Heavy Load (>15%).

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Backpack and body weights were measured using calibrated digital scales to ensure precision. This classification allowed for comparative analysis of postural and gait parameters across varying load intensities.

Postural assessment was performed using the Posture and Postural Ability Scale (PPAS), a validated and standardized tool designed to quantify postural alignment and control under both static and dynamic conditions (13). The PPAS scoring system ranges from 1 to 7, where scores of 1–2 represent normal posture, 3–4 reflect mild deviations, 5–6 indicate moderate deviations, and a score of 7 denotes severe postural instability. Children were assessed in upright standing and during functional movement, with specific attention given to spinal curvature, forward trunk lean, shoulder level asymmetry, and overall stability. Gait biomechanics were evaluated using a motion analysis protocol that included measurement of stride length (in centimeters), walking speed (in meters per second), and step frequency (in steps per minute). Stride length was defined as the distance between two consecutive heel strikes of the same foot, measured over a marked 10-meter walkway. Walking speed was recorded over the same distance, and step frequency was measured using a digital pedometer validated for pediatric gait assessment. All data were recorded and entered into SPSS version 25 for statistical analysis. Descriptive statistics were computed and presented as means with standard deviations. One-way Analysis of Variance (ANOVA) was applied to compare postural and gait differences among the three backpack load groups. A p-value of less than 0.05 was considered statistically significant, indicating meaningful differences in biomechanical outcomes.

## RESULTS

The study enrolled 200 schoolchildren, stratified into three groups based on backpack weight as a percentage of body weight: Light Load (<10%), Moderate Load (10–15%), and Heavy Load (>15%). The mean age of participants ranged from 10.5 ± 1.8 years in the Light Load group to 10.9 ± 1.9 years in the Heavy Load group, while mean body weight ranged from 32.5 ± 4.5 kg to 33.7 ± 5.3 kg. Average backpack weight increased progressively from 2.9 ± 0.4 kg in the Light Load group to 5.8 ± 0.6 kg in the Heavy Load group, corresponding to 8.9 ± 1.2%, 12.4 ± 1.5%, and 17.2 ± 2.1% of body weight, respectively. Postural assessment using the Posture and Postural Ability Scale (PPAS) demonstrated significant deviations associated with increasing backpack load. Forward trunk lean scores were notably higher in the Heavy Load group (5.2 ± 1.1) compared to the Moderate (3.7 ± 1.2) and Light Load groups (1.8 ± 0.9), with a p-value of 0.000. Shoulder asymmetry also followed a similar trend, increasing from 2.1 ± 0.7 in the Light Load group to 6.1 ± 1.4 in the Heavy Load group ($p = 0.000$). Postural stability scores declined substantially with increasing load, with the Heavy Load group scoring 5.6 ± 1.3 compared to 1.9 ± 0.8 in the Light Load group, indicating significantly reduced postural control ($p = 0.000$).

In terms of gait biomechanics, children in the Heavy Load group exhibited a shorter stride length (45.8 ± 6.0 cm) compared to those in the Light Load group (55.3 ± 4.2 cm), with a statistically significant difference ($p = 0.000$). Walking speed was reduced in the Heavy Load group (0.8 ± 0.1 m/s) relative to the Light Load group (1.2 ± 0.2 m/s), also statistically significant ($p = 0.000$). Step frequency showed a decreasing trend with increasing load, falling from 110 ± 5 steps/min in the Light Load group to 98 ± 6 steps/min in the Heavy Load group ($p = 0.000$). Further subgroup analysis by gender revealed variations in postural and gait parameters. Female participants exhibited slightly higher mean scores in forward trunk lean (3.8 vs. 3.5), shoulder asymmetry (4.3 vs. 4.2), and postural stability (4.2 vs. 3.9) compared to male participants. Similarly, gait performance differed modestly by gender, with females demonstrating shorter stride length (49.5 cm vs. 51.1 cm), slower walking speed (0.98 m/s vs. 1.01 m/s), and reduced step frequency (102 vs. 105 steps/min), indicating that girls may be more susceptible to postural strain and gait disruption under heavy backpack loads. To assess the predictive effect of backpack weight on postural and gait outcomes, linear regression models were applied after adjusting for age and body weight. The model examining forward trunk lean identified backpack weight percentage as a significant predictor ($\beta = 0.325$, $p < 0.001$), while age and body weight did not show significant influence. This suggests that backpack load intensity independently contributes to postural deviations. Likewise, in the model evaluating stride length, backpack weight percentage was inversely associated with stride length ($\beta = -0.724$, $p < 0.001$), confirming that heavier loads shorten walking stride regardless of age or body weight. Body weight showed a marginal effect ($\beta = -0.147$, $p = 0.051$), indicating a potential moderating role in gait dynamics.

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**Table 1: Demographic Characteristics of Participants**

| Variable | Light Load (<10%) | Moderate Load (10–15%) | Heavy Load (>15%) |
|---|---|---|---|
| Number of Students | 70 | 65 | 65 |
| Mean Age (years) | 10.5 ± 1.8 | 10.7 ± 1.6 | 10.9 ± 1.9 |
| Mean Body Weight (kg) | 32.5 ± 4.5 | 33.0 ± 5.1 | 33.7 ± 5.3 |
| Mean Backpack Weight (kg) | 2.9 ± 0.4 | 4.1 ± 0.5 | 5.8 ± 0.6 |
| Backpack % of Body Weight | 8.9 ± 1.2 | 12.4 ± 1.5 | 17.2 ± 2.1 |

**Table 2: Effect of Backpack Load on Posture (PPAS Scores)**

| Posture Parameter | Light Load | Moderate Load | Heavy Load | P-value |
|---|---|---|---|---|
| Forward Trunk Lean | 1.8 ± 0.9 | 3.7 ± 1.2 | 5.2 ± 1.1 | 0.000 |
| Shoulder Asymmetry | 2.1 ± 0.7 | 4.5 ± 1.3 | 6.1 ± 1.4 | 0.000 |
| Postural Stability | 1.9 ± 0.8 | 3.9 ± 1.1 | 5.6 ± 1.3 | 0.000 |

**Table 3: Effect of Backpack Load on Gait Biomechanics**

| Gait Parameter | Light Load | Moderate Load | Heavy Load | P-value |
|---|---|---|---|---|
| Stride Length (cm) | 55.3 ± 4.2 | 50.1 ± 5.1 | 45.8 ± 6.0 | 0.000 |
| Walking Speed (m/s) | 1.2 ± 0.2 | 1.0 ± 0.1 | 0.8 ± 0.1 | 0.000 |
| Step Frequency (steps/min) | 110 ± 5 | 105 ± 7 | 98 ± 6 | 0.000 |

**Table 4: Subgroup Differences by Gender**

| Gender | Forward Trunk Lean | Shoulder Asymmetry | Postural Stability | Stride Length (cm) | Walking Speed (m/s) | Step Frequency (steps/min) |
|---|---|---|---|---|---|---|
| Male | 3.50 | 4.17 | 3.86 | 51.14 | 1.01 | 105.33 |
| Female | 3.80 | 4.28 | 4.18 | 49.49 | 0.98 | 101.66 |

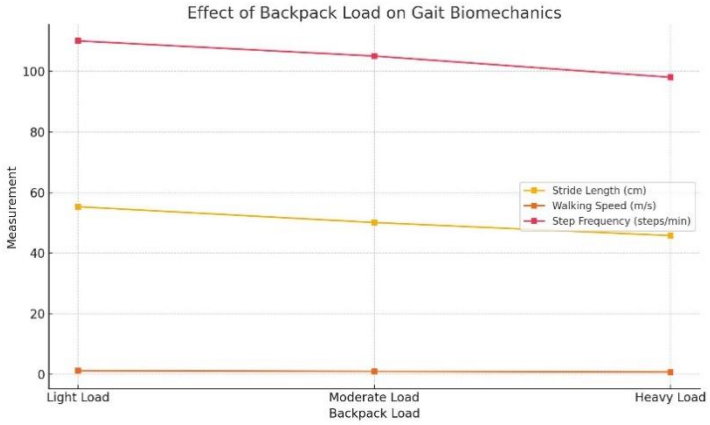


*Figure 1 Effect of Backpack Load on Gait biomechanics*

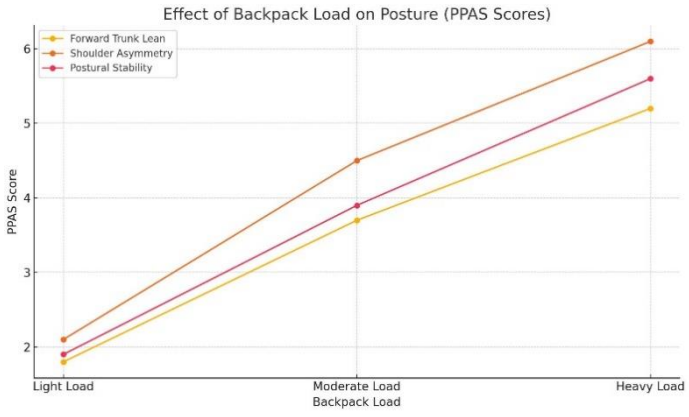


*Figure 2 Effect of Backpack Load on Posture (PPAS Scores)*

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## DISCUSSION

The findings of this study offer compelling evidence that excessive backpack weight has a significant impact on both posture and gait biomechanics among school-aged children. These outcomes reinforce previous literature that has consistently identified the adverse musculoskeletal effects of carrying schoolbags exceeding recommended load thresholds. The structured assessment using the Posture and Postural Ability Scale (PPAS) facilitated a reliable evaluation of postural deviations and highlighted a clear pattern of increasing trunk lean, shoulder asymmetry, and reduced postural stability with rising backpack weight. The evidence supports the notion that forward trunk inclination is a compensatory adaptation to posterior load displacement, increasing mechanical stress on the spine and potentially contributing to chronic musculoskeletal conditions (15,16). Notably, forward trunk lean emerged as a key indicator of postural strain, correlating with increased spinal curvature and potential long-term consequences such as lumbar stress and lower back pain. These findings are aligned with previous reports that observed greater spinal inclination and postural disruption in children carrying backpack loads beyond 15% of their body weight (17). Similarly, elevated shoulder asymmetry scores in the heavier load group point toward unequal muscle recruitment and postural compensation, which may elevate the risk of spinal misalignment, including scoliosis or compensatory muscular fatigue (18).

In parallel, significant impairments in gait parameters were observed, including shortened stride length, decreased walking speed, and reduced step frequency. These adaptations are indicative of biomechanical compromise, likely adopted by children to preserve balance under the strain of excessive loading. Such compensatory patterns were previously associated with increased muscular effort, fatigue, and restricted mobility, echoing current findings that show a substantial deviation from normative gait mechanics under heavier loads (19,20). The reduction in step frequency and stride length signals inefficient locomotion, which can curtail children's physical activity levels and contribute to fatigue-related limitations during school hours and beyond (21). This problem holds particular importance in the context of Pakistan, where school systems in many urban areas lack digital learning infrastructure and adequate locker facilities. Consequently, students are often compelled to transport multiple heavy textbooks daily. In contrast to educational systems in countries with better logistical support, the burden placed on Pakistani students places them at heightened risk of musculoskeletal strain. These findings stress the urgent need for policy-level interventions that enforce backpack weight regulations and promote the use of ergonomically designed schoolbags. Evidence from other research shows that padded shoulder straps, waist belts, and even dual-compartment bag designs can distribute weight more evenly and minimize postural disruption (22,23).

Among the strengths of this study was the use of a validated, quantitative assessment tool (PPAS) that allowed for objective comparison of postural deviations across load groups. The incorporation of both postural and gait-related outcomes provided a holistic view of the biomechanical burden of backpack use, enhancing the study's clinical relevance. Furthermore, stratified random sampling and inclusion of both public and private schools helped ensure diversity in the sample, lending greater credibility to the observed patterns. However, limitations must be acknowledged. As a cross-sectional study, it only captured short-term biomechanical outcomes without assessing the potential long-term effects of repeated exposure to heavy backpack loads. Musculoskeletal outcomes such as chronic pain, spinal deformities, or reduced functional mobility were beyond the study's temporal scope and should be addressed in future longitudinal investigations. Additionally, while the PPAS offered valuable insights, advanced motion capture technologies could yield more precise biomechanical data, particularly regarding joint kinematics and dynamic balance. Another limitation was the geographic concentration of the study in Lahore, which may restrict the applicability of findings to children in other regions of Pakistan, especially rural areas where infrastructural and socioeconomic challenges may differ. Moreover, gender- and age-based variations in postural response, although briefly analyzed, warrant more detailed exploration in larger samples to determine whether younger children or females are disproportionately affected by load-related biomechanical changes. Future studies should aim to integrate electromyographic and kinematic analyses to better understand the physiological strain on spinal and lower limb musculature during load carriage. Educational and ergonomic interventions could also be evaluated longitudinally to assess their efficacy in reducing the biomechanical burden. Overall, these findings emphasize the pressing need for preventive strategies, including school policy reforms, public health education, and ergonomic innovations, to safeguard the musculoskeletal health of schoolchildren.

## CONCLUSION

This study concludes that excessive backpack weight has a detrimental effect on postural alignment and gait biomechanics in school-aged children, highlighting a significant risk to their musculoskeletal health. The presence of forward trunk lean, compromised gait patterns, and reduced postural stability among students carrying heavier loads reflects the physical strain imposed by improper load

carriage. These findings underscore the importance of introducing practical measures such as awareness initiatives, ergonomic backpack designs, and policy-level changes within schools to regulate backpack weight. By addressing these factors, it is possible to prevent long-term postural deformities and promote healthier physical development in children, particularly within the Pakistani educational context.

**AUTHOR CONTRIBUTION**

| Author | Contribution |
|---|---|
| Intsam Aslam | Substantial Contribution to study design, analysis, acquisition of Data<br>Manuscript Writing<br>Has given Final Approval of the version to be published |
| Amina Shameen | Substantial Contribution to study design, acquisition and interpretation of Data<br>Critical Review and Manuscript Writing<br>Has given Final Approval of the version to be published |
| Nazeer Ahmed | Substantial Contribution to acquisition and interpretation of Data<br>Has given Final Approval of the version to be published |
| Muhammad Asif Javed* | Contributed to Data Collection and Analysis<br>Has given Final Approval of the version to be published |
| Kirn Arshad | Contributed to Data Collection and Analysis<br>Has given Final Approval of the version to be published |
| Muhammad Aqeel | Substantial Contribution to study design and Data Analysis<br>Has given Final Approval of the version to be published |

## REFERENCES

1. Kyung MG, Bak PR, Lim JW, Lee DO, Park GY, Lee DY. The effect of backpack load on intersegmental motions of the foot and plantar pressure in individuals with mild flatfoot. J Foot Ankle Res. 2022;15(1):76.
2. Wang HH, Tsai WC, Chang CY, Hung MH, Tu JH, Wu T, et al. Effect of Load Carriage Lifestyle on Kinematics and Kinetics of Gait. Appl Bionics Biomech. 2023;2023:8022635.
3. Machado Á S, Priego-Quesada JI, Jimenez-Perez I, Gil-Calvo M, Carpes FP, Perez-Soriano P. Effects of different hydration supports on stride kinematics, comfort, and impact accelerations during running. Gait Posture. 2022;97:115-21.
4. Mexi A, Kafetzakis I, Korontzi M, Karagiannakis D, Kalatzis P, Mandalidis D. Effects of Load Carriage on Postural Control and Spatiotemporal Gait Parameters during Level and Uphill Walking. Sensors (Basel). 2023;23(2).
5. Krajewski KT, Bansbach HM, McLean L, McKenzie C, Rawcliffe A, Graham SM, et al. Effects of Short-Term Unilateral Strength Training on Measures of Postural Control When Wearing "Operationally Relevant" Backpack Loads. J Strength Cond Res. 2020;34(10):2743-50.
6. Dai Y, Li J, Cui W, Li J. The effects of shoulder morphology on the distribution of shoulder pressure during load carriage. Ergonomics. 2024:1-20.
7. Mrozkowiak M, Stępień-Słodkowska M. The effects of the weight of school supplies carried on the right or left shoulder on postural features in the sagittal and transverse planes in seven-year-old pupils of both genders. Acta Bioeng Biomech. 2021;23(3):33-45.
8. Genitrini M, Dotti F, Bianca E, Ferri A. Impact of Backpacks on Ergonomics: Biomechanical and Physiological Effects: A Narrative Review. Int J Environ Res Public Health. 2022;19(11).
9. Hell AK, Braunschweig L, Grages B, Brunner R, Romkes J. [The influence of backpack weight in school children: gait, muscle activity, posture and stability]. Orthopade. 2021;50(6):446-54.
10. Balkó Š, Tufano JJ, Jelínek M, Svoboda Z, Błaszczyszyn M, Vaverka F. Influence of school backpack load on plantar foot pressure during walking in 9-11 years old girls. Cent Eur J Public Health. 2022;30(3):185-9.
11. Sturdy JT, Rizeq HN, Whittier TT, Daquino CJ, Silder A, Corman AC, et al. Joint moments and muscle excitations increase with body-mass normalized backpacks across walking slopes. Gait Posture. 2025;120:234-41.

12. Jiang T, Tian S, Wang L, Fan Y. Multi-joint protective effects of lumbar brace on lumbar, hip, knee, and ankle in parachute landing with backpack load. Med Biol Eng Comput. 2023;61(12):3279-87.
13. Bajin M, Kojić M, Romanov R, Ahmetović Z. Neglected problem: Influence of school bag on lumbar segment in children. Front Pediatr. 2022;10:1045666.
14. Huang L, Yang Z, Wang R, Xie L. Physiological and biomechanical effects on the human musculoskeletal system while carrying a suspended-load backpack. J Biomech. 2020;108:109894.
15. Sankaran S, John J, Patra SS, Das RR, Satapathy AK. Prevalence of Musculoskeletal Pain and Its Relation With Weight of Backpacks in School-Going Children in Eastern India. Front Pain Res (Lausanne). 2021;2:684133.
16. Estrázulas JA, Estrázulas JA, Gheller RG, Gadotti IC, Moro ARP, Vieira ER. Usability and effects on gait of an optimized schoolchildren backpack. Work. 2023;74(4):1419-27.
17. Sturdy JT, Sessoms PH, Rizeq HN, Silder A, Whittier TT, Silverman AK. Walking Slope and Heavy Backpacks Affect Peak and Impulsive Lumbar Joint Contact Forces. J Biomech Eng. 2025;147(1).
18. Cuenca-Martínez F, Varangot-Reille C, Calatayud J, Suso-Martí L, Salar-Andreu C, Gargallo P, et al. The influence of the weight of the backpack on the biomechanics of the child and adolescent: a systematic review and meta-analysis with a meta-regression. Pediatric Physical Therapy. 2023;35(2):212-26.
19. Alam W, Shah FA, Shah MN, Shah F, Khan L, Zaman Y. Frequency of back pain in school going children carrying school bags. Rawal Medical Journal. 2024;49(2):334-.
20. Suri C, Shojaei I, Bazrgari B. Effects of school backpacks on spine biomechanics during daily activities: a narrative review of literature. Human factors. 2020;62(6):909-18.
21. Hell AK, Braunschweig L, Grages B, Brunner R, Romkes J. The influence of backpack weight in school children: gait, muscle activity, posture and stability. Der Orthopäde. 2021; 50:446-54
22. Agarwal P, Sharma A, Rai RH, Bansal N, Sharma N, Sidiq M, et al. Exploring the Impact of Backpack Carrying on Plantar Pressure and Gait Patterns in Children: A Systematic Review. Journal of Bodywork and Movement Therapies. 2025.
23. Mrozkowiak M, Stępień-Słodkowska M. The impact of a school backpack's weight, which is carried on the back of 7-year-old students of both sexes, on the features of body posture in the frontal plane. BMC Sports Science, Medicine and Rehabilitation. 2022;14(1):57.