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Scientific paper

The school backpack and physical parameters relationship with spinal alignment in the sagittal plane. Are changes in the design of school backpacks for younger school-age children necessary?

Anna Brzęk[1,ABCDF,*], Regina Wysocka-Bochenek[1,BCDF], Jacek Sołtys[1,BCF], Agata Chmielarz[2,CEF]

[1]*Department of Physiotherapy, Faculty of Health Sciences in Katowice, Medical University of Silesia, Medyków 12 Street; 40-754 Katowice, Poland*
[2]*Chair of Industrial Design Faculty of Design, the Academy of Fine Arts and Design in Katowice, Raciborska 37 Street, 40-074 Katowice*
**Corresponding author: Anna Brzęk; abrzek@sum.edu.pl*

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Abstract

Introduction. A school backpack, as an off-axis external load, induces changes in the spinal alignment within the compensatory mechanism.

Objective. Considering the above, the aim of this study was to examine how the angular parameters of the sagittal plane, the thoracic kyphosis angle, and the lumbar lordosis angle change under normative school backpack load. Additionally, the study aimed to assess how carrying a backpack affects the symmetry of foot load distribution in children.

Materials and Methods. The study included 75 children (45 girls and 30 boys) aged 7-9 years (Mean = 8.48; SD = 0.89). A backpack model closely resembling those currently available on the Polish market was developed. The backpack's weight was standardized, and sagittal plane measurements were taken using a digital inclinometer. The symmetry of load distribution was assessed using a stabilometric platform, and the endurance of postural muscles was evaluated with the Matthias test. The study only included backpacks that met the standard weight range of 10–15% of the child's body weight.

Results. Three previously undescribed types of compensation were identified: flexion type, extension type, and balanced type. Only in the balanced type did the endurance of postural muscles not significantly decrease after wearing the school backpack.

Conclusions. It is necessary to modify the design of school backpacks to prevent spinal alignment changes in the sagittal plane, even within normative or excessive load values. Proper spinal curvatures are crucial for maintaining an upright body posture. Non-invasive, modern technologies based on thermal imaging should be considered as potential solutions.

Keywords: school backpack, physical parameters, sagittal plane, body weight distribution

Introduction

The topic of children's school backpacks, although not new, continues to spark discussions, particularly regarding the weight of the backpack and the associated spinal overload. This is most commonly related to nonspecific pain complaints, although there is no certainty or solid scientific evidence that the school backpack is the direct cause of these issues[1,2].

Previous research conducted by the first author identifies the school backpack as a recognized risk factor for postural abnormalities and highlights its significance in preventive programs addressing postural disorders[3,4].

Ongoing discussions focus on the percentage of body weight that a school backpack should meet to be considered safe for children. Globally, the recommended backpack weight load ranges between 5-20% of the individual's body weight[5,6]. In Poland, the guidelines of the Chief Sanitary Inspectorate recommend a range of 10-15%[7].

From a biomechanical perspective, external load, which represents an off-axis burden, triggers compensatory mechanisms that alter spinal alignment as an adaptive response[8]. The spinal curvatures – thoracic kyphosis and lumbar lordosis – are crucial for maintaining proper upright posture[9]. A sedentary lifestyle and a decreasing level of physical activity, increasingly observed in children, especially post-pandemic, contribute to the weakening of postural muscles[10]. Improper habits resulting from a lack of ergonomic practices during learning and play lead to asymmetries and dysfunctions in the trunk muscles, as confirmed by thermographic studies[11-15].

The most common postural defects, apart from flatfoot, occur in the sagittal plane, which is challenging to assess reliably and requires significant experience from the examiner. One

Authors' contribution: A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of the article.

particularly noteworthy finding during the research was the alteration of spinal alignment in the sagittal plane, which triggered compensatory mechanisms such as head protraction, particularly pronounced in children with weakened postural muscle endurance. Furthermore, the authors investigated whether a repetitive pattern of this compensation exists, as there is limited knowledge on this subject.

Considering the above, the aim of this study was to examine how the angular parameters of the sagittal plane – thoracic kyphosis angle and lumbar lordosis angle – change under normative backpack load and how carrying a school backpack affects the symmetry of foot pressure distribution.

Material and methods

Ethics Statement

This study was a cross-sectional observational study. The study was conducted in accordance with the guidelines of the Declaration of Helsinki reviewed and approved by The Bioethics Committee of Medical University of Silesia in Katowice, Poland (Decision no. BNW/NWN/0052/KB1/124/II/22/23/24 date 30 Jan 2024)

Participants

The recruitment for the study took place during presentations for parents at school meetings, with a detailed explanation of the study procedure involving a prototype school backpack, conducted by the first and second authors. The school where the study was conducted was selected randomly, without the knowledge of the person drawing the lot.

The recruitment of children followed this scheme:

Stage I – Children aged 7-9 years, whose parents provided informed consent for participation (n=1002).

Stage II – Sample size calculation (n=353) with a confidence level of 98% and a margin of error of 5%.

Stage III – Analysis based on school backpack weight; children with non-standard or incompletely packed school backpacks were excluded (n=112).

Stage IV – Final qualification for statistical analysis (n=75: 45 girls and 30 boys) aged 7-9 years (M = 8.48, SD = 0.89).

Exclusion criteria: Lack of parental consent, postural defects, scoliosis, musculoskeletal injuries within three months prior to the study, neurological diseases, vestibular system disorders, motion sickness, significant visual impairment, and a backpack exceeding the weight limits recommended by the GIS (Polish Chief Sanitary Inspectorate).

Methods

The main study consisted of four elements:

(I) Verification of the child's body mass according to the methodology adopted in the project. Body mass was assessed using a medical scale with an accuracy of 0.1 kg, and height was measured using a stadiometer with an accuracy of 0.1 cm (Tanita DC-430MA). During both measurements, children were required to stand barefoot and without clothing. BMI percentiles were calculated based on the Polish population norms (Ola and Olaf, PL)[16], considering BMI values within the range of 1 ≥ z-score ≥ -2 as normal, overweight as a value above +1.0 standard deviation (SD), and obesity as above +2.0 SD (according to WHO, 2007).

(II) Examination of the child's school backpack: (1) Assessment of backpack weight in relation to the child's body weight and verification against the recommendations of the Chief Sanitary Inspectorate, which set the normative value at 10-15% of body mass; (2) Measurement of backpack strap length using a measuring tape. These assessments were part of a project evaluating both normative and non-normative backpacks based on GIS recommendations. However, only normative backpacks were considered in this analysis.

(III) Replication of the school backpack weight in a prototype (model) backpack (**Figure 1A**). The replicated weight was accurate to 1 decagram (weights of 0.5 kg and a small bottle with sand for precise adjustment).

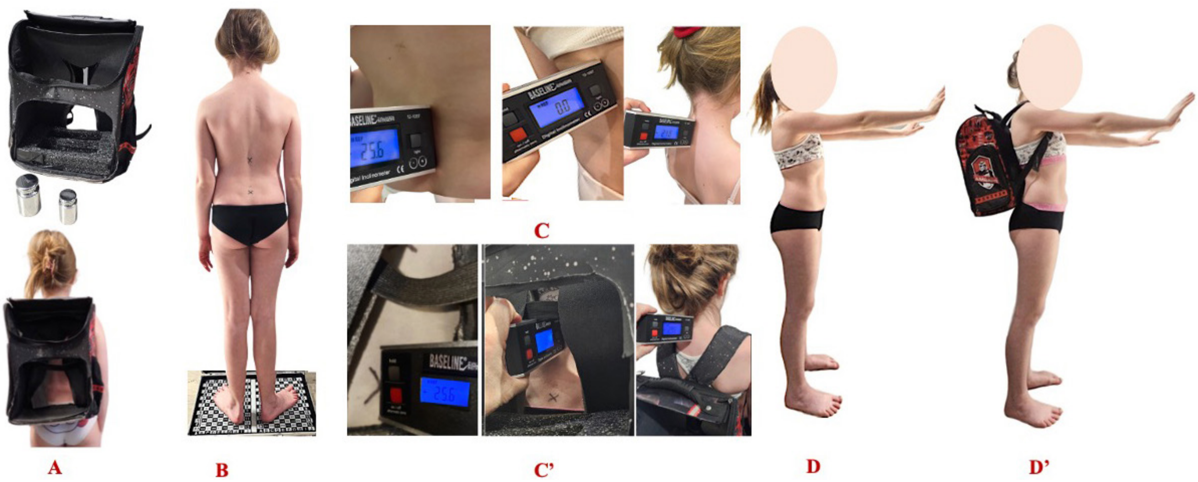

Figure 1. Research protocol: A - Backpack model; B - Testing on the platform: C - Assessment of the sagittal plane without a backpack, C' - Assessment of the sagittal plane with the backpack model; D - Matthias test without a backpack, D' - Matthias test with the backpack model.

(IV) Main study:

1. Measurement of thoracic kyphosis and lumbar lordosis angles in a relaxed standing position without a backpack (**Figure 1C**).
2. Measurement of thoracic kyphosis and lumbar lordosis angles in a relaxed standing position 10 seconds after putting on the backpack (**Figure 1C'**).
3. Assessment of postural muscle endurance using the Matthias test without a backpack (**Figure 1D**).
4. Assessment of postural muscle endurance using the Matthias test with a backpack (**Figure 1D'**).

We did not randomize the order of the examinations; they were conducted according to the specified protocol. Short breaks of 5-10 seconds were provided between subsequent tests to avoid the learned posture effect.

We also sought to prevent the carryover effect (as well as a potential training effect) by introducing short breaks between measurements, which, however, lasted only a few seconds. It should be noted, however, that these loads and durations were part of the children's daily routine. The reliability of the placement of topographic points on the subject's body had been previously examined[17], and their application was carried out by a highly trained examiner with many years of experience.

School Backpack Study

First, the class schedule of the children qualified for the study was reviewed. Since the participants were students from grades 1-3, whose lesson schedules at each grade level did not differ in terms of the number of classes, the backpack weight was comparable across different days. The analysis did not take into account additional extracurricular activities, as these varied greatly and involved an irregular additional load, often carried in the children's or parents' hands, sometimes with more contents and at other times only sporadically (e.g., for school balls, fairs). Therefore, only the contents inside the backpack were examined, and any additional items carried in hand were not considered as part of the backpack's load. The study was conducted in the morning to ensure that the backpack contents also included breakfast, bottled drinks, and that the backpack was worn on the back in a manner most representative of how it would be carried on the way to school. The backpack was weighed and measured according to the methodology described above, and its parameters were replicated on a model backpack.

Backpack – Model

The construction of our backpack model was based on a standard school backpack, as determined by a prior study conducted within the framework of the proprietary program *"I Take Care of My Spine"* and other educational projects for children[14]. The model represented the most commonly used backpack in Polish schools, maintaining the same dimensions in terms of length, width, and height, and featuring side compartments.

The front flap was removed with a scalpel in a way that did not compromise the backpack's structure. A polystyrene insert was placed at the bottom to stabilize the base, with cutouts corresponding to the backpack's compartments, where weights were placed to simulate the actual load of a child's backpack.

The back panel of the backpack was cut out along its entire length to allow for easy measurement of the thoracic kyphosis and lumbar lordosis angles. The width of this cutout was sufficient to accommodate a digital inclinometer freely (**Figure 1A**).

Evaluation of Curvatures in the Sagittal Plane

To assess spinal curvatures in the sagittal plane, the Saunders inclinometer (Baseline Digital Inclinometer, Saunders Group Inc., USA) was used, and measurements were conducted according to the guidelines of the American Medical Association[18-20]. Before measuring the thoracic kyphosis angle and the lumbar lordosis angle, topographic points were marked on the skin using a dermographic pen (**Figure 1B**). These points were identified through palpation and corresponded to bony landmarks: the lumbosacral junction, L5/S1 (LS point), the thoracolumbar junction, Th12/L1 (ThL point), and the cervicothoracic junction, C7/Th1 (CTh point).

The marking of topographic points and the assessment of thoracic kyphosis and lumbar lordosis angles were performed by a single researcher (the first author), who has 20 years of experience in this field due to numerous studies conducted and clinical expertise. To eliminate errors, the reliability of the measurements and the measurement error were assessed. For this purpose, spinal curvatures in the sagittal plane were evaluated in 10 randomly selected children from the study group. Measurements were performed twice, with a seven-day interval (on the same day of the week). The reliability error and measurement error for the thoracic kyphosis angle (kKP) were 0.87 and 2.9°, respectively, and for the lumbar lordosis angle (kLL), 0.85 and 3.1°. Normative values were adopted from Prof. Dobosiewicz[21].

Postural Muscle Performance Assessment

The assessment was conducted in the same position immediately after measuring spinal curvatures in the sagittal plane. The child assumed a relaxed standing position for 30 seconds, after which the researcher provided instructions for adopting a corrected posture following the sequence of body self-correction[22]. The child then raised their arms to a 90-degree angle. Once the test position was assumed, the countdown began using a stopwatch. Maintaining the corrected posture for 30 seconds was considered the norm.

The same assessment was repeated with a backpack worn on the child's back in the following order: the backpack was placed on the child's back, the child assumed a relaxed standing position for 30 seconds, then, following the researcher's instructions, adopted the corrected posture. Next, the child raised their arms to a 90-degree angle, at which point the stopwatch countdown was initiated.

Assessment of Foot Load Distribution Symmetry

The assessment was conducted using the Balce4Me stabilometric platform by Oldmed, PL (No. PL 70611Y1). Static condition tests in open-eye (OE) trials were performed for 30

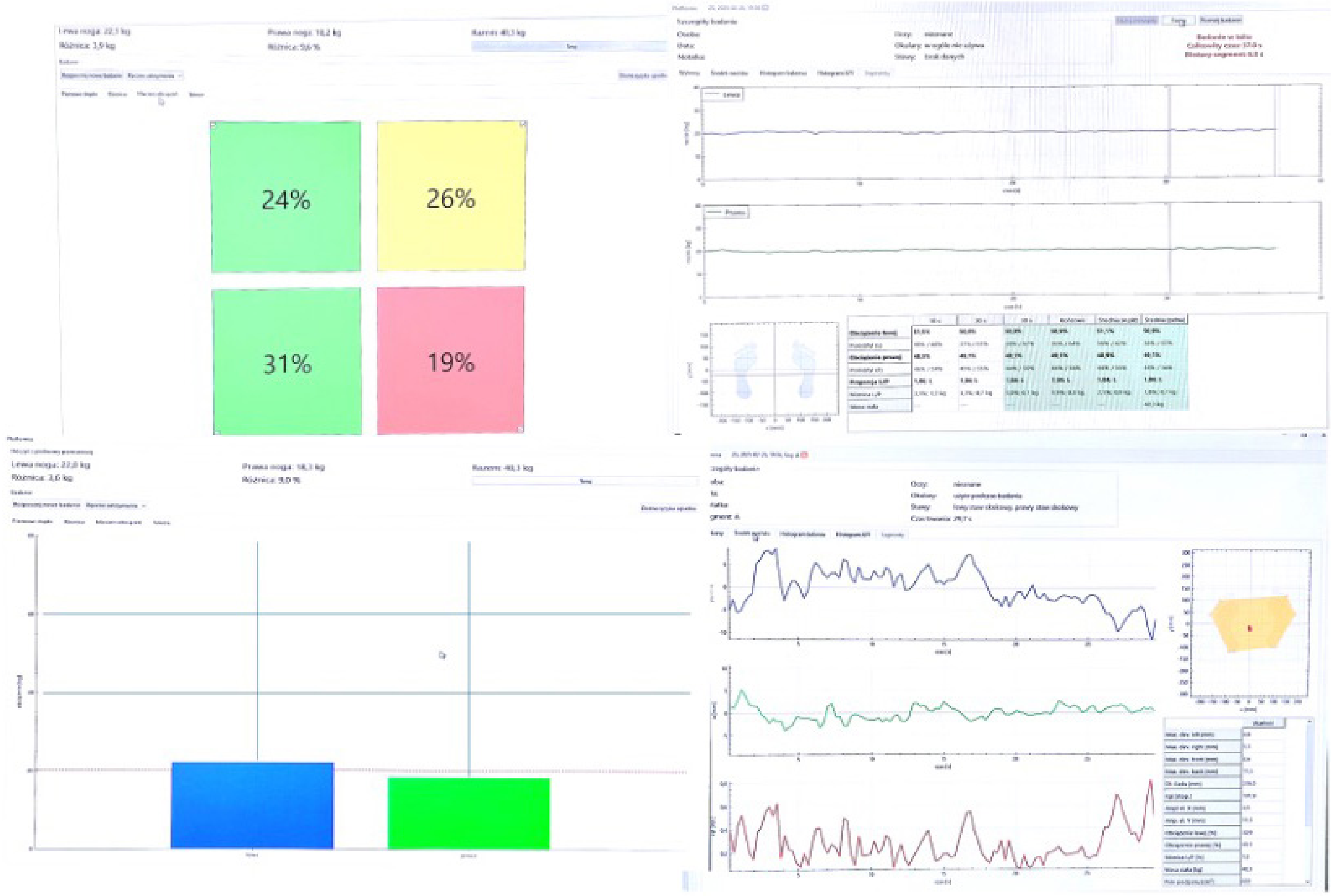

Figure 2. Study of the symmetry distribution of the load.

seconds per trial. During the examination, the child's gaze was directed forward, focused on a single point at nose height. The test was conducted twice:

- Test I: without a backpack on the child's back,
- Test II: with a backpack on the child's back.

Each measurement included three trials, each lasting 30 seconds, with a 30-second break between trials. The mean values of the results from the three trials were used for analysis.

During both tests, participants stood barefoot on the force platform (placed on the ground), with arms extended along the torso.

The following posturographic parameters were analyzed (**Figure 2**):

- ΔBWD (Body Weight Distribution, %) – the distribution of load between the right and left sides of the body.
- APD (Anterior-Posterior Distribution, %) – the distribution of load between the forefoot and hindfoot: right/left forefoot, right/left hindfoot.

Statistical Analysis

The statistical analysis was conducted using the Statistica 13.3 software (StatSoft, Poland). The Kolmogorov–Smirnov test was applied to assess the normality of the distribution. Descriptive statistics, including means and standard deviations, were calculated. To evaluate differences between studies, the Student's t-test was used, and in cases where normality was not met, the Mann–Whitney U test, Wilcoxon test, or Kruskal–Wallis (K-W) test was applied accordingly. A significance level of $\alpha < 0.05$ was adopted.

Confirmation of Compliance with PEDro Criteria

The study group was randomly assigned without the knowledge of the principal investigators, and all participants met the inclusion criteria. The researcher examining the child on the platform was unaware of the results obtained in the sagittal plane by the second researcher. Neither of the researchers knew whether the child's backpack was classified as normative or overloaded. Ultimately, 83 children were qualified for the study, and the final analysis considered 75 participants with normative school backpacks (75 out of 83, 90.36%), meeting the final PEDro criterion of 85%. After the study, all parents received information in the form of prepared brochures[23] regarding the necessity of checking the backpack's contents and promoting ergonomic behaviors. This element was introduced only after the study was completed to ensure that this knowledge did not influence the child's backpack weight.

Results

Among the examined children, 68% had a normal body weight in relation to their height, 17.33% were overweight, 8% were obese, and 6.6% were underweight. The weight of all school backpacks, regardless of gender ($p>0.05$), ranged from 4.76%

to 15.38% (X=9.87; SD=2.844) of body weight, fully meeting the GIS recommendation (**Table 1**).

Both the thoracic kyphosis and lumbar lordosis angles in the examination without a backpack were within the normal range according to Dobosiewicz and studies on the Polish population[17], which was one of the inclusion criteria for the study. After putting on the school backpack, the kyphosis and/or lordosis angle values changed beyond the normative values in 82.66% of cases (**Table 2**).

A decreased efficiency of postural muscles was observed in the examination without a backpack. In the first quartile, below 8 seconds, 22.66% (n=17) of participants were recorded; in the second quartile, below 23 seconds, 52% (n=39); while high results in the third quartile were achieved by 24% (n=18), of which 14.66% (n=11) reached the full 30-second value.

In the examination with a backpack, the results were significantly worse, amounting to 57.33% (n=43), 32% (n=24), and 9.33% (n=7), respectively, with only one child achieving the full 30-second result.

The addition of an extra load on the child's back did not significantly change the distribution of foot load in the sagittal plane (**Table 3**). In all cases, a compensatory mechanism was observed, involving a slight but statistically insignificant shift of weight towards the forefoot.

Based on the results obtained from sagittal plane measurements, three recurring mechanisms of spinal compensation (**Figure 3**) were observed after putting on a school backpack:

1. *Flexion type:* aTH >38°, aLL <22° (n=33)
2. *Extension type:* aTH <23°, aLL >38° (n=21)
3. *Balanced type*: aTH and aLL within the range of 22-38° (n=12)

Eight individuals exhibited a nonspecific compensatory mechanism:

- Flexion-extension type (n=6)
- Preserved kTh with reduced kLL (n=2)

Detailed results for each type are presented in **Table 3**.

A decreased efficiency of postural muscles was noted in the test without a backpack (**Table 2**). In the first quartile, 22.66% (n=17) of participants scored below 8 seconds, in the second quartile, 52% (n=39) scored below 23 seconds, while high results in the third quartile were observed in 24% (n=18), with 14.66% (n=11) reaching the full 30 seconds. In the test with a backpack, the results were significantly worse: 57.33% (n=43), 32% (n=24), and 9.33% (n=7), with only one child achieving the full 30-second score. The highest values in both the test without a school backpack and with a normative external load on the back were obtained by children with a balanced postural type (**Table 4**). The other types – flexion and extension – were characterized by low postural muscle efficiency in

Table 1. Schoolbags' parameters in the groups taking sex division into account.

Parameters	Girls (n=45)		Boys (n=30)		P
	X (SD)	Range	X (SD)	Range	
BMI (percentiles)	58.82 (30.48)	3 – 97	52.9 (27.45)	5 – 97	0.398[1]
Schoolbags' weight	3.23 (0.99)	1.60 – 5.80	2.69 (0.72)	1,60 – 4.40	0.016[1]
% SW vs. BW	10.34 (2.61)	5.79 – 15.07	9.19 (3.08)	4.76 – 15.38	0.088[2]

Abbreviations: X – Average; SD – Standard Deviation; %SW vs. BW – % schoolbags weight vs. body weight. Notes: [1] P-value for K-W: Kruskal-Walli's test; [2] P-value for t-Student.

Table 2. Parameters of the thoracic kyphosis angle and lumbar lordosis angle, as well as the efficiency of postural muscles, in the study without a schoolbag and with a schoolbag.

Parameters	Without Schoolbag		With Schoolbag		P[1]
	X (SD)	Range	X (SD)	Range	
aTH (°)	34.31 (3.92)	23.0 – 38.0	40.57 (8.53)	24.43 – 58.67	10^{-5}
aLL (°)	32.93 (4.13)	22.7 – 38.0	37.48 (7.29)	18.57 – 55.27	0.0002
Mathiass Test (sek)	13.77 (9.19)	0.0 – 30.0	9.08 (8.33)	0.0 – 30.0	10^{-5}

Abbreviations: X – Average; SD – Standard Deviation; aTH – Thoracic Kyphosis angle; aLL – Lumbar Lordosis angle. Notes: [1] P-value for Z-test: Wilcoxon test.

Table 3. Stabilometric parameters in the study without a schoolbag and with a schoolbag.

Parameters	Without Schoolbag		With Schoolbag		P
	X (SD)	Range	X (SD)	Range	
ΔBWD (%)	7.71 (6.32)	0.1 – 27.5	5.75 (5.02)	0.0 – 26.0	*0.077[2]*
Right leg (%)	48.98 (4.91)	36.20 – 62.30	49.42 (3.77)	36.70 – 57.40	*0.397[1]*
Left leg (%)	51.02 (4.91)	37.70 – 63.80	50.57 (3.77)	42.60 – 63.30	
Right forefoot (%)	16.55 (3.61)	10.01 – 27.03	16.94 (4.87)	0 – 27.77	*0.248[1]*
Right hindfoot (%)	32.44 (5.34)	23.03 – 47.34	31.16 (7.11)	0 – 40.63	*0.099[2]*
Left forefoot (%)	18.05 (3.76)	10.90 – 27.93	17.45 (4.87)	0.1 – 28.50	*0.106[1]*
Left hindfoot (%)	32.96 (5.16)	23.03 – 45.96	31.78 (7.30)	0.1 – 44.96	*0.356[1]*
Forefoots (%)	12.98 (2.59)	8.47 – 21.0	25.94 (6.84)	0 – 39.50	*0.00001[1]*
Forefoots (%)	65.24 (6.55)	49.0 – 79.0	62.77 (12.63)	0 – 77	*0.06[1]*

Abbreviations: X – Average; SD – Standard Deviation. Notes: [1] P-value for Z-test: Wilcoxon test; [2] P-value for t-Student.

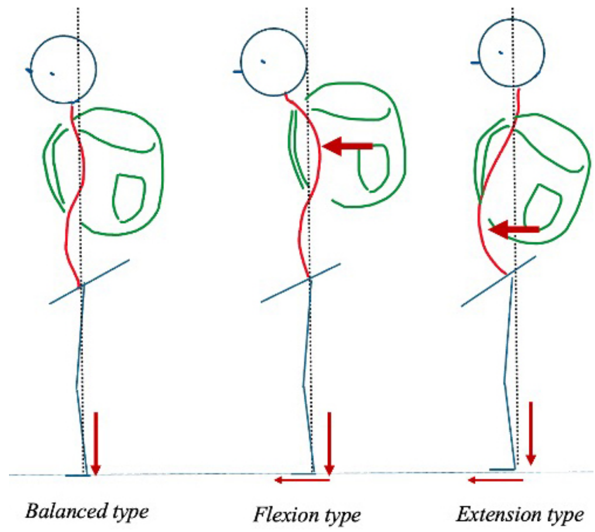

Figure 3. Three types of compensation mechanisms for spinal alignment in the sagittal plane after additional loading of a child's back.

Table 4. Parameters for assessing the sagittal plane the postural muscles efficiency, and foot load distribution in three types of spinal alignment compensation.

Parameters	Flexion type n=33	Extension type n=21	Balanced type n=12	P^1
	X (SD)	X (SD)	X (SD)	
Mathiass Test[I] (sek)	15.06 (9.01)	12.66 (8.33)	18.08 (8.37)	0.04[a]
Mathiass Test[II] (sek)	5.73 (4.22)	7.92 (7.90)	22.83 (3.83)	0.002[ab]
P^2	*<10⁻⁵*	*0.0005*	*0.081*	
ΔBWD[I] (%)	7.17 (5.92)	8.22 (6.46)	8.17 (6.420	0.938
ΔBWD[II] (%)	5.91 (4.51)	6.16 (5.21)	5.61 (7.04)	0.749
P^2	*0.251*	*0.279*	*0.074*	
Forefoots sin/dex[I] (%)	13.50 (2.92)	13.13 (2.50)	12.36 (2.14)	0.273
Forefoots sin/dex[II] (%)	27.56 96.02)	25.52 97.41)	25.92 (4.81)	0.204
P^2	*10^{-6}*	*10^{-6}*	*10^{-6}*	
Hindfoots sin/dex[I] (%)	63.47 (7.71)	66.29 (5.26)	66.21 (5.98)	0.124
Hindfoots sin/dex[II] (%)	63.45 (7.96)	61.52 (15.42)	65.42 (6.44)	0.976
P^3	*0.265*	*0.190*	*0.454*	

Abbreviations: X – Average; SD – Standard Deviation. Notes: [I] without schoolbag; [II] with schoolbag; [1] P-value for ANOVA; [2] P-value for t-Student; [3] P-value for Wilcoxon test; post-hoc for: [a] difference between extension type and balanced type; [b] difference between flection type and balanced type.

both tests. However, it should be noted that after putting on the backpack, their efficiency significantly decreased, which was not observed in the balanced type (p=0.081).

Discussion

The aim of the study was to assess changes in the sagittal curvatures of the spine in children after putting on a school backpack. The study was innovative and is part of a larger research project focused on developing a novel school backpack. The literature clearly indicates that spinal curvatures – thoracic kyphosis and lumbar lordosis – are crucial for maintaining a proper upright posture while standing or sitting, and external load influences their alignment[24-26]. The latter was examined by Czaprowski et al. in studies on postural correction following the command "Straighten Your Back"[27].

It is important to consider the frequent adoption of non-ergonomic postures by children throughout the day, carrying an overloaded school backpack, and environmental exemplifications of posture patterns that influence the vertical alignment of a child's body[4,28]. The recommended weight limit for a school backpack has been set at 10-15% of a child's body weight, which is considered non-harmful. Therefore, researchers found it crucial to examine the spinal response in the sagittal plane after putting on a school backpack within the normative weight range. Despite existing critical systematic reviews[29] and attempts to assess body posture with a school backpack in static and dynamic conditions – beginning with Negrini's research[26] on stability assessment, postural control impairment, and changes in the COP path length due to loading[30] we found no similar studies. Numerous studies by Chow et al.[31-33] have evaluated school backpack load in children with scoliosis.

Interesting research was conducted by Mongkonkansai et al.[34], using a photographic method after exposing bony landmarks such as the shoulders, head, and hips. The researchers measured head inclination using Kinovea software during a 5-minute recording of backpack usage. The program allowed for precise measurement of neck and trunk angles. However, our study focused not on head positioning but on spinal alignment in the sagittal plane, making a direct comparison difficult. Polyong et al. provided an intriguing research direction[35], indicating in their results that prolonged carrying of a school bag may affect the positioning of the cervical spine, shoulders, and lumbar spine. They emphasized that students carrying a bag for more than 20 minutes reported greater pain symptoms. Therefore, it is worth investigating how the sagittal plane alignment changes over time as children in Poland carry their backpacks. However, replicating real-life conditions of the journey to school, rather than conducting the study in isolated laboratory settings such as on a treadmill, poses a challenge. Nevertheless, the concept itself is inspiring.

In our study, we used a Backpack Model that was a realistic representation of the most commonly used backpacks in Polish schools. An important aspect of this research was that the Backpack Model had comparable dimensions in terms of length, width, and height, and it also included side compartments. Although our study analyzed the immediate response after putting on the school backpack – acknowledging that this response may change with prolonged loading – it is crucial to note that such a backpack elicits a reflexive response in a child, based on established adaptation and compensatory mechanisms. This aspect was highlighted in Negrini & Negrini's research conducted in dynamic conditions on a treadmill[30].

A longer time interval between the implementation of a metal structure simulating a backpack and the assessment of body posture was applied by Polish researchers Mrozkowiak and Stępień-Słodkowska[36]. However, in their studies, a photogrammetric evaluation was used in the frontal plane, and various symmetrical, asymmetrical, unilateral, and bilateral loads were assessed.

In our research, we were not concerned with evaluating changes caused by backpack asymmetry, as it is already known from other studies that it induces changes in body posture[30,37]. Our goal was to determine whether a backpack, conventionally worn on both shoulders and of normative weight, is entirely safe for children's spines.

In the lower grades of school, parents ensure that children wear their backpacks on both shoulders, as this information is widely known among parents. By paying attention to this ergonomic aspect, they feel they are fulfilling their parental duty of caring for their child's health. However, it turns out that this is merely an illusion. These observations come from the first author's years of research on school backpacks and their analysis within the "*I Take Care of My Spine*" program[4].

In our study, we identified three types of adaptation to backpack load:

1. *Flexion type*, which increases the thoracic kyphosis angle while maintaining normative or reduced values for the lumbar lordosis angle.
2. *Extension type,* characterized by an increased lumbar lordosis angle with a preserved or reduced thoracic kyphosis angle.
3. *Balanced type,* where normative values are maintained for both the thoracic kyphosis and lumbar lordosis angles.

These classifications were named based on their distinctive characteristics. However, what surprised the authors was that the balanced mechanism was observed so infrequently when using a normative school backpack. This finding underscores the need for further research on normative backpacks. These studies require additional analyses that consider the positioning of the entire body. Research by Italian scientists Negrini and Negrin[30] indicated seemingly contradictory reactions: increased forward trunk inclination and a reduction in the kyphosis angle, accompanied by a decrease in the lordosis angle. The authors explained the former as a likely result of spinal elongation and an attempt to achieve better posture in the sagittal plane. This compensation occurs due to insufficient strength in the lumbar region, which leads to a decrease in the lumbar lordosis angle. However, the authors did not examine postural muscle efficiency. In our study, the efficiency of postural muscles increased in the balanced type, supporting the ability to maintain spinal curvatures within normative ranges. Unfortunately, this group was the least numerous. Evaluating muscle activation in this context could be an interesting area for further research. The introduction of new and innovative imaging techniques seems crucial, not only to show the final positioning of the spine but also to provide quantitative physical parameters. These could be obtained from inexpensive, rapid, yet highly precise non-invasive techniques that would help assess spinal positioning. Such methods might offer explanations for the changes in spinal alignment observed by researchers. Advancements in technology and innovative diagnostic approaches align with our understanding of the processes involved in scoliosis development and treatment, where back muscles and their varying tension play a crucial role. The paraspinal muscles, in particular, have different metabolic levels depending on tension variation, leading to temperature gradient changes. This change in muscle temperature gradient, caused by heat transport processes, manifests on the body's surface in the paraspinal area as a differentiated skin temperature gradient on the back. Analyzing gradient changes provides essential information about muscle tension variations, helping predict spinal alignment under loads such as a school backpack. Moreover, considering the duration of backpack use, future studies should examine how long these changes persist after removing the backpack and whether they might contribute to trunk asymmetry or spinal disorders. Muscle metabolism alterations on one side of the spine due to excessive tension may cause a muscle imbalance between both sides, a phenomenon already demonstrated in previous studies[11-15].

Therefore, in response to the question posed in the title of this paper – whether there is a need to change the design of school backpacks for younger school-age children – the answer is yes, such a need exists. It is difficult to maintain strict control over school backpacks in terms of their weight and the quality of packing, as well as the length adjustment of the shoulder straps, as has already been presented in a previous study by the first author[3]. This is supported by the fact that many children were excluded from this study due to overloaded school backpacks, despite meeting the criterion of proper body posture.

Moreover, maintaining the recommended percentage of backpack weight relative to the child's body weight is only feasible in the early stages of school education. Later, as the number of textbooks and other necessary school supplies increases, these recommendations become unrealistic, and parental supervision significantly decreases. This, in confrontation with the effects of excessive backpack weight, becomes a serious problem and a basis for seeking new, alternative solutions.

Our team, based on our research on an innovative school backpack model, has identified a way to optimally minimize postural disturbances caused by external, off-axis loads. Furthermore, we have already proposed such an innovative school backpack model and conducted prototype testing on a group of children in grades 1–3. The first author's idea to create this innovative school backpack resulted from years of research on school backpacks and clinical work in pediatric physiotherapy. The entire design process was carried out by a team of specialists from various fields, with the involvement of scientists from the Academy of Fine Arts.

This research did not cover the final project results, as these will be presented in future publications. Additionally, the innovative backpack design has been submitted for a patent, which will allow the disclosure of interesting findings.

In Poland, current guidelines regarding the proper backpack weight are based on the percentage recommendations of the Chief Sanitary Inspectorate, which state that a backpack should weigh 10-15% of the child's body weight. Of course, there are ergonomic recommendations regarding symmetrical carrying of the backpack on both shoulders, strap adjustment, proper packing of school supplies, and backpack reinforcements[3,4,38-40]. However, there is still no definitive answer regarding what backpack weight is truly safe. Worldwide, various weight limits have been empirically explored, most commonly around 10%[41,42].

We attempted to replicate real-world conditions while conducting short-term studies, as we were concerned that repeated testing could lead to learning effects as well as fatigue, which might impact the research results.

Negrini and Negrini concluded their research with a crucial finding: the lack of regulations protecting youth from carrying excessive loads, in contrast to the existing regulations for adults regarding spinal pain complaints[30,42]. Therefore, in our study, the choice of age was deliberate, as recommendations for this age group exist, which we aimed to verify. The comparability of the number of lessons and backpack weight in younger grades is very high, as textbooks in these classes are usually selected from the same publisher. Consequently, these results can be generalized to the Polish population for this age group.

The construction of our backpack model was based on a standard school backpack. We aimed to avoid incorporating metal structures, which are perceived by children as different and "cold," potentially attracting more attention than their regular backpacks. This could have influenced angular changes in the sagittal plane during the study.

This study included an evaluation of children with correct posture; however, the challenge lies in adjusting school backpacks for children with postural defects and severe spinal deformities.

Study Limitations

Our study has certain limitations. Although the sample size may initially appear small, it is sufficient. It is worth emphasizing that we specifically planned our research on a group of children with correct posture, which was already challenging given the high prevalence of postural defects. Other studies confirm this, highlighting that in Poland, the recognition rate of postural defects ranges from 10% to 80%, depending on the definitions of correct posture and the diagnostic tools used[24,43].

In the first stage of our study, slightly over 1,000 children participated. Additionally, we included only children with backpacks within normative weight limits, which further reduced the study group. Despite some limitations – such as not distributing books in the backpack model in a 1:1 manner compared to a child's actual backpack and instead replacing this load with weights (due to the design of the backpack model and the need for full, unrestricted access to the child's back) – we believe that our study results hold both scientific and clinical significance. The study involved a homogeneous group and was conducted using reliable diagnostic tools and measurement accuracy. Therefore, the results of this study can be considered relevant in practical applications.

Conclusions

Further research on school backpacks and their design modifications is necessary to prevent changes in spinal alignment in the sagittal plane, even when using backpacks within normative weight limits or overloaded backpacks. Proper spinal curvatures are essential for maintaining an upright posture. Future studies should also incorporate thermal parameters obtained from thermovision imaging.

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Conflicts of Interest

Declare no conflicts of interest

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