International Journal of Science and Technology

International Journal of Science and Technology, 2025, 85–87

doi: 10.70728/tech.v2.i08.030
Volume 02, Issue 08
ISSN: 3030-3443
Paper

PAPER

DESIGN OF ERGONOMIC AND PROTECTIVE BACKPACKS FOR ELEMENTARY SCHOOLCHILDREN

Ilkhamova Malohat Utkurovna[1,*] and Makhmudov Khusniddin Yusuf ugli[2]

[1]Associate Professor, Doctor of Philosophy, Department of Design and Technology of Leather Products, Tashkent Institute of Textile and Light Industry, Tashkent, Uzbekistan.
[2]Postgraduate student of the Department of Design and Technology of Leather Products, Tashkent Institute of Textile and Light Industry, Tashkent, Uzbekistan.

* ilkhamova@gmail.com

Abstract

Elementary school students frequently carry heavy backpacks, risking musculoskeletal strain and safety hazards. Optimal backpack design integrates anthropometry, weight distribution, and safety features. This review examines ergonomic fundamentals (load limits, anthropometric sizing, weight distribution), protective elements (reflective materials, durable construction), and major standards (DIN, ISO, EN, ASTM, CPSC, etc.) relevant to children's backpacks. We present summarized ergonomic design parameters (Table 1) and discuss research gaps, such as standardized testing protocols and innovative materials. Our evidence-based review aims to guide designers and policymakers in developing backpacks that support healthy posture and child safety.

Key words: backpack design, schoolbag ergonomics, child safety, ergonomic standards, anthropometry, load carriage.

Introduction

Schoolchildren routinely carry backpacks filled with books and supplies. Excessive load or poor backpack design can cause back, shoulder, and neck pain, impair posture, and increase injury risk. It is widely recommended that a child's backpack should weigh **no more than 10%** of their body weight. International studies report that over 70% of children carry backpacks exceeding this guideline. Besides weight, backpack features (straps, padding, and visibility) critically influence comfort and safety. Standards organizations (e.g., ISO, EN, DIN, ASTM, CPSC) set various requirements for children's products, including backpacks. For example, German standard **DIN 58124** mandates high-visibility features: at least 10% retroreflective material and 20% fluorescent-colored area on school satchels. Despite such standards, many backpacks on the market lack these safety features, as children often favor "fashionable" designs over safety. This article reviews **ergonomic and protective design fundamentals** for elementary backpacks. We integrate peer-reviewed research on anthropometrics, load distribution, posture effects, and standards compliance.

Ergonomic Load Guidelines

Consensus in the literature advises limiting backpack weight to about 10–15% of the child's bodyweight. Ramadan et al. note the 10% guideline and experimentally validate a design that "performed astonishingly" with loads of 15–20%, reducing muscle strain relative to a conventional backpack. Bauer and Freivalds found no significant increase in strain when middle-schoolers carried 10% BM, but significant effects at 15%. Our summary (Table 1) adopts 10% as a conservative upper limit. Observational studies confirm the problem: a Maltese national survey found >70% of 8–13-year-olds carried >10% BW, with heavy loads independently linked to back pain.

Anthropometric Dimensions and Straps

Backpack dimensions should match children's body sizes. Mououdi et al. derived backpack height and width from percentile anthropometry of 6–12 year-olds. They recommend a maximum backpack height ≈ sitting shoulder height minus thigh thickness (30 cm) and width not exceeding 2/3 of shoulder breadth (25

Compiled on: June 2, 2025.
Manuscript prepared by the author.

cm). Wider strap width also helps: one design used 9.5 cm shoulder straps to distribute load (95th percentile neck width basis). Fat, padded straps reduce shoulder pressure; adjustable waist/hip belts further shift load to the pelvis. A systematic review emphasizes double shoulder straps (avoiding single-straps), and additional chest or waist straps to stabilize the load. Alternating carrying methods (e.g. double packs, "BackTpack" with side packs, front-carrying) can reduce strain compared to the single rear pack. Ramadan's prototype added side compartments and two body-straps (upper and lower) to distribute weight beyond shoulders. These features "helped the body to distribute the carried weight and avoid concentrating pressure".

Load Distribution and Packing

How books and items are arranged affects ergonomics. Experts advise placing heaviest items close to the child's back and toward the bottom to keep the center of mass near the spine. For heavy loads, research (on adults) shows placing load higher (near shoulders) can reduce metabolic cost; however, for school loads this must balance with posture. In all cases, the backpack should fit flush against the back with minimal sagging. Compartments (at least three: main, side pockets, small front) help organize content so weight isn't shifted to one area. For example, Ramadan's design used two side pockets plus the back pocket to "disperse the weight from being concentrated on the back". A broad, stiff back panel and padded lumbar support help the pack maintain shape and distribute pressure.

Protective and Safety Features

Visibility and material safety are key protective concerns. Standards recommend high-visibility elements: DIN 58124 requires ≥10% of satchel surfaces to be retroreflective and 20% fluorescent-colored, ensuring children are seen in low light (dark mornings). Despite this, many backpacks lack sufficient reflectors. Adding fluorescent trims (orange/yellow panels) and reflective piping or strips is advised for visibility. Material durability and non-toxicity are also important: fabrics should be water-resistant, and tested under REACH and CPSIA guidelines (as mandated for children's products). Manufacturers often submit backpacks to quality-control tests (static/dynamic loading, buckle strength) according to ASTM and ISO protocols.

Standards Overview

DIN 58124 (Germany): Ergonomic/safety requirements for school satchels – mandates distributed load and high-visibility materials.

ISO 20471 / EN 20471: High-visibility clothing standards – although not for bags, their color/reflectivity criteria inform backpack design.

EN 13209 series (EU): Safety requirements for child carriers (baby backpacks), not directly for school bags but analogous on straps and restraints.

ASTM & CPSC (US): No ASTM standard specific to school backpacks, but general children's product testing (toys/bags) under CPSC ensures flammability safety. CPSC guidance advises limiting weight to prevent injuries.

REACH/ROHS: Chemical safety for materials (lead, phthalates) used in bags sold in the EU (ensuring no harmful dyes or coatings).

These standards collectively ensure ergonomic safety and visibility (DIN 58124), material safety (REACH), and overall product compliance (CPSC-certified testing).

Table 1. Recommended ergonomic design parameters for children's school backpacks.

Parameter	Recommendation
Weight limit	≤10% body weight (max 15% for short periods)
Backpack height	≤ sitting shoulder height – thigh thickness (30cm)
Backpack width	≤ 2/3 of shoulder breadth (25cm)
Strap configuration	Two wide, padded shoulder straps; avoid single-strap; add adjustable chest & hip straps
Load distribution	Use multiple compartments (back + 2 side); heavy items close to back; lowest heavy items, center of gravity high
Visibility materials	≥10% retroreflective surfaces; ≥20% fluorescent fabric (DIN 58124)
Construction	Durable, water-resistant fabric; seams & buckles stress-tested (ASTM/ISO); no toxic components (REACH/CPSIA)

Discussion

Protective features are equally vital. The high incident rate of backpack-related injuries (over 1,200 ER visits annually in U.S. children) and traffic hazards for walking kids highlight the need for bright and reflective packs. Compliance with DIN 58124's visibility criteria can significantly enhance road safety for young users. Yet research indicates industry lag: many parents now choose style over safety, compromising visibility. Therefore, education and regulation should reinforce standards. Additionally, standard quality-control tests (e.g. dynamic loading tests for straps, abrasion for fabrics) should be applied routinely to school backpacks, even though such tests are not universally mandated for all backpacks.

Finally, emerging technologies (e.g. pressure sensors in straps, "smart" buckles) offer future opportunities. Research could explore adaptive backpacks that monitor load and posture, alerting users if weight limits are exceeded. Also, customization for children with special needs (e.g. prosthetics, scoliosis) is largely unexplored.

Research Directions

- **Standardization of testing:** Develop consensus protocols for evaluating backpack ergonomics (posture analysis, muscle activity, balance) to compare designs objectively.
- **Long-term clinical studies:** Investigate how backpack use in childhood affects musculoskeletal health into adulthood (e.g. risk of chronic back pain).
- **Smart/material innovations:** Design backpacks with integrated sensors (to measure weight distribution) or advanced materials (lightweight high-strength fabrics) and test their efficacy.
- **User-centered design studies:** Incorporate children's feedback and usage patterns into design (preferred shapes/colors that still meet safety), ensuring ergonomic features are also accepted by kids.
- **Cross-cultural standards comparison:** Analyze how different countries' standards (Chinese GB standards for children's products) compare and integrate best practices globally.

Conclusion

An ergonomic, protective school backpack must balance weight, fit, and safety. Evidence supports limiting loads to 10% of body weight and using anthropometrically sized, well-strapped designs to minimize strain. Backpacks should carry heavy items close to the torso, employ wide padded straps, and

include secondary chest or waist straps to share the load. Visibility features (reflective/fluorescent areas per DIN 58124) and durable, non-toxic materials are essential for child safety. Despite clear guidelines, many children's backpacks fall short, indicating a need for stronger implementation of standards and consumer education. Our review synthesizes current knowledge and provides a foundation for designers, educators, and regulators to enhance backpack design. By applying these ergonomic principles and standards, manufacturers can help ensure that children carry their school gear safely and comfortably.

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