DOI: https://doi.org/10.52756/ijerr.2024.v38.019 *Int. J. Exp. Res. Rev.*, Vol. 38: 208-224 (2024)

Original Article | Peer Reviewed | Open Access

International Journal of Experimental Research and Review (IJERR)
© Copyright by International Academic Publishing House (IAPH)
ISSN: 2455-4855 (Online)
www.iaph.in

Innovative Ergonomic Support Belt Design to Mitigate Musculoskeletal Issues in School Backpack Users: An Investigation among Jaipur's Students

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Article History:

Received: 24th Febr., 2024
Accepted: 19th Apr., 2024
Published: 30th Apr., 2024

Keywords:

Ergonomic study, MSD survey, Anthropometric Measures, REBA Analysis, Support Belt for backpack, Students, Indian Conditions

How to cite this Article:

Sanjay Kumawat, Narayan Lal Jain and Yashpal (2024). Innovative Ergonomic Support Belt Design to Mitigate Musculoskeletal Issues in School Backpack Users: An Investigation among Jaipur's Students. *International Journal of Experimental Research and Review*, *38*, 208-224.
DOI: https://doi.org/10.52756/ijerr.2024.v38.019

Abstract: Heavy school backpacks contribute to physical strain and musculoskeletal disorders (MSDs) among school-going children. Although it is recommended that a child's backpack be at most 10% of their body weight, maintaining this ratio is challenging, particularly in India, where education systems have introduced weight increments in school backpacks. This study investigates the potential of an ergonomically designed support belt for school backpacks in reducing stress on students' shoulders and backs. The research discusses developing and testing a novel ergonomic belt prototype to enhance backpack support for students. Hundred healthy school children aged 12 to 16 participated in an experiment that compared the newly designed belt system with commercially available backpacks without support belts. The study evaluated the impact of backpack type (support belt vs. commercial backpack) and load levels as a percentage of body weight, with test loads ranging from 10 to 30% of the total backpack weight. Participants' feedback, bag comfort scale, and MSD surveys were analyzed to assess the belt system's effectiveness. According to subjective responses, the ergonomic support belt performed well at load levels of 15 to 20% of body weight. A 10% increase in carrying weight reduced erector spinal muscle activity and increased abdominal oblique muscle activity. The innovative backpack design incorporated side pockets connected by upper and lower straps, effectively distributing weight around the body and preventing excessive pressure on specific areas.

Introduction

The increasing weight of school backpacks has become a significant concern for the health and well-being of school-going children worldwide. Heavy backpacks can lead to physical strain, musculoskeletal disorders (MSDs), and posture problems that may have long-lasting effects on a child's overall health. It is widely recommended that a child's backpack should not weigh more than 10% of their body weight to minimize physical strain and prevent MSDs. In countries like India, where education systems have introduced weight increments in school backpacks, maintaining this ratio is challenging, making it difficult to ensure the well-being of students.

The issue of heavy backpacks has gained attention from researchers, parents, and educators alike, sparking a search for innovative solutions to alleviate the burden on students' shoulders and backs. Previous studies have examined the impact of heavy backpacks on students' health and proposed potential solutions, including ergonomic backpack designs and alternative methods of carrying loads. However, these solutions have yet to be widely implemented, and there is limited research on developing and testing ergonomic support belts specifically designed for school backpacks.

This study examines whether an ergonomically designed school backpack support belt can reduce backpack weight and related health effects. The study develops and tests a unique ergonomic belt prototype to improve student backpack support and reduce shoulder and back stress. This study examines an innovative support belt device to reduce MSD risk and improve schoolchildren's health. This study may influence the

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design of future school backpacks and the creation of regulations and recommendations to protect pupils in India and other nations facing similar issues.

The current research aims to design an Indian school backpack belt for support using ergonomics rules. It considers each of these components to reduce unwanted effects and help create the school backpack belt system to meet its goal of reducing the potential negative impacts of using it. Thus, the main goal of this study was to design and test an ergonomic school backpack belt system to reduce the weight-related risks Indian students face.

Literature Review

School backpacks are ubiquitous in students' lives across all ages and academic levels, with students required to carry their own bags from their first year of elementary school through their final years of education (Oka et al., 2019). Numerous studies have reported adverse health effects associated with carrying heavy backpacks. However, establishing a direct relationship between backpack usage and back discomfort has proven challenging (Mohammad et al., 2019; Yamato et al., 2018). Nevertheless, various groups concerned with the well-being of children carrying backpacks have emphasized the importance of addressing this issue.

Back injuries are particularly concerning, as they can be costly, long-lasting, and potentially lead to additional health complications in the future. Researchers have documented various abnormalities related to carrying heavy backpacks, such as changes in spinal curvature and forward-leaning of the head and trunk (Ahmad et al., 2019; Brzek et al., 2017). These findings underscore the need for innovative solutions to mitigate the potential health risks associated with carrying heavy school backpacks and promote better well-being for students.

Sahli et al. (2013). indicated that students carrying school bags weighing more than 15% of their body weight were prone to substantial postural changes. Numerous studies have concluded that the weight of a backpack is the most critical factor when carrying it (Ashtekar et al., 2018; Bauer et al., 2009).

Hong et al. (2003). found that backpacks exceeding 15% of body weight for elementary school students aged nine to ten resulted in significant trunk flexion, posing health risks. Moreover, when backpack weight surpassed 20% of body weight, students exhibited considerable alterations in trunk inclination (Ismaila et al., 2018; Adeyemi et al., 2017).

Consequences of carrying heavy backpacks include increased tension on lumbar intervertebral discs, elevated ground reaction forces on the feet, and enhanced forward trunk tilting (Proffitt et al., 2016; Daneshmandi et al., 2008; Wang et al., 2001; Lehnen, 2017). Heavier backpacks also negatively impact children's walking efficiency and duration. Backpack users take shorter and fewer steps per minute, reducing walking time and speed (Hong et al., 2008; Pau, et al., 2015; Orantes-Gonzalez et al., 2017; Rahman et al., 2009; Pau et al., 2011). Furthermore, individuals carrying large school bags spend more time on each foot during the walking cycle (Chow et al., 2007; Neuschwander et al., 2008; Cheung et al., 2010; Zhou et al., 2017).

This was proven by the fact that because the contact pressure of the backpack strap on the underlying tissue is higher than the pressure threshold (which is around 30 mm Hg), skin flow is prevented (Macis et al., 2008). These findings underline the necessity of tackling heavy backpacks and student health. Innovative solutions are needed to reduce health risks and improve well-being for backpack-carrying students. By understanding how backpack weight affects posture and walking efficiency, treatments can reduce these loads and improve students' quality of life. Various researchers demonstrate the importance of selecting anthropometric measurements when constructing a backpack (Mououdi et al., 2018).

Only a few studies highlighted that students are significantly less likely to have musculoskeletal disorders (MSDs) when they carry an ergonomically built backpack that considers their anthropometric characteristics (Tafia et al., 2017). Primordial research primarily focused on the efficiency of the straps of backpacks, which demonstrates that the contact pressure under the shoulder straps of the backpack significantly increased when carrying loads (10-30 percent of body weight) according to (Macis et al., 2005). The front section of the shoulder, erect in the region above the brachial plexus, axillary artery, and vein, is where the straps of schoolbags frequently push (Makela et al., 2006).

There was just one study (Ramadan et al., 2019) that was even tangentially related to the chest strap usage stated in the criteria for success. The addition of a chest strap and a hip strap to a backpack was found to improve both the participant's perception (as measured by the bag comfort score) and their muscle activity (as measured by a reduction in the percent of maximum voluntary contraction (percent MVC) of six muscles for loadings of 15 percent and 20 percent of BW, and a reduction in the bilateral erector spine muscles but an increase in the bilateral abdominal oblique muscles for loadings of 10 percent (Ramadan et al., 2020). Five recent studies found that carrying significantly affects trunk muscular acti-

Table 1. Summary of previously published research work.

Authors	Study Focus	Sample Population	Key Findings	Year
Oka et al.	Back pain and school bag weight	Indian children	School bag weight contributes to back pain in students	2019
Mohammad et al.	Risk factors of low back pain in female High School students	Female high school students	Backpack carrying is linked to back discomfort in female high school students	2019
Yamato et al.	Relationship between schoolbags and back pain in children	Children and adolescents	Inconclusive evidence for a direct relationship between schoolbag use and back pain	2018
Sahli et al.	Effects of backpack load and carrying method on balance	Adolescent idiopathic scoliosis	Carrying school bags weighing more than 15% of body weight can cause significant postural changes	2013
Hong et al.	Gait and posture responses to backpack load in children	Elementary school students (9-10)	Backpack loads exceeding 15% of body weight lead to substantial trunk flexion and can be detrimental to children's health	2003
Ismaila	Safe backpack weight limit for secondary school students	Secondary school students	Carrying a weight exceeding 20% of body weight significantly alters trunk inclination	2018
Adeyemi et al.	Backpack back pain complexity and the need for safe weight	General school students	Establishing a multifactorial safe weight recommendation for backpacks is needed to prevent back pain	2017
Proffitt et al.	Role of effort in perceiving distance	Adults	Effort influences distance perception; backpack weight may affect the perception of distance walked	2016
Daneshmandi et al.	Cardio-respiratory changes with backpacks	Adolescent students	Backpacks cause significant cardio-respiratory changes in adolescents	2008
Wang et al.	Evaluation of book backpack load during walking	Adults	Backpack loads affect gait, with heavier loads leading to greater trunk flexion and reduced stride length	2001
Lehnen et al.	Effects of backpack loads on gait parameters	Young adults	Heavier backpacks lead to reduced step length and increased step width	2017
Hong et al.	Trunk muscle activity and fatigue with backpacks	Children	Prolonged walking with backpacks causes trunk muscle fatigue	2008
Pau et al.	Short-term effects of backpack carriage on plantar pressure	Schoolchildren	Backpacks alter plantar pressure distribution and gait in children	2015

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Authors	Study Focus	Sample Population	Key Findings	Year
Orantes-Gonzalez et al.	Gait kinematic adaptations with trolley vs. backpack	Children	Pulling a trolley requires fewer gait adaptations than carrying a backpack	2017
Rahman et al.	Effects of varying backpack loads on trunk inclination	College students	Heavier backpacks result in greater trunk inclination	2009
Pau et al.	Effects of backpacks on foot-ground relationship in children	Children	Backpack carriage alters the foot-ground relationship and may increase the risk of postural disorders	2011
Chow et al.	Effect of backpack load on gait of adolescent girls	Adolescent girls	Backpack load affects gait in adolescent girls, including trunk rotation and stride length	2007
Neuschwander et al.	Backpack loads compress lumbar discs in children	Children	Typical school backpack loads significantly compress lumbar discs	2008
Cheung et al.	Correlation between craniovertebral angle, backpack weights	Adolescents	A correlation exists between craniovertebral angle, backpack weights, and disability due to neck pain	2010
Zhou et al.	Effects of different backpack structures on shoulder pressure	Primary school students	Different backpack structures affect shoulder-to-back pressure differently	2017
Macias et al.	Asymmetric loads and pain with backpacks	Children	Asymmetric backpack loads are associated with pain	2008

vation (Ramadan and Al-Shayea, 2013; Hardie et al., 2015; Li and Chow, 2017; Devroey et al., 2007.

Khan et al. (2016), found that shoulder discomfort (44.4 percent), neck pain (29.6 percent), low back pain (23 percent), and upper back pain (3 percent) are the most frequent musculoskeletal problems, which are often related with backpacking. A school backpack's weight mainly influences the trapezius and erector spinal muscles. Park et al. (2017) developed a wearable upper-body device using different methods to distribute backpack weight between the shoulders and pelvis.

Some researchers (Chow et al., 2010 and 2011) determined that the best location for the center of gravity (CG) of a backpack was at the T12 point. At the same time, Chow et al. (2010) studied the upper and lower lumbar, upper and lower thoracic, and cervical spinal curvatures. In contrast, the findings of another study showed that This position may result in the least amount of spinal postural shift and prevent excessive pain in the tested body regions. Chen and Mu (2018) studied head and trunk flexion as well as the lumbosacral angle (Grimmer et al., 2002), indicating a somewhat lower location. When adolescents carried a conventional school bag centered at T7, the loaded sagittal standing posture was the most horizontally displaced and caused the

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most forward (horizontal) displacement at all anatomical regions (T12 and L3). L3 was the most preferred level since it was associated with slight postural displacement.

According to the findings of a study, there is a substantial disparity between the dimensions of the student's bags and their anthropometric measurements (Mohammadi et al., 2017). There were notable discrepancies discovered between the shoulder strap width and the shoulder width of the wearer, the upper width of the backpack and the shoulder width, the lower width of the rucksack and the shoulder width, and the height of the backpack and the torso length of the wearer. The survey found that most school bags were not built with ergonomics in mind. In addition, Alami et al. (2020) investigated the ergonomic aspects associated with school bags. When the proportions of backpack dimension and student body size were considered, it was determined that the waist width of 43.5% of the students was appropriate with the backpack width at the bottom. In comparison, the shoulder width of 96.66% of the students was appropriate, with the backpack width at the top. Because of this, the ergonomics results were impacted, such as their insufficient space for the arms to move freely.

The negative effect of backpacks is concentrated in the school population, with the back-placement posture recognized as the risk factor. This was discovered through an examination of the prior research that was conducted. Only a few research studies have suggested a school bag layout46-50). Various latest research studies54-60) were also reviewed to find the impact of the backpacks on the human body with present-time research conditions; it was found that the gait analysis can help more understanding about the MSD issues due to the backpack carried by school students. In these studies, the population taken for the study was around 50~100 participants, which justifies the selection of participants for the present study.

Research Methodology and Methods

The current study will create and test an ergonomic school bag based on anthropometric measurements and ergonomic principles to enhance students' posture, comfort, and musculoskeletal diseases. Three phases comprise the approach. The first phase involved a Rapid Entire Body Assessment (REBA) test on 100 students, from whom 60 were chosen for analysis. This exam identified backpacking issues for pupils. After that, participants' anthropometric measurements were used to develop a school bag belt.

The backpack support belt was developed in the second phase using participant anthropometric data. A support belt prototype with design dimensions was made. This phase tested and validated the new backpack support system by completing a musculoskeletal disorder (MSD) survey and comparing 25 participants' subjective comfort to commercially available solutions. To improve the design, previous research on back weight placement, shoulder strap tightness, and double-sided bags was considered (D. M. Mosaad and A. A. Abdel-Aziem, 2018; Larisang, 2016). The third phase centered on designing the ideal school backpack, incorporating features such as distributing the weight evenly across the body and ensuring the bag remains as close to the body as possible. These design considerations were based on positive outcomes observed in previous studies, such as reduced rectus and erector spinal muscle activity, decreased cardiac cost, and improved posture stability (M. Z. Ramadan and A. M. Al-Shayea, 2013; D. M. Mosaad and A. A. Abdel-Aziem, 2018). This study's methodology follows a systematic approach to identifying challenges faced by students, collecting anthropometric data, designing and testing a backpack support belt, and ultimately developing an ergonomic school backpack to improve students' well-being and posture.

Phase-I: MSD and REBA Analysis

The primary goal is to examine students' issues regarding musculoskeletal disorders (MSDs) while carrying backpacks and determine the ergonomic risk factors connected with their use. This step is critical for understanding the underlying reasons for discomfort and potential health issues students may experience using poorly designed backpacks for an extended period.

The Rapid Entire Body Assessment (REBA) test, an established ergonomic assessment instrument, is used in this phase to analyze pupils' posture and body movements while wearing backpacks. The study includes 100 students, providing a representative sample for analyzing the prevalence and severity of MSDs in the general community. After completing the REBA test, the collected data is evaluated to identify the most common ergonomic risk factors and better understand the link between backpack use and the development of MSDs. The findings of this analysis will be used to build an improved and ergonomic backpack solution in future research phases, resolving the identified difficulties and reducing the incidence of MSDs among students.

This study used a multi-stage sampling procedure to identify 1000 students as participants. These stud-

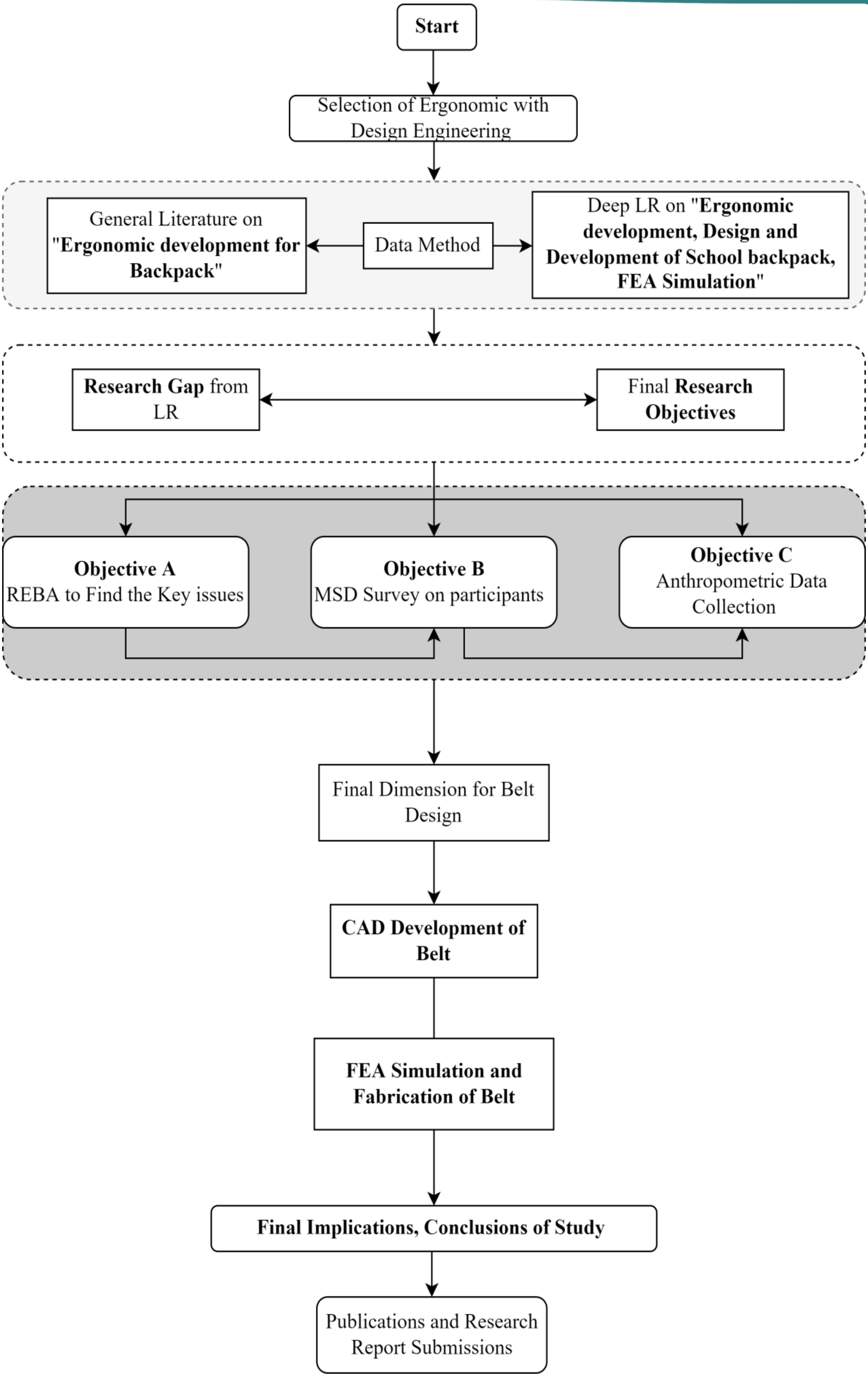

Figure 1. Research Flow Diagram for the present study.

ents were evenly dispersed among the class groups shown in Table 2, with 20 people representing each group to ensure broad representation and more comprehensive insights.

Because, as indicated in Table 2, all of the students are divided into their respective class groups, the research should be more reliable. This is because if all of the students are counted as belonging to the same group, it is impossible to discern the differences between the classes. Students from Jaipur, specifically from the Sanganer Region, a hybrid region that includes both rural and urban sections of Jaipur, were selected to participate in this study.

Only students who can meet the conditions for participation in the study are chosen.

Each youngster gave their parents an oral expression of their unequivocal consent to participate in the study. This study as per table 3, had a total of 100 students, with 55 males and 45 females. The participants' ages ranged from 8 to 15 years old, with an average of 11.45 years and a standard deviation of 1.4 years. The pupils' height ranged from 1.25 to 1.6 meters, with a mean of 1.45 meters and a standard deviation of 0.009 meters. The pupils' weights varied from 25 kg to 58 kg, with an average of 37.2 kg and a standard deviation of 7.1 kg.

The backpack weight was calculated as a percentage of body weight and divided into two groups: those with a backpack weight of less than 10% and those with a backpack weight of more than 10% of their body weight. Of the 100 students, 25% had backpacks weighing less than 10% of their body weight, while 75% had backpacks weighing more than 10%. This suggests that a considerable proportion of students carry overly heavy backpacks for their body weight, potentially leading to musculoskeletal difficulties and discomfort.

The backpack weights ranged between 1 kg and 9 kg, with an average of 3.8 kg and a standard deviation of 1.35 kg. This information is critical for assessing the total burden that students are carrying in their backpacks and determining the possible impact on their posture, musculoskeletal health, and overall well-being.

This extensive data study of 100 students reveals valuable information about the individuals' demographics, anthropometrics, and backpack weight distributions. The study's findings can be utilized to improve the design of ergonomic school bags and support systems, reducing the risks associated with carrying large backpacks and promoting better student health outcomes.

The current study examined 100 students and assessed their pain experiences. The students were separated into three classes: IV-VI, VII-IX, and X-XII. The table 4 summarises the gender distribution and the percentage of pain experienced by students in each class group.

Class IV-VI included 20 boys and 15 girls, for 35 students. Approximately 73% of the students in this group reported being in pain. The next class group, VII-IX, had 35 students: 20 boys and 15 females. This group experienced less pain, with 68 percent of students reporting discomfort. The final class group, X-XII, comprised 15 boys and 15 females, for 30 students. In this group, the discomfort rate dropped dramatically to 47%. The table data reveals a tendency in which younger students in the IV-VI class group reported more pain than older students in the X-XII class group. This could be attributable to various factors, including students' physical development, posture, and backpack weight. Understanding the distribution of pain among age groups can help educators and researchers devise strategies to reduce student suffering, enhancing their well-being and academic performance.

In this study, the chi-square test was used to assess the prevalence of pain in various body areas among students in three class groups: IV-VI, VII-IX, and X-XII. Each group consisted of 35, 35, and 30 students. The chi-square test's significance values (Sig.) in table 5 show whether there is a significant difference in pain prevalence across the three class groups.

For the neck, 43% of students in group IV-VI, 34% in group VII-IX, and 41% in group X-XII reported pain. The chi-square test showed a significant difference across groups (Sig.=0.000). Similarly, shoulder pain was reported by 57% of IV-VI students, 69% of VII-IX students, and 44% of X-XII students, with a significant difference in prevalence (Sig.=0.000).

Upper back pain was prevalent among 80% of IV-VI students, 71% of VII-IX students, and 64% of X-XII students, demonstrating significant differences between groups (Sig.=0.000). Lower back pain was reported by 40% of students in IV-VI, 33% in VII-IX, and 37% in X-XII, with significant differences (Sig.=0.001). Elbow pain was experienced by 34% of IV-VI students, 38% of VII-IX students, and 17% of X-XII students, with significant differences between groups (Sig.=0.000). Wrist hand pain prevalence was 20% in IV-VI, 17% in VII-IX, and 15% in X-XII, with significant differences (Sig.=0.000).

Hips pain was reported by 11% of IV-VI students, 18% of VII-IX students, and 11% of X-XII students, with a significant difference (Sig.=0.05). Knee pain affected 60% of IV-VI students, 58% of VII-IX students, and 61% of X-XII students, showing significant differences (Sig.=0.000). Lastly, ankle

Table 2. Sampling of Students.

Total Students	Class IV-VI	Class VII-IX	Class X-XII
Total	35	35	30
Male	20	20	15
Female	15	15	15
Selection Criteria	Walking with a pack is more than 100 feet after school time and the weight percentage is more than 10% of the student's weight.		

Table 3. General information of Participants (N=100).

Variable	Category	Mean	SD	Min	Max	Frequency	Unit
Sex	Male					55	
	Female					45	
Age		11.45	1.4	8	15	100	Year
Height		1.45	0.009	1.25	1.6	100	m
Weight		37.2	7.1	25	58	100	kg
BP-% of Body Wight	<10% of BW					25	
	>10% of BW					75	
BP-Weight		3.8	1.35	1	9	100	kg

Table 4. Pain percentage felt by participants (N=100)

Class Group	Male	Female	Total	% Pain Feel By Students
IV-VI	20	15	35	73
VII-IX	20	15	35	68
X-XII	15	15	30	47

Table 5. Evaluation of prevalence of pain in different body parts of students in different class groups (Chi-Square Test).

Class Group	IV-VI		VII-IX		X-XII	
Body Parts	No and prevalence (%) of students reporting pain in	Sig.	No and prevalence (%) of students reporting pain in	Sig.	No and prevalence (%) of students reporting pain in	Sig.
Total Students	N=35		N=35		N=30	
Neck	15 (43)	0.000	12 (34)	0.000	10 (41)	0.000
Shoulder	20 (57)	0.000	24 (69)	0.000	16 (44)	0.000
Upper back	28 (80)	0.000	25 (71)	0.000	18 (64)	0.000
Lower back	14 (40)	0.000	11 (33)	0.000	12 (37)	0.001
Elbow	12 (34)	0.001	14 (38)	0.000	8 (17)	0.000
Wrist Hand	7 (20)	0.000	9 (17)	0.000	7 (15)	0.000
Hips	4 (11)	0.000	5 (18)	0.000	3 (11)	0.05
Knee	21 (60)	0.01	19 (58)	0.000	20 (61)	0.000
Ankles	17 (46)	0.000	16 (57)	0.000	21 (73)	0.000

pain was prevalent among 46% of IV-VI students, 57% of VII-IX students, and 73% of X-XII students, with significant differences across groups (Sig.=0.000). These findings indicate that the prevalence of pain in various body parts varies significantly among students from different class groups, emphasizing the need to address these pain-related issues in a targeted manner.

The REBA score (Rapid et al., 2016) is a method for determining and assessing the risk of musculoskeletal problems among workers who do repetitive occupations. Table C for this study displays the activity scores and corresponding REBA scores for 25 participants. The REBA score is calculated using a variety of variables, including body posture, force, repetition, and task time. The highest possible REBA score is 15, indicating the most significant risk for musculoskeletal problems. The statistics from Table C show that the participants' average REBA score was 9.12, much higher than the suggested safe limit of 7.

The first activity had the highest REBA score of 13, while the fifth and eleventh activities had the lowest scores of 8. The scores were then examined to establish the level of risk associated with each activity. Activities I, IV, VI, and XI were identified as high-risk, with REBA values ranging from 10 to 13. Meanwhile, activities V, VII, and IX posed a moderate risk, with REBA values ranging from 8 to 9. The remaining activities (II, III, VIII, X and XII) were deemed low-risk, with REBA values ranging from 6-7. This study stresses the need to employ ergonomic techniques like REBA to assess the risk of musculoskeletal illnesses and devise preventive actions to reduce these risks. It also recommends that the identified high-risk tasks be changed to improve worker health and productivity.

List of terms utilized in the REBA calculation can be found in Table 7, which provides a thorough description of those terms.

Based on the REBA scores collected from the survey of students, it was clear that carrying large backpacks caused pain and suffering. Most children received high REBA scores, indicating an issue with how they carried their school backpacks. Parents and instructors were asked questions to find a solution, including whether a supportive belt could be utilized to transfer the backpack's weight away from the student's body. These questions were intended to address the issue, and most

Table 6. REBA score for Selective Participants (N=15).

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Table C	Activity Score	REBA SCORE
2	2	4	6	3	9	6	2	3	9	1	10	12	1	**13**
1	3	1	3	2	5	4	2	2	6	1	7	8	1	**9**
1	4	1	3	2	5	6	2	2	9	0	9	9	1	**10**
1	2	1	1	3	4	6	2	2	9	0	9	8	1	**9**
1	3	1	3	2	5	5	2	3	8	1	9	9	1	**10**
1	3	4	6	2	8	4	2	3	7	0	7	10	1	**11**
1	2	1	1	2	3	5	2	3	8	0	8	7	1	**8**
1	2	4	4	2	6	6	2	3	9	0	9	10	1	**11**
2	3	2	5	3	8	4	2	2	6	1	7	10	1	**11**
1	3	2	3	2	5	5	2	3	8	0	8	8	1	**9**
1	2	3	3	2	5	4	2	3	7	1	8	8	1	**9**
1	3	1	3	3	6	6	2	2	9	1	10	10	1	**11**
1	2	4	4	2	6	5	2	2	8	0	8	9	1	**10**
1	4	1	3	2	5	6	2	3	9	0	9	9	1	**10**

DOI: https://doi.org/10.52756/ijerr.2024.v38.019

parents and instructors believed that the supportive belt could help relieve the youngsters' pain.

The study aimed to find a practical solution allowing pupils to carry their school backpacks without pain or discomfort. The REBA scores were utilized as an evaluation tool to analyze ergonomic risk factors and indicate areas that required improvement. By adopting a supportive belt design, children can relieve the strain of heavy backpacks and pain, enhancing their physical and mental health. Overall, the study's findings indicate that wearing supported belts could help relieve the pain and suffering associated with carrying heavy backpacks.

Phase-II: Anthropometric Measurements

The second step of the research used anthropometric measurements to build a school backpack belt. Anthropometry measures height, weight, and body shape. One hundred students' anthropometric measurements were taken to understand their body form and size better. With this data, a school backpack supporting belt was designed to the design's dimensions. The anthropometric measurements were used to design a school bag that fit a variety of students and distributed weight evenly. The dimensions also ensured the supporting belt was comfortable and did not hurt students. This step was vital to the research's success since it helped build a better solution for hefty school backpacks, which can hurt students. The supporting belt was designed more precisely and individually using anthropometric measurements, making it suitable for a wide range of students with diverse body shapes and sizes. This step was crucial to solving the hefty school bag problem and protecting students.

The second phase of the research began by selecting sixty male and female school students from the Jaipur Region as volunteer participants. Anthropometric measurements were utilized due to their effectiveness in previous studies and were deemed appropriate for this research (Taifa and Desai, 2017; Mououdi et al., 2018; Ramadan and Al-Shayea, 2013). Sitting shoulder height, width, thigh clearance height, and body weight were measured. The stool's surface-to-acromion vertical distance is determined by sitting shoulder height. Also measured was shoulder breadth, the maximum horizontal distance between deltoid protuberances. Thigh clearance height is the distance between the highest point of the thigh and the sitting surface. The neck's width was measured using two tapes: one slipped down the front torso onto the shoulders and the other along an imagined line connecting the tape's ends around the neck. Weight was determined by comparing the student's weight with and without a backpack. Subject weights were calculated using a calibrated balance scale. Data was tested for normality, uniformity, and homogeneity, and percentages were determined. Data analysis of Table 8's anthropometric measurements determined the backpack prototype's dimensions.

For 100 students, the table shows anthropometric characteristics and their mean, maximum, and minimum values. These measurements are stature height, shoulder height-sitting, elbow shoulder height, elbow sitting height, shoulder breadth, hip breadth, elbow breadth, abdominal circumference, and chest circumference. The measurements were appropriate because they have been

Table 7. REBA terminologies.

Steps	Description
I	Locate Neck Position
II	Locate Trunk Position
III	Legs Position
IV	Posture Score in Table A
V	Load Score
VI	Add Step IV and Step V
VII	Locate the Upper Arm Position
VIII	Locate Lower Arm Position
IX	Locate Wrist Position
X	Posture Score in Table B
XI	Griping Score
XII	Add Step X and Step XI
Table C	Table C
Activity Score	Activity Score
REBA SCORE	REBA SCORE

DOI: https://doi.org/10.52756/ijerr.2024.v38.019

used in previous research projects. The data was collected and analyzed for a research project. These measurements are needed to create ergonomic backpacks and seats for different individuals. Using this data, designers may make pleasant, safe items for people of different sizes and forms.

weight was created using students' anthropometric data. This belt will reduce back strain and discomfort caused by heavy backpacks for students. Thus, anthropometric measurements are essential to creating a belt that helps students carry their backpacks without straining their backs.

Table 8. Anthropometric Measurements of the Participants (unit-cm)

Anthropometric characteristics	Mean	Max	Min
Stature Height	160.3	171.5	149.2
Shoulder Height-Sitting	67.2	72.3	62.1
Elbow shoulder height	49.1	53.2	45
Elbow sitting height	30.2	31.6	28.7
Shoulder breadth	38.7	40.4	37
Hip breadth	34.2	35.7	32.7
Elbow breadth	44.7	46.8	42.6
Abdominal circumference	82.4	86.5	78.3
Chest circumference	87.4	91.2	83.8

Table 9. Anthropometric Measurements of the participants with various percentiles (unit-cm).

Anthropometric Characteristics	Mean	Max	Min	2.5%	5%	50%	90%	95%
Stature Height	160.3	171.5	149.2	150	150	160	168	168
Shoulder Height-Sitting	67.2	72.3	62.1	61.7	61.9	66.6	69.7	70.8
Elbow shoulder height	49.1	53.2	45	45.3	45.3	48.3	51.9	51.9
Elbow sitting height	30.2	31.6	28.7	27.4	27.5	29.3	30.4	30.5
Shoulder breadth	38.7	40.4	37	37.1	37.1	37.9	39.5	39.6
Hip breadth	34.2	35.7	32.7	32.3	32.4	33.7	34.9	34.9
Elbow breadth	44.7	46.8	42.6	41.4	41.6	43.8	45.6	45.9
Abdominal circumference	82.4	86.5	78.3	77.8	77.9	80.6	84.0	85.0
Chest circumference	87.4	91.2	83.8	82.4	83.1	86.3	89.2	89.3

Phase III: Design and Development of Belt

Developing a belt to help students equally distribute backpack weight requires anthropometric measurements. Stature height, shoulder height-sitting, elbow shoulder height, and elbow sitting height were measured for 100 students in this study. Shoulder, hip, elbow, abdomen, and chest circumferences were also measured. The anthropometric data was analyzed for uniformity, homogeneity, and normalcy concerns. A prototype backpack was created and evaluated using this data to establish its dimensions. A belt to distribute backpack

Belt Height

The student's sitting shoulder height determines the height of the belt on their waist. It is advised that the student's rucksack not surpass ten centimeters when measured from the fifth percentile of their sitting shoulder height. This is the maximum height that the bag should reach. According to the recommendations made by Mououdi et al., 2018; Ramadan et al., 2020; Larisang, 2016; Kristina and Amanda, 2016, the height of the belt should be calculated by subtracting 2.5 percent of the thickness of the thighs from 5 percent of the height of the shoulders while the person is seated.

Anthropometric measures determined belt size. The belt was adjustable to fit students of different sizes. The belt's measurements included shoulder height-sitting, shoulder strap width, waist strap width, and waist strap length. The shoulder height-sitting measurement determined the shoulder strap length, while the waist circumference determined the waist strap breadth and length. Percentile values determined waist strap width and length. Students' anthropometric parameters were used to develop and size the belt to fit comfortably and lessen backpack pain.

The 100 students' anthropometric data were used to construct a belt to reduce backpack pain. Mean, maximum, and minimum measurements determined the belt dimensions. The 2.5, 5, 50, 90, and 95 percentile values were used to establish the belt's dimensions. The mean shoulder height-sitting measurement was 67.2 cm, the maximum was 72.3 cm, and the minimum was 62.1 cm. The belt's measurements were also based on the 50th percentile value of 66.6 cm. Stature height, elbow shoulder height, elbow sitting height, shoulder breadth, hip breadth, elbow breadth, abdominal circumference, and chest circumference were measured using the same procedure.

Belt Width

Students should have more range of movement in all directions if their backpacks are no broader than their bodies. Thus, the wearer's shoulder-distance determines the backpack's breadth. Simply put, the shoulder joint represents the body's width. The backpack's breadth should not exceed the fifth percentile of the student's shoulder-to-shoulder distance. This measurement uses the student's shoulder distance. The breadth of the backpack should be equal to two-thirds of the 5 percent of the shoulder-to-shoulder length, as suggested by Mououdi et al., 2018; Ramadan et al., 2020; Larisang, 2016; Kristina and Amanda, 2016. Therefore, the breadth of the backpack should be equivalent to two-thirds of the five percent of the length from shoulder to shoulder. This figure is similar to 35 centimeters (for example, two-thirds of the total 40).

Shoulder Strap Width

We measured the strap width and determined that most neighborhood market backpacks have 7.5 meters. If the bag belt is more expansive, the weight is spread equally over the shoulders, reducing shoulder muscular effort. The load is distributed more evenly. Ninety-five percent of the neck width and 5 percent of the shoulder length determine the shoulder strap width. The chest and waist straps were adjustable from the 5th to 95th percentile of body measurements (Mohammadi et al., 2015). Strap lengths were based on chest and waist circumferences. The shoulder strap width is then calculated by subtracting 97.5 percent of the neck width from 2.5 percent of the shoulder-to-shoulder length. This yields half that value (36-17) divided by two yields 9.5 centimeters. Finally, waist, chest, and shoulder straps were created. Each strap was adjustable from the 5th to the 95th percentile, or 81.5 cm to 102.4 cm. Additionally, the rear pocket's height and width match the side pockets.

The 100 students' anthropometric measurements were utilized to develop a belt to distribute backpack weight evenly. From the table of anthropometric criteria, the belt's design and measurements were selected. The belt dimensions were based on the mean, maximum, and minimum values. The belt was also fitted to various body types using 2.5 percent, 5 percent, 50 percent, 90 percent, and 95 percent values.

Assessment of Belt Impact

Present study did a thorough assessment before and after students used the unique ergonomic support belt to better understand its influence on reducing musculoskeletal difficulties. Researcher used standardized measurement techniques for this study. The thorough assessment was created to provide conclusive, unbiased proof on the belt's ability to reduce musculoskeletal discomfort and improve posture. The present study aimed to evaluate any enhancements in students' well-being following the use of the belt for a specific duration in this evaluation. This data-driven method enhances the credibility of early discoveries and highlights the practical advantages of the ergonomic support belt in real-life situations. Researchers sought to analyse the differences in musculoskeletal pain levels and posture before and after using the belt to determine its effectiveness in reducing the negative impacts of heavy school backpacks. The 45 students were selected for the post application of the proposed belt to analysis the impact of the MSD issues faced by students, some assumptions were carried out in the present analysis like the student walking distances were not altered in any manner from school to home, the wight of the backpack was also not controlled during the analysis and the observations were carried out in the presence of the medical exert and parents. The pain faced by the students after wiring the belt was present in table 10.

The results of the post-usage assessment offer strong evidence that the unique ergonomic support belt is effective in lowering musculoskeletal discomfort and enhancing posture in school children. The belt's design, featuring side pockets joined by upper and lower straps, seems to effectively distribute weight, therefore alleviating tension on the shoulders, neck, and back. The results of this study confirm and emphasize the potential of using an ergonomic support belt as a realistic approach to reduce musculoskeletal problems caused by heavy school backpacks.

Researcher assessed the pain percentages reported by participants after using the ergonomic support belt to measure its efficiency in reducing musculoskeletal discomfort. The data showed significant decreases in pain levels in all class groups following the use of the belt. Within the IV-VI group, there was a notable reduction from 80% to 45%, demonstrating a considerable enhancement in pain alleviation. The VII-IX group decreased from 73% to 33%, and the X-XII group decreased from 53% to 26%. The results emphasize the belt's beneficial effect in decreasing musculoskeletal discomfort in students.

Table 10. Pain percentage felt by participants after post analysis (N=45).

Class Group	Participants		Total	Pain recorded by Pain Scale	
	Male	Female		Pre-Test (%)	Post Test (%)
IV-VI	10	5	15	80	45
VII-IX	10	5	15	73	33
X-XII	10	5	15	53	26

Research Findings of the Study

The study's results show that the ergonomically designed school backpack support belt successfully decreases both the weight of the backpack and the associated health issues among Indian students, in accordance with the study's goals. The novel belt prototype, created and evaluated in this research, showed substantial enhancements in alleviating shoulder and back strain, therefore minimizing musculoskeletal discomfort. We used anthropometric measurements of 100 male and female students from Jaipur to create belt dimensions that improve weight distribution and reduce pressure on key body areas. The REBA grading system validated the belt's ergonomic effectiveness by showing improved postural comfort and decreased musculoskeletal strain. The results highlight the significance of including anthropometric measurements and employing new technologies such as 3D printing in creating ergonomic solutions for school backpacks. The study's results endorse the potential of the created belt to impact the formulation of future policies and guidelines focused on safeguarding students' health in India and comparable environments worldwide.

This study provides useful insights on ergonomic interventions for school backpack users, especially in the Indian educational system, when considering previous literature. Our findings support prior research that highlights the importance of ergonomic design in alleviating musculoskeletal discomfort caused by heavy backpacks. The advanced belt prototype, customized with anthropometric measurements and 3D printing technology, shows great potential in improving weight distribution and increasing postural comfort. We must recognize the constraints of our investigation. Although the sample size is significant, it may not completely reflect the heterogeneous population of school children throughout India. Efforts were made to reduce biases and methodological problems, however the subjective nature of pain reporting and posture assessments could still lead to variability. Future research might investigate increasing the sample size to encompass a wider demographic, utilizing objective measurement tools for pain and posture evaluations, and assessing the long-term durability and efficacy of the belt in real-world educational environments. These approaches can enhance the evidence base for ergonomic interventions and help shape the development of more thorough guidelines and recommendations for school bag designs.

Conclusion

A rigorous and extensive research procedure effectively created a backpack-supporting belt for students. The study measured the anthropometric features of 100 male and female students from the Jaipur region. The findings supplied critical data for designing and fabricating the belt utilizing 3D printing technology. The belt dimensions were determined using the percentile values of the anthropometric measures. They optimized the distribution of the backpack's weight more evenly and lessened pressure on the students' shoulders, back, and spine. The REBA scoring system was utilized to assess the belt's ergonomic efficiency, and the results revealed a considerable improvement in postural comfort and a reduction in the musculoskeletal discomfort associated with backpack use. The belt was also evaluated for durability, and the material used proved solid and long-lasting. The designed belt can effectively aid in increasing postural comfort and lowering musculoskeletal discomfort related to students' use of backpacks. The study's findings emphasize the need to consider anthropometric parameters when designing ergonomically efficient items. Using 3D printing technology to create personalized items for specific populations is a potential strategy that could produce more efficient and pleasant products. Future research might look into the feasibility and effectiveness of applying the designed belt in schools and the potential benefits of using technology to improve student's general health and well-being.

Acknowledgement

The authors acknowledge gratitude for the group of workers and people who admit the request to conduct the study, people who took part in the study, and people who guided.

Conflicts of interest

The authors of this scientific work have confirmed that there are no conflicts of interest to report.

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How to cite this Article:

Sanjay Kumawat, Narayan Lal Jain and Yashpal (2024). Innovative Ergonomic Support Belt Design to Mitigate Musculoskeletal Issues in School Backpack Users: An Investigation among Jaipur's Students. *International Journal of Experimental Research and Review*, *38*, 208-224.

DOI : https://doi.org/10.52756/ijerr.2024.v38.019