

Research and Development of a Prototype Student Backpack: Emphasis on Ergonomic Criteria

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ABSTRACT

This study investigates the ergonomic design of student backpacks, considering factors such as load distribution, proper fit, strapping, accessibility, and aesthetics. Through a comparative analysis of five sample backpacks and a developed backpack prototype, various performance metrics were evaluated. The analysis revealed notable variations in dimensions, weight, strap length, and compartmentalization among the sample backpacks. Results indicated that the developed backpack prototype exhibited favourable characteristics in load distribution, proper fit, and strapping, outperforming some of the sample backpacks. However, there were areas of improvement identified across all backpacks, particularly in accessibility and aesthetics. The findings underscore the importance of ergonomics in backpack design, highlighting the need for careful consideration of user comfort and functionality. Additionally, the study provides valuable insights for designers and manufacturers to enhance the design of student backpacks, aiming to mitigate the risk of musculoskeletal issues and improve overall user experience. Further research may explore additional design features and conduct empirical testing to validate the effectiveness of proposed ergonomic solutions. In conclusion, this study contributes to advancing the field of ergonomic backpack design, with potential implications for student well-being and academic performance.

KEYWORDS: Ergonomic design, Student Backpacks, Load Distribution, Proper Fit, User comfort

1. INTRODUCTION

Backpacks serve as indispensable tools for a diverse array of individuals, prominently including students, hikers, campers, commuters, athletes, and military personnel, facilitating the transport of personal belongings from one location to another (Mertes, 2023). While the use of backpacks for this purpose is longstanding, spanning centuries, their design has evolved over time. Nevertheless, fundamental features persist across most backpacks, typically including one or more shoulder straps, a back panel, and compartments for organizing belongings. Amongst these users, students, in particular, heavily rely on backpacks to transport study materials such as laptops, books, and stationery for prolonged durations throughout their academic years (Mansoorian et al., 2019). Consequently, the design of backpacks assumes paramount importance for students, necessitating consideration of numerous factors during the design and development phases. These factors significantly influence how students utilize backpacks, impacting their overall health and academic performance. Research has highlighted concerns regarding the weight of backpacks carried by students, with studies revealing that many students exceed recommended load limits relative to their body weight (Adeyemi et al., 2014; Olatunya, 2017; Ismaila, 2018). This excess burden often results from concerns about unexpected classes or tests, contributing to musculoskeletal stresses and subsequent pain in areas such as shoulders, neck, and lower back (Kristina & Amanda, 2018).

Moreover, the use of backpacks among students has prompted scrutiny regarding its effects and associated issues. Research underscores the significant impact of heavy backpacks on student health, correlating increased backpack weight with heightened occurrences of bodily discomfort

(Olatunya, 2017). Prolonged exposure to these issues can yield long-term repercussions on students' health, academic performance, and overall quality of life. Traditional backpacks frequently lack features conducive to proper load distribution, comfort, and componentry. Consequently, designing backpacks tailored explicitly to students necessitates attention to addressing these deficiencies (Mertes, 2023). Integrating ergonomic principles into backpack design and development emerges as a critical consideration. Backpacks designed with students' ergonomic needs in mind aim to afford ease of use, comfort, proper weight distribution, and reduced musculoskeletal disorder risks.

Despite the burgeoning market offering various backpack designs, few cater specifically to students' ergonomic requirements (Dianat, et al., 2014). Often, manufacturers prioritize aesthetics and material quality over functionality and comfort, leading to inadequate weight distribution, strap design, and back support. This oversight compromises comfort and usability, potentially resulting in discomfort, postural changes, and musculoskeletal issues (Moore et al., 2007).

Moreover, beyond physical health implications, poorly designed backpacks can detrimentally impact students' psychological well-being, inducing stress and anxiety. Consequently, there is a compelling need to develop ergonomic backpacks for students to mitigate musculoskeletal disorders and enhance functionality. While prior studies have documented the prevalence and health consequences of backpack-related musculoskeletal problems among students (Adeyemi et al., 2014; Olatunya, 2017; Ismaila, 2018) and have proposed general ergonomic guidelines for backpack design (Dianat et al., 2014; Mansoorian et al., 2019),

comparatively few have progressed from guideline formulation to the design, prototyping, and comparative evaluation of a physical backpack against commonly used alternatives, particularly within a Nigerian university context. This gap, between recommended ergonomic principles and a tested, ready-to-use design, is what the present study seeks to address. This study aims to address existing gaps in research by developing an ergonomic backpack design, thereby advancing the field and offering practical guidance for developers. The study will utilize CAD software to create a virtual prototype, incorporating design modifications such as weight distribution systems, support cushioning, and adjustable straps. Emphasis will be placed on enhancing usability through considerations such as storage, accessibility, and convenience.

2. RESEARCH METHODOLOGY

2.1 Survey Design

This study utilized a survey research design to gather data from a broad spectrum of students through surveys or questionnaires aimed at assessing the ergonomic design of student backpacks. The survey encompassed both quantitative and qualitative aspects to ensure a comprehensive evaluation. Primarily, participants were drawn from the student body of Olabisi Onabanjo University across at Ibogun campus. The choice of Olabisi Onabanjo University (OOU) as the primary participant source was based on its proximity and accessibility for data collection. The diverse student population at the university makes it an ideal setting for compiling a sample that accurately represents the target population. Participants were provided informed consent before participating in the study.

2.2 Sampling Method

Convenience sampling was employed for participant recruitment in this survey research study. This method was selected for its practicality and accessibility, considering the researcher's affiliation with Olabisi Onabanjo University and potential challenges associated with random sampling. The study aims to include students from various academic disciplines to ensure diversity in the sample. The sample size for this investigation was determined based on practical considerations and available resources. To ensure an adequate amount of data for analysis, about 500 participants were recruited. A cohort of one hundred and sixty (160) students was meticulously chosen. Depending on response rates and data accuracy, the actual sample size may be adjusted during the data collection process. The participants' demographic data, including age, gender, course of study, and year of study, was collected to ensure the participant pool accurately reflects the university's student body and to provide a comprehensive overview of the sample.

Data collection for this survey research study was conducted exclusively through an online survey administered via Google Forms. This method allows for convenient and efficient data collection from participants. During the survey, participants provided quantitative data by rating each backpack on a scale of 1 to 10 for each evaluation criterion, and qualitative data by offering detailed feedback on their experiences, preferences, and suggestions for improvement.

The survey data was analyzed using percentages and frequencies to determine the prevalence of musculoskeletal disorders and summarized participant demographics, providing a fundamental understanding of the collected data. Quantitative

data from user testing sessions was used to calculate average ratings for each evaluation criterion, while qualitative data was analyzed to identify common themes and patterns, offering insights into the strengths and weaknesses of the backpacks. This comprehensive analysis contributed to a thorough evaluation of the ergonomic design of student backpacks. Comparisons between backpacks in Section 3 (Results) are based on differences in these mean ratings and on the descriptive top- and worst-performer summaries in Tables 1 and 2; formal inferential statistical testing (e.g., ANOVA) was not performed and is noted as an area for future analysis once a larger, randomly sampled dataset is available.

2.3 Product Design Considerations

Several key factors were carefully considered as they play a critical role in reducing the risk of musculoskeletal issues and enhancing the functionality of the backpack. By closely attending to these dimensions, the overall design of the backpack can be optimized to provide students with maximum comfort, support, and utility.

Backpack Weight Threshold: The weight of a student backpack is paramount in ergonomic design. Drawing from comprehensive literature review, it was recommended that the backpack weight ideally should not surpass 10% of the average student's body weight.

$$\begin{aligned} &\text{Average Weight of the Population (kg)} \\ &= \frac{\text{sum of all student weights}}{\text{total number of students}} \end{aligned} \quad (1)$$

$$\text{Weight Limit (kg)} = \frac{10}{100} \times \text{Average Weight of the Population} \quad (2)$$

Height Compatibility for Backpacks: Ideally, the height of the backpack should correspond to the student's torso length, ensuring proper alignment and fit on the student's back. Research indicates that a rough estimate of torso length can be determined by multiplying the student's height by 0.27 (Brumelis, 2023).

$$\begin{aligned} &\text{Average Height of the Population (cm)} \\ &= \frac{\text{sum of all student heights}}{\text{total number of students}} \end{aligned} \quad (3)$$

$$\begin{aligned} &\text{Backpack Height (cm)} = \\ &\text{Average Height} \times 0.27 \end{aligned} \quad (4)$$

Backpack Width: For enhanced mobility, it's essential that the width of the backpack remains within the confines of the student's body width and ideally matches the width of the chest.

$$\begin{aligned} &\text{Average Chest Width of the Population (cm)} \\ &= \frac{\text{sum of the chest widths}}{\text{total number of students}} \end{aligned} \quad (5)$$

$$\text{Backpack Width (cm)} = \text{Average Chest Width} \quad (6)$$

Strap Length Consideration: In order to ensure even distribution of the load on the shoulders and prevent undue strain on the muscles in that area, it's imperative that the straps are sufficiently wide. Determining the optimal length of the strap involves establishing a correlation between height and chest width to ensure the backpack position aligns with the torso.

$$\begin{aligned} &\text{Minimum Strap Length (cm)} \\ &= \text{Backpack Height} + \text{Average Chest Width} \end{aligned} \quad (7)$$

To also allow for adjustability, an additional length can be added to be set by the webbing strap.

$$\begin{aligned} &\text{Maximum Strap Length (cm)} \\ &= \text{Backpack Height} + \text{Maximum Chest Width} \end{aligned} \quad (8)$$



Figure 1 Sample of Backpacks from the existing packs

3. RESULTS AND DISCUSSION

A cohort of one hundred and sixty (160) students was meticulously chosen from the participant pool of 500 students recruited to offer valuable insights derived from their past experiences with backpacks, including potential musculoskeletal issues or discomfort. The primary aim was to evaluate the functionality, comfort, and user-friendliness of five selected backpacks, which were representative of commonly utilized options among students. It is important to note that this user testing (Sections 3) was conducted exclusively on the five existing sample backpacks; the subsequently developed prototype (Section 4) was evaluated through a dimensional and design-feature comparison against these backpacks rather than through direct physical user testing, with empirical user validation of the prototype identified as a direction for future work. Five backpacks showcasing diverse designs and features were chosen for user testing, representing typical options used by students across various educational settings. A series of tasks was devised to replicate common activities students undertake when utilizing a backpack, such as carrying it for

extended periods, adjusting straps, and loading/unloading books. These tasks aimed to gauge the overall functionality, comfort, and ease of use of the backpacks. Numerous test scenarios were formulated to comprehensively evaluate the backpacks. Participants engaged in the following scenarios: Wearing each backpack for a specified duration while performing routine tasks like standing, bending, and walking, Filling the backpacks with a predetermined set of items to assess comfort and weight distribution during movement, Adjusting the straps to their liking, participants evaluated the fit and adjustability of the backpacks and the loaded backpacks' weights were recorded both before and after participants filled them with a predetermined set of items typically used by students on a daily basis at school. Individual testing sessions were conducted with each participant, wherein clear instructions were provided, and participants were encouraged to offer feedback during and after testing. They were prompted to assess the backpacks based on predefined evaluation criteria.

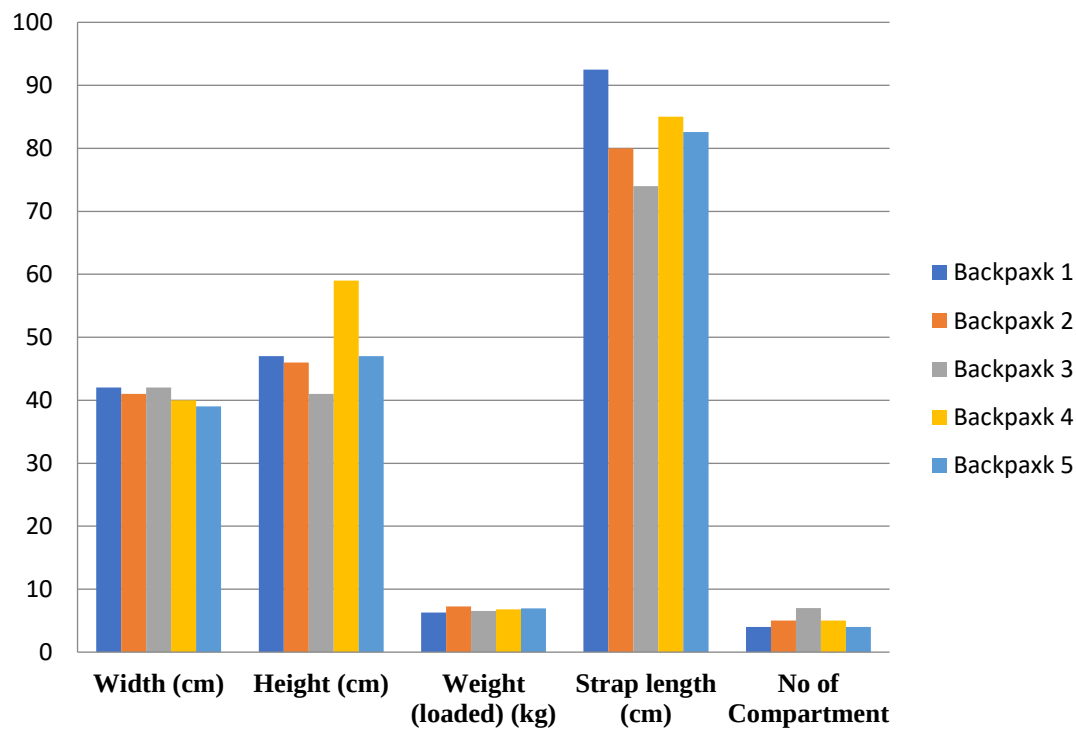


Figure 2 provides a comparison of various attributes among five different sample backpacks

The study shows that the width and height (cm) dimensions indicate the physical size of the backpacks. Sample Backpack 5 has the smallest width at 39 cm, while Sample Backpack 1 and Sample Backpack 3 have the largest width at 42 cm. In terms of height, Sample Backpack 4 is the tallest at 49 cm, while Sample Backpack 3 is the shortest at 41 cm. Similarly, weight (Loaded) (kg) shows the weight of the backpack when loaded with items. Sample Backpack 2 has the highest loaded weight at 7.25 kg, while Sample Backpack 1 has the lowest at 6.28 kg.

However, the strap length (cm) indicates the length of the straps, which is crucial for adjusting the backpack to fit the wearer comfortably. Sample Backpack 1 has the longest strap length at 92.50 cm, while Sample Backpack 3 has the shortest at 74.00 cm. The number of compartments represents the number of compartments or sections within each backpack for organizing items. Sample Backpack 3 has the highest number of

compartments at 7, providing ample storage options, while Sample Backpacks 1, 4, and 5 have 4 compartments each, and Sample Backpack 2 has 5 compartments. Based on this comparison, it's evident that each backpack has its own unique set of characteristics in terms of size, weight, strap length, and compartmentalization. The choice of the most suitable backpack would depend on individual preferences, such as the need for additional storage compartments or preference for a lighter or more compact design. Figure 3 shows the breakdown of the performance of each backpack in terms of different criteria. For each backpack, the average rating for a given criterion (load distribution, proper fit, strapping, accessibility, and aesthetics) was computed as the arithmetic mean of the individual 1-to-10 ratings assigned by all participants who tested that backpack, in line with the data analysis procedure described in Section 2.2

Table 1 Top Performer for Each Criterion

TOP PERFORMERS	
Load Distribution	Backpack 4
Fit	Backpack 1
Strapping	Backpack 1
Accessibility	Backpack 2
Aesthetics	Backpack 5

Table 2 Worst Performers for Each Criterion

WORST PERFORMERS	
Load Distribution	Backpack 5
Fit	Backpack 5
Strapping	Backpack 3
Accessibility	Backpack 3
Aesthetics	Backpack 1

The study shows that Backpack 4 performed the best in load distribution, with a rating of 6.47, indicating that it effectively distributed the weight of the contents across the wearer's back. Backpack 1 also performed well in this aspect, with a rating of 6.17. Backpack 5 received the lowest rating for load distribution at 5.53. Similarly, Backpack 1 received the highest rating for proper fit at 6.53, suggesting that it fit the wearer's body well and provided comfort. Backpack 2 and Backpack 4 also scored relatively high in this aspect, with ratings of 6 and 6.2 respectively.

However, Backpack 5 received the lowest rating for proper fit at 5.43. Backpack 1 received the highest rating for strapping at 6.6, indicating that its shoulder straps were comfortable and provided adequate support.

Backpack 2 also scored well in this aspect, with a rating of 6.23. Backpack 3 received the lowest rating for strapping at 5.47 while Backpack 2 also received the highest rating for accessibility at 6.53, suggesting that it was easy for users to access the contents of the backpack. Backpack 4 also performed well in this aspect, with a rating of 6.13. Backpack 3 received the lowest rating for accessibility at 5.4. Backpack 5 similarly, received the highest rating for

aesthetics at 6.53, indicating that it was visually appealing to users. Backpack 4 also scored relatively high in this aspect, with a rating of 6. Backpack 1 received the lowest rating for aesthetics at 5.73.

The finding revealed that each backpack has its strengths and weaknesses across different criteria. Backpack 1 performed well in terms of load distribution, proper fit, and strapping, while Backpack 2 excelled in accessibility. Backpack 5 stood out in terms of aesthetics. These ratings provide insights into the performance of each backpack and can help users make informed decisions based on their preferences and needs.

In analyzing the top performers in the table 1 based on various criteria, it is evident that each backpack excels in different aspects, contributing to a comprehensive evaluation of their performance.

The study shows that Backpack 4 emerges as the top performer in load distribution, suggesting that it effectively distributes the weight across the wearer's back. This indicates that Backpack 4 likely features a sturdy frame, adequate padding, and adjustable straps, which are crucial for evenly distributing the load and reducing strain on the wearer's back and shoulders. Backpack 1 is recognized for providing an excellent fit, implying that it offers adjustable features that allow users to customize the backpack to their torso size and shape. A proper fit is essential for ensuring comfort and minimizing discomfort or strain during prolonged use.

Similar to its performance in fit, Backpack 1 also excels in strapping, suggesting that it features wide and padded shoulder straps that effectively distribute pressure and enhance comfort. Additionally, the adjustable nature of the straps allows for personalized adjustments to accommodate different body sizes and

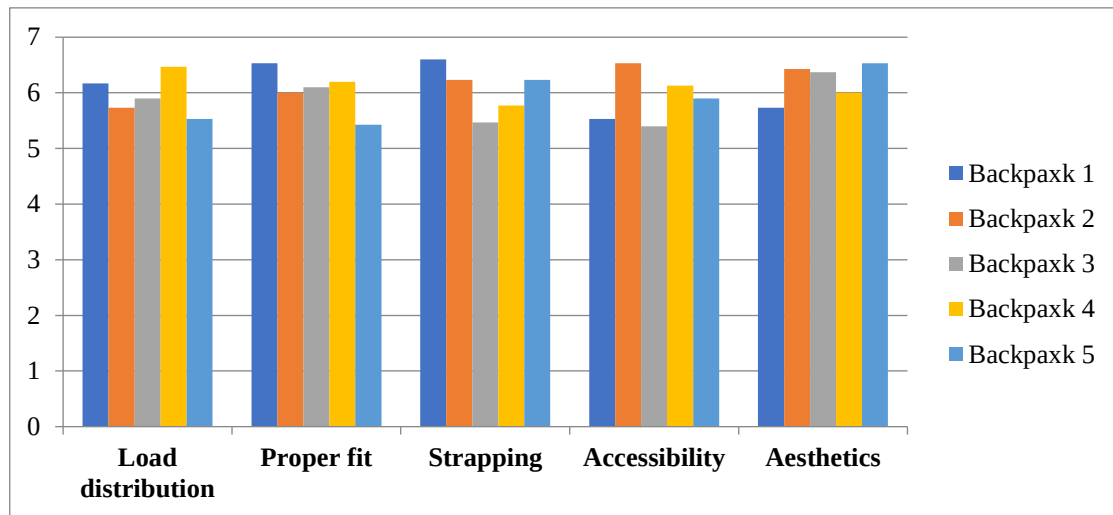


Figure 3 Comparison of the Backpacks Average Rating Criteria (1 – 10)

preferences. Backpack 2 stands out in accessibility, indicating that it offers convenient access to belongings through multiple compartments and pockets. This feature enhances organization and facilitates easy retrieval of items, contributing to overall user convenience and efficiency.

However, Backpack 5 receives recognition for aesthetics, implying that it features a visually appealing design that resonates with users. Aesthetics play a significant role in user satisfaction and can influence the likelihood of regular usage, making Backpack 5 an attractive option in terms of style and design preferences. The study finding revealed that the top performers in the table exhibit strengths across different dimensions, ranging from load distribution and fit to strapping, accessibility, and aesthetics. Each backpack offers distinct advantages that contribute to overall user satisfaction and usability, highlighting the importance of considering multiple criteria when evaluating backpack performance.

Table 2 shows the analysis of the backpack based on the worst performers in various criteria sheds light on areas where certain backpacks may fall short in terms of user satisfaction and functionality. The study revealed that, Backpack 5 was identified

as the worst performer in load distribution, suggesting that it may struggle to evenly distribute the weight across the wearer's back. This could indicate insufficient padding or structural support, leading to discomfort or strain, particularly during extended use. Similarly, Backpack 5 was recognized as the worst performer in fit, indicating that it may not offer adequate adjustability to accommodate different torso sizes and shapes. A poor fit can result in discomfort, instability, and potential strain, detracting from the overall user experience.

However, Backpack 3 emerges as the worst performer in strapping, implying that it may feature narrow or poorly padded shoulder straps that contribute to discomfort and pressure points on the wearer's shoulders and neck. Additionally, inadequate adjustability may further exacerbate fit issues and discomfort.

Backpack 3 was also identified as the worst performer in accessibility, suggesting that it may lack sufficient compartments or organization features to facilitate easy access to belongings. This could lead to frustration and inefficiency when retrieving items, negatively impacting the user experience.

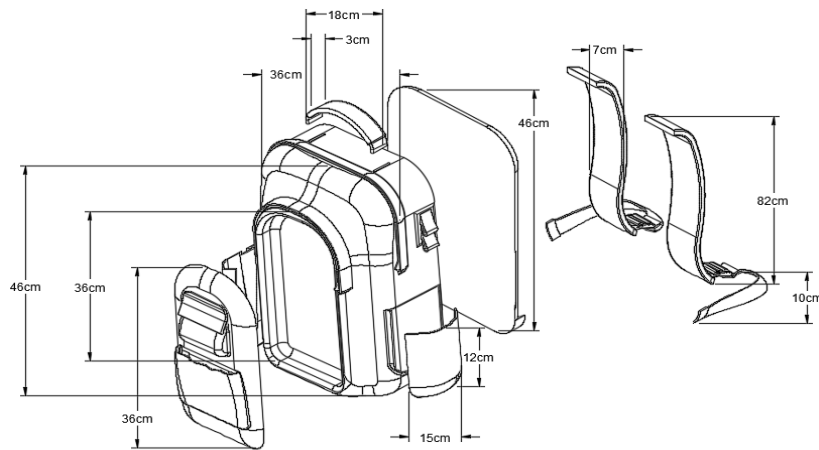


Figure 4 Design Isometric View 1

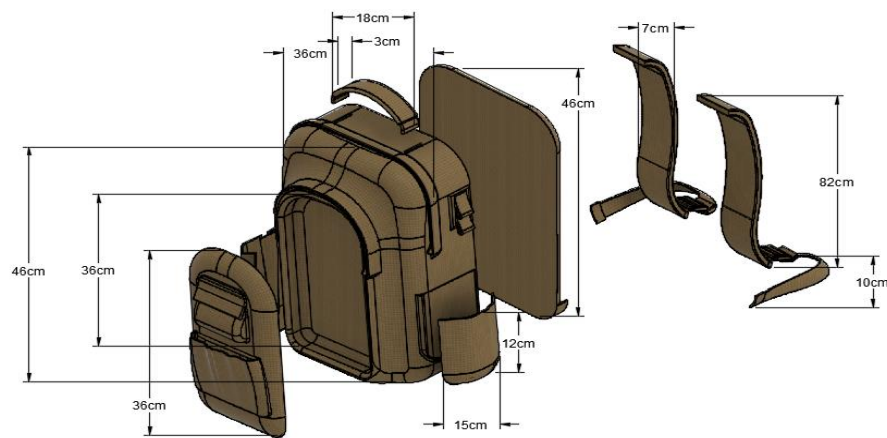


Figure 5 Design Isometric View 2



Figure 6 Proposed Design Front View

The findings also revealed that Backpack 1 is recognized as the worst performer in aesthetics, indicating that it may feature a design that is less visually appealing to users. While aesthetics are subjective, a design that is perceived as unattractive or outdated may influence user satisfaction and preference. The worst performers in the table exhibit shortcomings across various

dimensions, including load distribution, fit, strapping, accessibility, and aesthetics. These deficiencies highlight areas where certain backpacks may fail to meet user expectations and emphasize the importance of addressing these factors in backpack design to enhance overall user satisfaction and functionality.

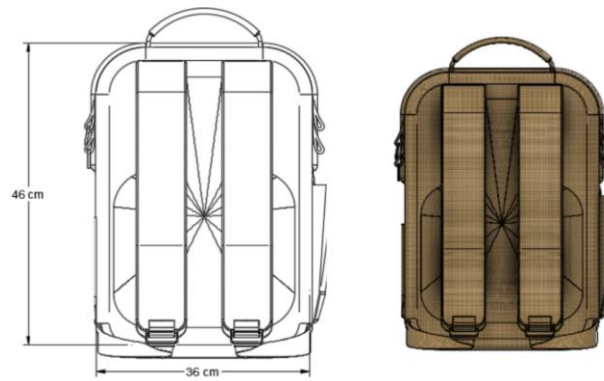


Figure 7 Proposed Design Back View

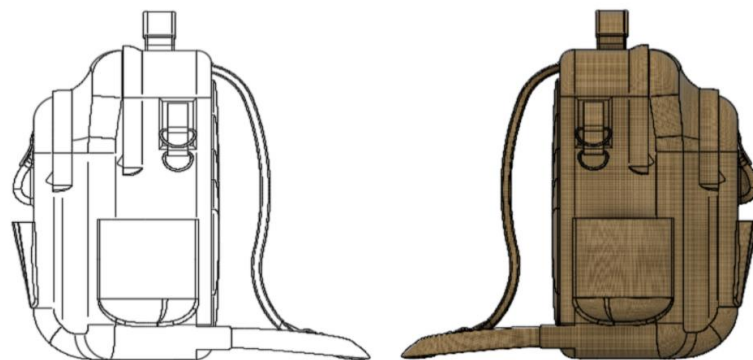


Figure 8 Proposed Design Side View

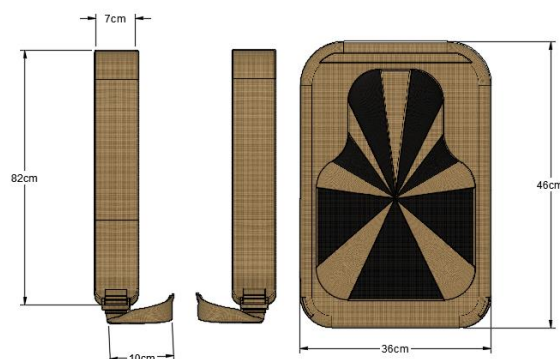


Figure 9 Proposed Design Straps and Back Panel

4. PROPOSED PRODUCT DESIGN

4.1 Comparison of Developed Backpack with the Existing

In comparing the developed backpack with the other options based on the provided figure 11 several key observations was made regarding various dimensions and features: The developed backpack has a width of 36 cm and a height of 46 cm, which are within the range of the widths and

heights of the other backpacks. However, it is notable that Backpack 3 has a relatively smaller height compared to others, potentially affecting its overall capacity and fit for larger items. The loaded weight of the developed backpack is 6.7 kg, falling within a comparable range to the weights of the other backpacks. While Backpack 2 has the highest loaded weight at 7.25 kg, indicating potentially higher carrying capacity, this may also contribute to



Figure 10 Assembly of Proposed Design

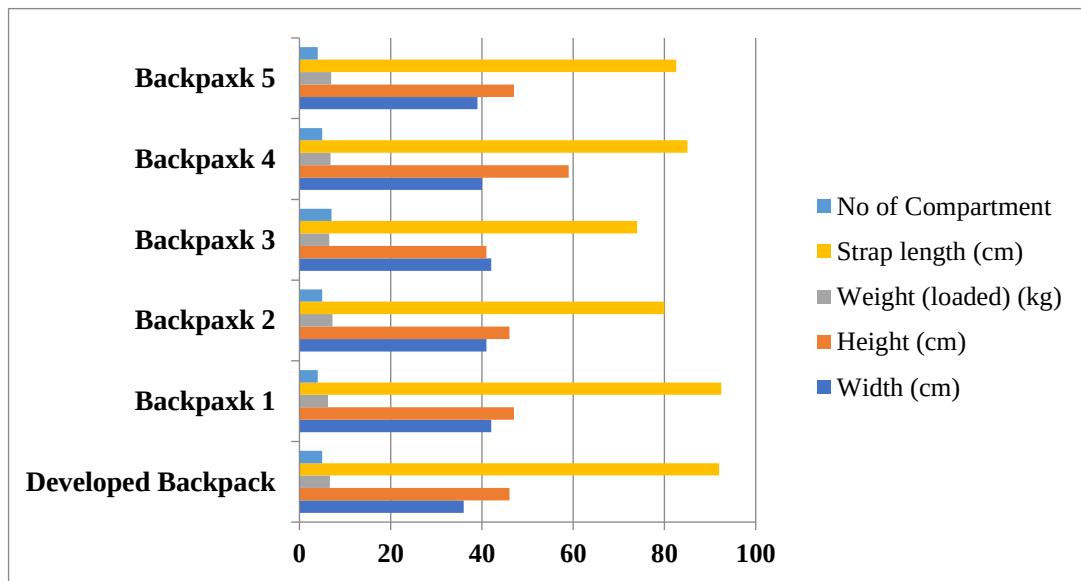


Figure 11 Comparison of Developed Backpack with the Existing

increased strain on the wearer, particularly if the weight exceeds recommended limits. The strap length of the developed backpack is 92 cm. This is comparable to Backpack 1, which has a marginally longer strap length of 92.5 cm and may therefore offer slightly better adjustability. By contrast, Backpack 2's strap length of 80 cm is noticeably shorter than that of the developed backpack, which may limit its adjustability range for taller users. The developed backpack features 5 compartments, which is comparable to the number of compartments in Backpacks 2, 4, and 5. However, Backpack 3 stands out with 7

compartments, potentially offering more organizational options for users.

This study discovered that the developed backpack aligns closely with the dimensions and features of the other options presented in the table, it offers a balanced combination of width, height, weight, strap length, and compartmentalization. Additionally, the inclusion of ergonomic considerations such as proper weight distribution, adjustable straps, and sufficient compartmentalization aims to enhance user comfort and functionality, distinguishing it as a viable choice among the compared options.

5. CONCLUSION

This research aimed to develop an ergonomic, functional student backpack that mitigates the risk of health problems. Through a thorough literature review on backpack design and functionality, an assessment of disorders among students (Amiri, et al., 2012), and the creation of a computer-aided design (CAD) model, this study identified six primary ergonomic requirements crucial for designing student backpacks: backpack weight limit, load distribution, proper fit, strapping, accessibility, and aesthetics. A CAD representation of the backpack incorporating these ergonomic features was developed, with specifications including a weight limit of 6.7 kg, a height of 46 cm, a width of 36 cm, and adjustable strap lengths ranging from 82 cm to 92 cm. Additional features such as front compartments, back padding, and proper strapping were integrated to enhance comfort, support, and usability for students.

The developed prototype Backpack enhances comfort, support, and usability with a significant advancement in ergonomic design for student backpacks. However, future research should conduct empirical testing of the proposed design on real users to assess its effectiveness in reducing musculoskeletal pain, improving comfort, and enhancing usability. Consideration of additional ergonomic elements such as ventilation, water resistance, durability, security, and personalization could further enhance the performance of student backpacks. Future studies can investigate the feasibility and desirability of incorporating such features and their impact on user satisfaction.

Further studies can examine how ergonomic backpacks influence academic achievement and quality of life using objective and subjective measures, such as attendance, grades, and overall well-being. These recommendations can

contribute to advancing research and design practices aimed at creating ergonomic, user-friendly backpacks that promote student health and well-being.

6. ETHICAL APPROVAL

All procedures involving human subjects in this study were performed in compliance with relevant laws and institutional guidelines. Informed consent was obtained from all human participants involved in the experimentation. The privacy rights of all participants were strictly observed and protected throughout the study.

7. CONFLICT OF INTEREST

Authors approve that to the best of our knowledge, there is not any conflict of interest or common interest with an institution / organization or a person that may affect the review process of the paper.

8. AUTHOR CONTRIBUTIONS

Dr. Adekunle Ibrahim Musa formulated the research concept, design process, overseeing research management and finally approved the manuscript. Mr. Adeleke Babatunde Ogunsona undertook data collection, analysis and collated the results for the manuscript draft preparation. Mr. Ayomide Idris Musa conducted data analysis, interpreted the results, and prepare the draft of the manuscript.

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