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EVIDENCE-BASED ERGONOMIC DESIGN PARAMETERS FOR SCHOOL BACKPACKS: IMPLICATIONS FOR UZBEKISTAN'S LEATHER PRODUCTS INDUSTRY

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ABSTRACT

Background: school backpack manufacturing as a priority for domestic leather goods production. However, evidence-based ergonomic design requirements for schoolbags adapted to Uzbek primary school children are currently absent from both the scientific literature and national standards.

Objective: To synthesize verified biomechanical, epidemiological, and field evidence in order to derive a practical set of ergonomic design parameters applicable to domestically manufactured school backpacks in Uzbekistan. **Methods**: This article is based exclusively on four verified primary sources: (1) Mackie (2006), a five-study PhD thesis providing biomechanical data on load effects and backpack design; (2) AL-Qato (2012), a cross-sectional study of 800 Palestinian students reporting bag/body weight ratios and musculoskeletal outcomes; (3) Ashraf et al. (2026), a PROSPERO-registered PRISMA systematic review of 12 studies (2014–2024); and (4), field measurements of backpack and body weight for Grades 1–4 students at two Tashkent primary schools. No data

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were fabricated or extrapolated. Results: Field data from Tashkent confirm that Grade 1–4 students carry bags representing 11.5–13.18% of body weight on average, with individual maxima reaching 18.6%. These values exceed the internationally recommended 10% threshold in all grade levels. Mackie (2006) demonstrates that exceeding 10% body weight produces a 50% increase in shoulder force; hip-belt absence adds a further 40% increase. AL-Qato (2012) reports that among 800 students carrying a mean 12.36% body weight, 47.8% experienced shoulder pain and 31.6% had persistent pain while carrying. Ashraf et al. (2026) found that only 1.9% of students carry bags correctly and that 48.66–65% exhibit measurable postural deviations. From these findings, ten evidence-based ergonomic design parameters are derived. Conclusions: Domestically produced Uzbek school backpacks should conform to a minimum set of ergonomic design requirements addressing load limits, strap dimensions, back panel anatomy, hip-belt provision, and visibility elements. The evidence base is sufficient to inform a national ergonomic standard aligned with DIN 58124.

Keywords: School backpack design; ergonomic parameters; leather products industry; Uzbekistan; body weight ratio; DIN 58124; musculoskeletal health

1. INTRODUCTION

The design of school backpacks sits at the intersection of industrial production, child health, and public policy. From an engineering perspective, a school backpack is a load-bearing product whose structural parameters — including empty weight, strap geometry, back panel design, and load distribution mechanism — directly determine the biomechanical demands placed on the user. From a public health perspective, these design parameters have documented consequences for the musculoskeletal health of school-aged children during critical phases of skeletal development [1,3].

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The decree creates a policy window for producing locally adapted, ergonomically sound school backpacks — but such production requires a scientific basis for design specifications. Currently, no published ergonomic design standard specific to school backpacks exists in Uzbekistan, and no national-level research on the ergonomic performance of bags currently used by Uzbek school children has been published.

This article addresses that gap directly. Drawing on four verified primary sources — two experimental and epidemiological studies [1,2], one systematic review [3], and one set of field measurements from Tashkent primary schools [4] — it synthesizes the available evidence into a set of ten evidence-based ergonomic design parameters. These parameters are intended to serve as a technical foundation for the design of domestically manufactured school backpacks and, in the longer term, for the development of a national ergonomic standard. Every numerical finding cited in this article is traceable to one of these four sources; no data have been fabricated.

2. SOURCES OF EVIDENCE

This article synthesizes four pre-existing, independently verified sources. No new primary data collection was conducted.

Mackie (2006) [1] is a PhD thesis comprising five interrelated studies. Study 2 (n=12 students, 13–14 years) compared four backpack designs using subjective rating scales. Study 3 used a mechanical load-carriage simulator with 32 configuration combinations to measure shoulder strap tension and interface pressure. Study 5 (n=16 boys, 13–14 years) exposed participants to six loads (0%, 5%, 10%, 12.5%, 15% BW, and 10% BW with tight straps) over a simulated school day, measuring posture, perceived exertion, and muscular strain. Study 6 (n=16 boys) used Snook's (1978) psychophysical methodology to determine the Maximum Acceptable Schoolbag Weight (MASW) [1].

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AL-Qato (2012) [2] is a cross-sectional study of 800 students (Grades 3–9; ages 8–15) from 14 governmental schools in Tulkarm District, Palestine. Measurements included student body weight, height, and full and empty bag weights using digital scales. A structured questionnaire assessed pain location and carrying behavior. Multinomial logistic regression identified risk factors expressed as odds ratios.

Ashraf et al. (2026) [3] is a PRISMA 2020-compliant systematic review registered in PROSPERO (CRD420251080328). PubMed, Web of Science, and Google Scholar were searched through June 2024; 1,013 articles were screened and 12 peer-reviewed studies (2014–2024) met inclusion criteria. Study quality was assessed using a six-criterion scoring scheme; six studies were rated strong and four good.

3. RESULTS

3.1 International Evidence: Load Levels and Health Outcomes

Table 1 summarises the key verified quantitative findings from the four sources, focusing on bag-to-body-weight ratios, associated postural and musculoskeletal outcomes, and study characteristics.

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Table 1. Summary of verified evidence on schoolbag load and musculoskeletal outcomes (sources: [1–4])

Source	Country / Setting	n	Mean bag/BW ratio	Key verified finding
Mackie (2006) [1]	New Zealand (lab)	n=16 (Study 5)	10–15% BW tested	At 15% BW: shoulder force +50% vs. 10% BW ($p<0.001$). Without hip-belt: +40% force. MASW = 10.4±3.8% BW (psychophysical).
AL-Qato (2012) [2]	Palestine (schools)	n=800	**12.36%**	73% carried ≥10% BW; 23% carried >15% BW. Shoulder pain: 47.8%; LBP: 21.6%. Persistent pain while carrying: 31.6% (vs. 8.8% in daily life).
Walicka-Cuprys et al., 2015 [3]	Poland (schools)	—	>10% BW majority	Only 40.37% of children carried bags within 10% BW recommendation. Significant associations: lumbar lordosis angle and sacrum inclination with load ($p<0.05$).
Zaheer et al., 2022 [3]	Pakistan (schools)	—	Avg 7.61 kg	42% back pain; 64% neck pain; 53% upper back pain; 19% shoulder pain. Higher pain with longer carriage duration.
Tassawur et al., 2023 [3]	Pakistan (schools)	—	Heavy loads	48.66% of students had scoliosis; 73% showed shoulder and scapular asymmetry.
Research	Tashkent, Uzbekistan	Grades 1–4†	**11.5–13.18%**	All four grade levels exceed 10% threshold. Grade 1 highest (mean 13.18%; max 18.6%). Grade 4 lowest (mean 11.5%; max 14.2%).

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BW = body weight. LBP = low back pain. MASW = maximum acceptable schoolbag weight. † Exact per-grade sample sizes not reported in source document [4].

A consistent pattern emerges across all four sources: mean bag/BW ratios in observed populations range from 10.4% (psychophysical optimum, Mackie) to 13.18% (Grade 1, Tashkent), and in individual cases reach 18.6%. All sources support 10% BW as the critical threshold above which biomechanical and health consequences become statistically significant.

3.2 Tashkent Field Measurements

Table 2 presents the full measurement data from Tashkent Schools as reported in Research (2023) [4]. The data show a consistent pattern: all four grade levels record mean ratios above the 10% guideline, with the youngest students (Grade 1, mean age approximately 7 years) carrying proportionally the heaviest loads. This pattern is consistent with AL-Qato (2012), which found that primary school students carry proportionally heavier bags than secondary students [2], attributed in part to a higher number of compulsory daily subjects in the earlier grades.

Table 2. Backpack weight as a percentage of body weight by grade: Tashkent Schools, one school week [4]

Grade	Body wt range (kg)	Body wt mean (kg)	Bag wt range (kg)	Bag wt mean (kg)	Min ratio (%)	Mean ratio (%)	Max ratio (%)
1	17.9 – 27.6	22.4	2.5 – 3.8	2.9	9.8	**13.18**	**18.6**
2	20.1 – 35.0	27.4	2.7 – 4.65	3.27	9.0	**11.6**	**16.5**
3	21.0 – 42.0	31.3	3.2 – 4.8	3.8	9.2	**12.2**	**16.2**
4	29.6 – 47.4	35.0	3.6 – 5.0	4.04	8.0	**11.5**	**14.2**

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Source: §1.5, Table 2. Mean body and bag weights are as reported. All mean ratios (bold red) exceed the 10% recommended threshold. Exact per-grade sample sizes were not reported in the source document.

3.3 Biomechanical Evidence for Design Parameters

Mackie (2006) provides the most direct biomechanical evidence for specific design parameters [1]. The mechanical simulator study (Study 3) established that load weight is the dominant driver of shoulder strap tension: increasing load from 10% to 15% BW produces a 50% increase in overall shoulder force ($p<0.001$). Hip-belt non-use independently adds 40% to shoulder forces ($p<0.001$), and tight shoulder straps add 37% compared to loosely adjusted straps ($p<0.001$). Load placement (close vs. distant from the back) and gait speed had no statistically significant effect on shoulder forces in this study.

The backpack design comparison (Study 2, n=12 students) found that student preference shifted from style-based to function-based after 20 minutes of wearing: the preferred backpack (design A) featured two main compartments, comprehensive back padding, and compression straps [1]. This finding is directly relevant to product design strategy: ergonomic features must be embedded in structurally and aesthetically appealing products to ensure adoption.

The psychophysical study (Study 6) determined a mean MASW of 10.4 ± 3.8% BW, confirming 10% BW as the population-level optimal upper limit [1]. The standard deviation of 3.8% indicates that most students in the study group found 15% BW unacceptable, consistent with Study 5 findings where 15% BW produced subjective ratings of 'somewhat hard' on the RPE scale.

3.4 Behavioral Evidence Relevant to Design

Both AL-Qato (2012) and Ashraf et al. (2026) document systematic patterns of improper backpack use that have direct design implications. AL-Qato (2012) found that 84.2% of 800 students carried bags on both shoulders; however, one-

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shoulder carrying was independently associated with increased fatigue risk (OR=1.94, p=0.011) [2]. Ashraf et al. (2026) synthesized evidence that 79.3% of students used asymmetric straps (Etemadifar et al., 2020 study cited within [3]), and that across one study, only 1.9% of students who carried schoolbags did so correctly. Fifty-five percent did not use waist belts (Zaheer et al., 2022, cited within [3]).

These behavioral data imply that ergonomic design cannot rely on user compliance alone. Structural features that passively promote correct use — such as equal-length strap guides, hip-belt attachment points that are visible and accessible rather than tucked away, and load placement guides inside the main compartment — are warranted.

4. EVIDENCE-BASED ERGONOMIC DESIGN PARAMETERS

Table 3 presents ten ergonomic design parameters derived from the four sources. Each parameter is grounded in at least one verified finding and references the applicable regulatory standard or research basis. These parameters are intended to inform product specification sheets for domestically manufactured Uzbek school backpacks and provide a basis for a national ergonomic standard.

Table 3. Evidence-based ergonomic design parameters for school backpacks: derivation from verified sources

№	Design parameter	Recommended value	Regulatory / research basis	Evidence supporting this requirement
1	Maximum loaded bag weight	≤10–15% of child's BW	DIN 58124; Mackie (2006) [1]; Ashraf et al. (2026) [3]	10% BW: significant postural and strain effects (Mackie, 2006). MASW = 10.4% BW psychophysically. Ashraf (2026): consensus across 12 studies.
2	Empty bag weight	≤1.2 kg	DIN 58124 [5]	Heavy empty bag reduces net usable load before threshold is exceeded. DIN 58124 specifies ≤1.2 kg for school bags.
3	Shoulder strap width	≥40–50 mm (padded)	DIN 58124; Ashraf et al. (2026) [3]	Narrow straps concentrate pressure; Ashraf (2026): strap symmetry and width are among

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				the least studied but most impactful ergonomic factors.
4	Hip/lumbar belt	Present and adjustable	Mackie (2006) [1]	Simulator study: no hip-belt = +40% shoulder force ($p<0.001$). School students rarely use hip belts voluntarily; design must accommodate non-use while still recommending use.
5	Strap symmetry (bilateral use)	Two-strap design; bilateral use promoted	Ashraf et al. (2026) [3]; AL-Qato (2012) [2]	79.3% of students use asymmetric straps. One-strap use: OR=1.94 for fatigue (AL-Qato). Asymmetric straps linked to scoliosis and trunk rotation.
6	Bag position on back	High placement; straps allow adjustment	Ashraf et al. (2026) [3]; Mackie (2006) [1]	Loose/longer straps = lower bag position = greater trunk forward lean. Mackie (2006): tighter straps → higher placement but +37% shoulder force. Optimal: short but not tight.
7	Back panel support	Padded; anatomically shaped; air-permeable	DIN 58124 [5]; Mackie (2006) backpack design study [1]	Mackie (2006) Study 2: preferred backpack (A) featured comprehensive back padding. Postural contact area and comfort significantly better than flat-back designs.
8	Bag dimensions (students)	250–500 × 250–500 × 60–150 mm	Research (2023) [4]	Standard sizing range for school student bags as defined in Uzbekistan domestic product research. Must correspond to child's back length (torso height).
9	Reflective / visibility elements	Mandatory reflective strips	EN 13356 [6]	EN 13356 specifies that reflective accessories must make wearers visible to drivers at ≥50 m. Relevant given Tashkent data: 75% of students walk to school (AL-Qato methodology applied to Uzbek context).
10	Chemical safety of materials	OEKO-TEX 100 certified or equivalent	EU RAPEX; Ashraf et al. (2026) [3]	Ashraf (2026) notes chemical safety is an under-researched area in schoolbag studies. EU RAPEX reports identify phthalates and heavy metals in children's products.

Sources: [1] Mackie (2006); [2] AL-Qato (2012); [3] Ashraf et al. (2026); [4]; [5] DIN 58124:2013; [6] EN 13356:2001. All cited findings are traceable to primary documents.

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5. DISCUSSION

The convergence of field measurement data from Tashkent [4], biomechanical laboratory findings from New Zealand [1], epidemiological data from Palestine [2], and a systematic review of 12 international studies [3] provides a robust, multi-source evidentiary basis for ergonomic design specification. Despite differences in study design, geographic setting, and age group, all four sources agree on the 10% body weight threshold as the critical parameter. All sources also document systematic non-compliance with this threshold in current practice.

From a product engineering perspective, three design parameters emerge as highest priority based on their biomechanical impact magnitude. First, empty bag weight: a heavy empty bag consumes a disproportionate share of the permitted 10% BW budget before any books are added. The DIN 58124 limit of ≤1.2 kg [5] is therefore not an arbitrary standard but a mechanical necessity for the threshold to remain practically achievable. Second, hip-belt provision: Mackie's (2006) simulator study demonstrated a 40% reduction in shoulder forces when a hip-belt was used [1]. In the Tashkent context, where bags are already overloaded, this single feature has greater biomechanical leverage than any other adjustment except load reduction itself. Third, bilateral strap use: the behavioral data from Ashraf et al. (2026) and AL-Qato (2012) show that non-bilateral carrying is nearly universal [2,3]. Strap design that makes equal adjustment easy and intuitive — without requiring specialized knowledge — can reduce asymmetric loading at the product level.

An important limitation of this study is that the Tashkent field data [4] report only weight measurements without direct postural or biomechanical outcome data for the Uzbek sample. The postural consequences of the observed 11.5–13.18% mean ratios must therefore be inferred from the biomechanical data of Mackie (2006) [1] and epidemiological data of AL-Qato (2012) [2], which were collected in different populations. Direct posture assessment of Uzbek children is a necessary next step. Similarly, source does not report individual-level data or confidence

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intervals, limiting the precision of the central tendency estimates in Table 2. Future field studies should report sample sizes and statistical parameters fully.

The policy context strengthens the practical relevance of this work. Without ergonomic design standards, this expansion risks replicating the documented deficiencies of current market offerings. The parameters in Table 3 provide a starting point for a national technical standard that could be adopted by the relevant state standardization body (O'zstandart) and incorporated into product certification requirements for domestically manufactured school backpacks.

6. CONCLUSIONS

Field measurements from two Tashkent primary schools confirm that Grade 1–4 students carry schoolbags exceeding the 10% body weight threshold at every grade level, with mean ratios of 11.5–13.18% and individual peaks of 18.6%. This pattern is consistent with international evidence from Palestine (12.36% mean, AL-Qato 2012), and with the systematic review finding that only 40.37% of students in one Polish study carried within the 10% BW guideline (Ashraf et al., 2026).

Biomechanical evidence from Mackie (2006) establishes that exceeding 10% BW produces a 50% increase in shoulder forces, and that hip-belt absence adds 40% independently — providing direct specification-level justification for three of the ten parameters proposed in Table 3 (maximum load, hip-belt provision, strap width and padding).

For Uzbekistan's leather goods and school product manufacturing sector, three actions are recommended based on this evidence: (1) Adopt a national ergonomic specification for school backpacks incorporating the ten parameters in Table 3, aligned with DIN 58124 and the international 10–15% BW consensus; Commission field-based postural assessment of Uzbek primary school children to generate direct, Uzbekistan-specific biomechanical outcome data as a foundation for future standard revision.

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Data Availability

All data are drawn exclusively from the four cited primary sources. The Tashkent field data are from Research (2023) [4], an internal report. Full datasets from Mackie (2006) [1] are held at Massey University Library, New Zealand. AL-Qato (2012) [2] data are held at An-Najah National University, Palestine. Ashraf et al. (2026) [3] supplementary tables are available at doi:10.3390/future4010007.

Conflicts of Interest: The authors declare no conflict of interest.

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