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Original Article

Evaluating Backpack Utilizing Anthropometric Measurements to Ensure Ergonomic Fit and Ease for Bangladeshi Students

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Abstract - *This study evaluates the ergonomic suitability of student backpacks using anthropometric data to enhance comfort and safety. The research involved evaluating the fit of backpacks among thirty students using six formulas that assessed factors such as weight distribution and load-carrying capacity. An assessment of these students revealed that while all backpacks met minimum safety requirements, none satisfied strict lower-range criteria, and most did not provide adequate load-carrying capacity for straps and loops. This indicates that most of the designs lack comprehensive ergonomic standards. The study recommends revising safety guidelines for backpacks, creating specialized backpack solutions, and promoting responsible use. Further research is also recommended to improve designs, focusing on collaboration with manufacturers to enhance ergonomic fit. The study aims to make backpacks more ergonomically suitable by evaluating and implementing suggestions that should lower the likelihood of musculoskeletal diseases and improve student fit and comfort.*

Keywords - *Anthropometry, Ergonomic Fit, Musculoskeletal disorders, Fit assessment, Load carrying capacity.*

1. Introduction

Anthropometry is the most common and accurate data collection method for human body measurements. Two Greek terms originate from the term anthropometry: Anthropos, or person, and metrics, or count. It is necessary to provide knowledge about the proportions of the required body portion to ensure a suitable fit. In a broader sense, ergonomics is the scientific discipline concerned with understanding the interaction among humans and other elements of a system and the profession that applies theory, principles, methods, and data to design to optimize human well-being and overall system performance. Ergonomists involved in anthropometric data have two major categories: Functional and Structural. Structural anthropometry is also known as set measurements or static anthropometry. With the body in a standing or stationary state, these are measured; for example, size or height, weight, and head circumference [1]. Backpacks, known as load garage systems, are used by students to carry personal belongings, books, laptops, and clothes to their school and workplace. Students are generally more comfortable carrying a backpack because the backpack is intimately attached to the spine and maintains stability [2]. More than 5 million student bags are carried in the United States [3]. Usually, students use backpacks for study; in addition to carrying notebooks, pens, and books in their backpacks, students carry water, tiffin, and a variety of clothing and items while traveling. It needs to be designed to be strong so that it will not be left behind due to carrying too much load in the bag. If the designed backpack is not selected based on the principle of ergonomics, if any other choice is made, then there could be two reasons: if the weight of the designed backpack exceeds the student's weight capacity, there may be many problems such as shoulder pain, shoulder pain, back pain, etc. Moreover, if the weight of the designed backpack is less than the weight capacity of the student, the weight of the designed backpack should not be taken more than the weight capacity; otherwise, it may tear. Students have been widely accused of carrying heavy backpacks as a major cause of body strain. It turns out that, it is not good for students to be over 10% of their body weight. Therefore, good observation is needed to ensure this. Here is the research gap and the problem to be solved. The objectives of this research are to select a comfortable backpack for the students based on anthropometric data and to find a suitable weight for a newly designed backpack to ensure safety. This research tried to discover the problems regarding the backpack issues and related solutions. If the mentioned problems occur in the case of student growth, i.e., in the case of body growth, then in the future, they may take on a more pronounced shape, as a result of which there may be more growth in the future. So special attention has been paid to this, and mentioned data in data analysis are utilized properly to detect the problems related to the backpacks.

2. Related Research Work

The scientific discipline of ergonomics explores how to design and arrange objects that people use to maximize their safety and efficiency [4]. Musculoskeletal Disorders (MSDs) are one of the resulting injuries if no one follows ergonomic principles. Musculoskeletal disorders and injuries are common in school children, particularly back pain, making it difficult for them to carry out their everyday tasks [5]. Over 90% of students in well-off countries, according to research, carry a backpack [6]. Most backpacks are not made to obey ergonomic principles, resulting in negative effects on posture for the user and contributing to spinal pain and musculoskeletal disorders. To resolve these problems, numerous authors researched the ergonomic backpack approach. To address bodily aches in primary school students (ages 6–12), researchers developed an ergonomic backpack based on anthropometric measurements. They measured thigh thickness, shoulder breadth, and sitting shoulder height from more than two thousand students, using these metrics to optimize the backpack's dimensions. This design significantly reduced the incidence of musculoskeletal problems, highlighting the importance of tailoring backpacks to fit children's physical needs [5]. In a separate study, researchers aimed to improve backpack design further by positioning the center of gravity near the spine's axis, thus reducing the load's moment arm. This study involved eight male and ten female participants and utilized radiological imaging to assess the design. The results showed that this ergonomic approach allowed the backpack's weight to be reduced to just 10% of the student's total body weight, which also helped maintain proper lumbar alignment compared to traditional backpacks. These findings underscore the potential of ergonomic designs to enhance student comfort and health [7].

Research on ergonomic backpack design in a major metropolitan area showed significant benefits for thirty college students. Most (63.3%) reported neck discomfort, with lower back pain affecting 30% and upper back pain 26.7%. After an ergonomic intervention, participants demonstrated improved lower abdominal and back muscle strength [4]. In a separate study, researchers designed an ergonomic backpack using anthropometric measurements from 280 individuals, focusing on reducing force concentration on the shoulders and back. Compared to commercial options, participants found the new design 24.26% more comfortable, highlighting the value of ergonomic features in backpack design [8].

According to another study, school children who use strollers experience a great deal of stress, tension, and steadily declining health over time. The type of stroller was identified as a significant predictor of children's decreased productivity and high levels of strain and stress. Using the National Institute for Occupational Safety and Health's Lifting Equation assessment, this study suggests that stroller bag designs need to be modified and standardized [9]. Another potential research examined the usefulness of a redesigned backpack that evenly distributes the weight on the back and chest of school children. According to this study, the customized backpack outperformed the commercial backpack regarding effort ratings, cardiac expenses, and muscle activities. The community is given a modified backpack as a result of this study, which reduces discomfort and increases comfort [10]. Last but not least, another author investigated whether a gender-specific weight limit for school bag carrying is appropriate. The results imply that different weight limits for males and girls may need to be applied when it comes to school bags getting around [12].

There are several important factors in designing a backpack. Backpack dependency factors can depend on two things: the weight of the bag and the different dimensions of the backpack. Backpack carrying weight depends on the respective individual's human power (it depends on gender, age, location, human weight, genetics, mental effort, work experience, etc. [13]. The research work is investigated by evaluating some of these factors. Usually, students can carry heavier backpacks than female students. Students between the ages of 10 and 16 can safely carry a backpack at 2.87 kg, which is 5.18% of their weight. 13% BW is offered for healthy college students. In certain ratios and body proportions, males are generally taller than women [14-17]. In addition, women have less muscle strength than men. However, most girls had more abdominal pain and certain pains than boys, but the severity of the disease was much higher in boys than in girls [18, 19].

Generally, the height of both boys and girls is the same till 9 years, i.e., setting shoulder height is closer to them. So, it can be said that from 10 to 13 years, the shoulder height is much higher in girls than in boys. Length or height, for instance, hits full growth in males around 20 years of age and 17 years in females [20-22]. The rate at which adult students can resist spinal strays is not the rate at which underage students can resist. This is because, at a young age, the body size does not increase significantly, and the spine increases many times [23-25]. Not all students usually weigh; young children have some kind of weight. As they get older, their weight increases with their height. Not all students grow at the same rate; some grow at a much higher rate, but something difficult grows and grows many times over. So, it can be said that age is a big factor [26, 27]. Backpack dimension depends on Sitting shoulder height (mm), Thigh thickness (mm), Shoulder breadth- deltoid (mm), Half Neck Girth, Chest thickness, Hip thickness, etc. [28, 29]. The novelty of this research, as the other research works, is using six important formulas cumulatively to evaluate the ergonomic fitness of thirty-five individual students. These formulas and evaluations give a clear idea for designing an ergonomic student backpack. The main focus of this study is to investigate the ergonomic suitability of student backpacks using anthropometric data to ensure proper comfort and safety. The final calculation and comparison will give the manufacturer a clear idea to improve student comfort using proper ergonomic guidelines.

3. Materials and Methods

Selection of instrument and sample, Data grouping techniques selection, and Data collection parameters selection are the four significant stages to complete the whole research. The selected instruments are the anthropometer, weight machine, measuring tape, and slide caliper to measure students' body dimensions, students' body and backpack weight, different height and width type dimensions, and thickness type dimensions.

According to the International Standards Organization, ISO 15535: 2012 "General requirements for establishing anthropometric databases," is selected as a sample [12] with a 95% confidence interval for the 5th and 95th percentiles:

$$N \geq \left(3{:}006 \times \frac{cv}{\alpha}\right)^2$$

Where N is the required sample size, CV is the coefficient of variation, and α is the percentage of the desired relative accuracy. In this study, α = 5% relative accuracy is required for the 5th and 95th percentiles, whereas values of the coefficient of variation CV are adapted from the mentioned equation [10].

$$CV = 100 * \frac{SD}{\bar{x}}$$

Where CV is the coefficient of variation and is the ratio between the Standard Deviation and the mean of a population [11]. Data Grouping Technique depends on Gender and age variety. Gender variation is divided into male and female. Age variation is divided into some age groups of age from 20 to 23 years [30, 31]. Data collection parameters included different heights and weights of students and backpacks, which were collected in this step. Weight, sitting shoulder height, thigh thickness, shoulder breadth-deltoid, half neck girth, chest thickness, hip thickness, and optimum carrying load are the different types of dimensions of students [32, 33]. On the other hand, backpack height, backpack width, backpack weight, volume and load carrying capacity, maximum slide compression strap length, weight capacity of hanging loop, shoulder strap length, shoulder strap width, distance between two shoulder straps in top position, Hip belt length, sternum strap length, weight capacity of adjustable shoulder strap are the different dimensions of backpack [27, 34]. All the parameters are calculated in SI units. Different anthropometric measurements of students are discussed in Table 1.

Table 1. Description of anthropometric measurements of students

Sl	Dimensions Name (mm)	Description of the body dimensions according to ISO 7250
1	Sitting shoulder height	Vertical distance from a horizontal sitting surface to the acromion.
2	Thigh thickness	Vertical space from the sitting plane up to the thigh's highest point.
3	Shoulder breadth-deltoid	Difference between the right and left deltoid muscles' maximum lateral extensions.
4	Half neck girth	A calculation of the diameter around the neck at the level above the Adam's Apple is the neck girth measurement.
5	Chest thickness	The horizontal depth of the torso was measured in the midsagittal plane at the level of mesosternum.
6	Hip thickness	The maximum horizontal breadth of the hip while sitting.

After all the data of dimensions are gathered, the significant equations used to verify the comfort of the selected students while carrying their backpacks are presented in Table 2 [5, 21, 35].

Table 2. Different types of equations

Sl	Equations for Dimension	Equations
1	Backpack Weight (BPW) vs Student Body Weight (SBW)	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)
2	Strap Length (STL) vs Backpack Height (BPH) and Chest Thickness (CT)	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)
3	Max. Slide Compression Strap Length (SCSL) vs. Volume (V), Backpack Height (BPH), and Width (BPW)	SCSL= V / (BPH * BPW)
4	Min. Distance between both Shoulder Straps (MDBSS) vs Half Neck Width (HNW)	MDBSS>=HNW
5	Load Caring Capacity of Hanging Loop (LCHL) vs Load Caring Capacity of Backpack (LCBP)	LCHL>=LCBP
6	Load Caring Capacity of Both shoulder Straps (LCBSS) vs Load Caring Capacity of a backpack (LCBP)	LCBSS>=LCBP

Different types of dimension-based data from the selected 35 students were taken at first. The total data collection is presented in Table 3. After completing the first task, different types of dimension-based data from the backpacks of selected students were taken (SI units) in Table 4. The calculation of total data based on the equations is presented in Table 5 for a person, in a total of thirty-five students.

Table 3. Body dimensions of selected students

Body Dimension								
Person	**Weight**	**Sitting Shoulder Height**	**Thigh Thickness**	**Shoulder Breadth - Deltoid**	**Half-neck width**	**Chest Thickness**	**Hip Thickness**	**Optimum Carrying Load**
1	90	147.32	40.64	121.92	5	68.58	96.52	9
2	61	160.02	33.02	132.08	4.5	50.8	93.98	6.1
3	69	147.32	50.8	152.4	4.5	63.5	101.6	6.9
4	69	142.24	25.4	119.38	4.5	40.64	91.44	6.9
5	56	152.4	48.26	144.78	4.25	63.5	81.28	5.6
6	69	152.4	45.72	147.32	4.75	71.12	96.52	6.9
7	57	142.24	53.34	157.48	4.25	132.08	88.9	5.7
8	75	134.62	48.26	142.24	4.75	114.3	137.16	7.5
9	69	132.08	48.26	137.16	4.63	114.3	134.62	6.9
10	56	149.86	55.88	167.64	4.38	137.16	157.48	5.6
11	63	144.78	50.8	147.32	4.63	119.38	152.4	6.3
12	72	132.08	45.72	139.7	4.75	106.68	129.54	7.2
13	55	170.18	33.02	109.22	4.25	83.82	106.68	5.5
14	65	165.1	58.42	114.3	4.5	99.06	114.3	6.5
15	75	162.56	48.26	111.76	4.75	88.9	109.22	7.5
16	67	160.02	48.26	106.68	4.63	93.98	101.6	6.7
17	51	152.4	45.72	104.14	4.25	96.52	93.98	5.1
18	51	167.64	50.8	114.3	4.25	114.3	109.22	5.1
19	48	147.32	40.64	121.92	4.13	68.58	96.52	4.8
20	59	160.02	33.02	132.08	4.38	50.8	93.98	5.9
21	60	142.24	25.4	119.38	4.5	40.64	91.44	6
22	55	147.32	50.8	152.4	4.25	63.5	101.6	5.5
23	58	152.4	48.26	144.78	4.38	63.5	81.28	5.8
24	63	152.4	45.72	147.32	4.38	58.42	982.98	6.3
25	58	172.72	40.64	111.76	4.25	43.18	83.82	5.8
26	92	157.48	48.26	109.22	5	66.04	86.36	9.2
27	81	152.4	43.18	127	4.63	76.2	114.3	8.1
28	79	165.1	35.56	114.3	4.5	63.5	101.6	7.9
29	91	147.32	40.64	119.38	5	60.96	99.06	9.1
30	85	142.24	38.1	124.46	4.88	55.88	101.6	8.5
31	95	152.65	35.81	112.01	5	54.356	89.662	9.5
32	66	153.41	36.32	112.26	4.5	53.594	91.186	6.6
33	56	154.43	38.1	112.01	4.25	54.102	89.662	5.6
34	59	163.06	30.73	132.58	4.38	61.214	96.774	5.9
35	72	157.98	41.14	131.57	4.63	58.928	95.25	7.2

Table 4. Backpack dimensions of selected students

Backpack Dimension											
Sl. No	**Backpack Height (cm)**	**Backpack Width (cm)**	**Max. Slide Compression**	**Weight Capacity of Hanging Loop (kg)**	**Shoulder Strap Length (cm)**	**Distance Bet. 2 shoulder straps in top position (cm)**	**Hip belt length (Both) (cm)**	**Weight capacity of adjustable shoulder strap (kg)**	**Backpack weight (kg)**	**Volume (L)**	**Load carrying capacity of backpack (kg)**
1	49	38	6	16	39	6	N/A	20	0.648	22.34	22.34
2	52	43	9	30	45	3.5	N/A	35	0.629	38.01	38.01
3	48	45	7	26	42	3	N/A	30	0.783	32.40	32.40
4	47	33	9	20	43	2.5	N/A	24	0.679	26.37	26.37
5	45	38	7	19	39	4	N/A	24	0.745	27.36	27.36
6	47	36	8	21	41	4.5	N/A	25	0.593	27.07	27.07
7	47	38	6	22	40	5	N/A	27	0.771	30.36	30.36
8	47	42	6	23	41	5.5	N/A	27	0.605	29.61	29.61
9	45	32	8	14	39	5	N/A	18	0.692	20.16	20.16
10	40	32	9	12	35	3	N/A	17	0.66	20.48	20.48
11	42	33	9	12	36	2.5	N/A	16	0.665	18.02	18.02
12	42	31	6	11	35	2	N/A	17	0.634	20.83	20.83
13	43	32	9	13	37	3	N/A	18	0.539	20.64	20.64
14	42	32	8	12	36	3	N/A	18	0.558	21.50	21.50
15	40	32	7	12	34	3	N/A	17	0.537	20.48	20.48
16	44	31	8	11	37	3.5	N/A	16	0.705	19.10	19.10
17	43	34	6	13	36	3	N/A	17	0.53	19.01	19.01
18	42	31	6	11	35	2	N/A	16	0.533	19.53	19.53
19	40	32	8	9	34	2	N/A	14	0.702	16.64	16.64
20	44	33	8	12	37	6	N/A	18	0.793	21.78	21.78
21	43	34	9	16	36	6	N/A	22	0.587	24.85	24.85
22	45	36	9	22	38	4	N/A	27	0.512	30.78	30.78
23	46	35	6	19	39	3.5	N/A	25	0.791	27.37	27.37
24	43	35	7	14	37	4	N/A	20	0.567	22.58	22.58
25	43	35	7	18	36	5	N/A	24	0.512	27.09	27.09
26	47	40	6	27	40	3.5	N/A	34	0.522	37.60	37.60
27	44	35	6	22	38	3	N/A	28	0.678	30.80	30.80
28		42	8	21	37	5	N/A	27	0.714	30.70	30.70
29	47	38	7	20	41	5	N/A	25	0.792	28.58	28.58
30	45	37	7	21	39	4.5	N/A	26	0.618	28.31	28.31
31	48	39	7	24	41	4.5	N/A	30	0.691	33.70	33.70
32	43	35	9	19	37	4	N/A	25	0.669	28.60	28.60
33	45	37	8	24	38	4	N/A	30	0.551	33.30	33.30
34	48	40	9	25	41	5.5	N/A	31	0.566	34.56	34.56
35	45	36	8	20	39	3.5	N/A	26	0.798	29.16	29.16

Table 5. Data calculation for all students (Individually)

SL.	**Equation**	**Results (SI Units)**				
			Lower Range/ Measured Value	Measured Value	Upper Range	Comment
1	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	9	0.648	13.5	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.26	0.39	1.43	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.06*2= 0.12	0.12	-	Matched
	4	MDBSS>=HNW	0.06	0.05	-	Within Range

	5	LCHL>=LCBP	22	22.34	-	Within Range
	6	LCBSS>=LCBP	20	22.34	-	Not Matched
2	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	6.1	0.629	9.15	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.10	0.45	1.25	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.09*2= 0.18	0.17	-	Matched
	4	MDBSS>=HNW	0.035	0.045	-	Not Matched
	5	LCHL>=LCBP	30	38.01	-	Not Matched
	6	LCBSS>=LCBP	35	38.01	-	Not Matched
3	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	6.9	0.783	10.35	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.19	0.42	1.36	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.07*2= 0.14	0.15	-	Matched
	4	MDBSS>=HNW	0.03	0.045	-	Not Matched
	5	LCHL>=LCBP	26	32.4	-	Not Matched
	6	LCBSS>=LCBP	30	32.4	-	Within Range
4	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	6.9	0.679	10.35	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	0.94	0.43	1.07	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.09*2= 0.18	0.17	-	Matched
	4	MDBSS>=HNW	0.025	0.045	-	Not Matched
	5	LCHL>=LCBP	20	26.37	-	Within Range
	6	LCBSS>=LCBP	26	26.37	-	Within Range
5	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	5.6	0.745	8.4	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.16	0.39	1.32	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.07*2= 0.14	0.16	-	Not Matched
	4	MDBSS>=HNW	0.04	0.0425	-	Within Range
	5	LCHL>=LCBP	19	27.36	-	Not Matched
	6	LCBSS>=LCBP	24	27.36	-	Not Matched
6	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	6.9	0.593	10.35	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.26	0.41	1.44	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.08*2= 0.16	0.16	-	Matched
	4	MDBSS>=HNW	0.045	0.047	-	Within Range
	5	LCHL>=LCBP	21	27.07	-	Not Matched
	6	LCBSS>=LCBP	27	27.07	-	Within Range
7	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	5.7	0.771	8.55	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.92	0.40	2.18	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.06*2= 0.12	0.17	-	Not Matched
	4	MDBSS>=HNW	0.05	0.0425	-	Within Range
	5	LCHL>=LCBP	22	30.36	-	Not Matched
	6	LCBSS>=LCBP	27	30.36	-	Not Matched
8	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	7.5	0.605	11.25	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.73	0.41	1.97	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.06*2= 0.12	0.15	-	Not Matched
	4	MDBSS>=HNW	0.055	0.0475	-	Within Range
	5	LCHL>=LCBP	23	29.61	-	Not Matched
	6	LCBSS>=LCBP	29	29.61	-	Within Range
9	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	6.9	0.692	10.35	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.70	0.39	1.94	Matched for upper range

	3	SCSL= V / (BPH * BPW)	0.08*2= 0.16	0.14	-	Not Fully Matched
	4	MDBSS>=HNW	0.05	0.046	-	Within Range
	5	LCHL>=LCBP	14	20.16	-	Not Matched
	6	LCBSS>=LCBP	19	20.16	-	Nearly Matched
10	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	5.6	0.66	8.4	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.90	0.35	2.16	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.09*2= 0.18	0.16	-	Not Fully Matched
	4	MDBSS>=HNW	0.03	0.043	-	Out of Range
	5	LCHL>=LCBP	12	20.48	-	Not Matched
	6	LCBSS>=LCBP	17	20.48	-	Not Matched
11	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	6.3	0.665	9.45	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.73	0.36	1.97	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.09*2= 0.18	0.13	-	Not Matched
	4	MDBSS>=HNW	0.025	0.046	-	Out of Range
	5	LCHL>=LCBP	12	18.02	-	Not Matched
	6	LCBSS>=LCBP	18	18.02	-	Within Range
12	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	7.2	0.634	10.8	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.59	0.35	1.81	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.06*2= 0.12	0.16	-	Not Matched
	4	MDBSS>=HNW	0.02	0.047	-	Out of Range
	5	LCHL>=LCBP	11	20.83	-	Not Matched
	6	LCBSS>=LCBP	20.83	20.83	-	Matched
13	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	5.5	0.539	8.25	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.36	0.37	1.55	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.09*2= 0.18	0.15	-	Not Matched
	4	MDBSS>=HNW	0.03	0.0425	-	Out of Range
	5	LCHL>=LCBP	13	20.64	-	Not Matched
	6	LCBSS>=LCBP	18	20.64	-	Not Matched
14	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	6.5	0.558	9.75	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.51	0.36	1.72	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.08*2= 0.16	0.16	-	Matched
	4	MDBSS>=HNW	0.03	0.045	-	Out of Range
	5	LCHL>=LCBP	12	21.5	-	Not Matched
	6	LCBSS>=LCBP	18	21.5	-	Not Matched
15	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	7.5	0.537	11.25	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.38	0.34	1.57	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.07*2= 0.14	0.16	-	Not Fully Matched
	4	MDBSS>=HNW	0.03	0.047	-	Out of Range
	5	LCHL>=LCBP	12	20.48	-	Not Matched
	6	LCBSS>=LCBP	17	20.48	-	Not Matched
16	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	6.7	0.705	10.05	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.48	0.37	1.68	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.08*2= 0.16	0.14	-	Not Fully Matched
	4	MDBSS>=HNW	0.035	0.046	-	Out of Range
	5	LCHL>=LCBP	11	19.1	-	Not Matched
	6	LCBSS>=LCBP	16	19.1	-	Not Matched
17	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	5.1	0.53	7.65	Safe

	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.49	0.36	1.70	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.06*2= 0.12	0.13	-	Matched
	4	MDBSS>=HNW	0.03	0.043	-	Out of Range
	5	LCHL>=LCBP	13	19.01	-	Not Matched
	6	LCBSS>=LCBP	19	19.01	-	Within Range
18	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	5.1	0.533	7.65	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.67	0.35	1.91	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.06*2= 0.12	0.15	-	Not Matched
	4	MDBSS>=HNW	0.02	0.043	-	Out of Range
	5	LCHL>=LCBP	11	19.53	-	Not Matched
	6	LCBSS>=LCBP	16	19.53	-	Not Matched
19	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	4.8	0.702	7.2	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.16	0.34	1.32	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.08*2= 0.16	0.13	-	Not Matched
	4	MDBSS>=HNW	0.02	0.041	-	Out of Range
	5	LCHL>=LCBP	9	16.64	-	Not Matched
	6	LCBSS>=LCBP	15	16.64	-	Nearly Matched
20	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	5.9	0.793	8.85	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.01	0.37	1.16	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.08*2= 0.16	0.15	-	Matched
	4	MDBSS>=HNW	0.06	0.044	-	Within Range
	5	LCHL>=LCBP	12	21.78	-	Not Matched
	6	LCBSS>=LCBP	18	21.78	-	Not Matched
21	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	6	0.587	9	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	0.89	0.36	1.02	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.09*2= 0.18	0.17	-	Matched
	4	MDBSS>=HNW	0.06	0.045	-	Within Range
	5	LCHL>=LCBP	16	24.85	-	Not Matched
	6	LCBSS>=LCBP	24	24.85	-	Within Range
22	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	5.5	0.512	8.25	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.16	0.38	1.32	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.09*2= 0.18	0.19	-	Matched
	4	MDBSS>=HNW	0.04	0.042	-	Within Range
	5	LCHL>=LCBP	22	30.78	-	Not Matched
	6	LCBSS>=LCBP	27	30.78	-	Not Matched
23	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	5.8	0.791	8.7	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.17	0.39	1.34	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.06*2= 0.12	0.17	-	Not Matched
	4	MDBSS>=HNW	0.035	0.044	-	Out of Range
	5	LCHL>=LCBP	19	27.37	-	Not Matched
	6	LCBSS>=LCBP	27	27.37	-	Within Range
24	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	6.3	0.567	9.45	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.09	0.37	1.24	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.07*2= 0.14	0.15	-	Matched
	4	MDBSS>=HNW	0.04	0.04	-	Within Range
	5	LCHL>=LCBP	14	22.58	-	Not Matched

	6	LCBSS>=LCBP	22	22.58	-	Within Range
25	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	5.8	0.512	8.7	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	0.92	0.36	1.05	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.07*2= 0.14	0.18	-	Not Matched
	4	MDBSS>=HNW	0.05	0.043	-	Within Range
	5	LCHL>=LCBP	18	27.09	-	Not Matched
	6	LCBSS>=LCBP	24	27.09	-	Not Matched
26	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	9.2	0.522	13.8	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.21	0.40	1.38	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.06*2= 0.12	0.20	-	Not Matched
	4	MDBSS>=HNW	0.035	0.05	-	Out of Range
	5	LCHL>=LCBP	27	37.6	-	Not Matched
	6	LCBSS>=LCBP	34	37.6	-	Not Matched
27	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	8.1	0.678	12.15	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.29	0.38	1.47	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.06*2= 0.12	0.20	-	Not Matched
	4	MDBSS>=HNW	0.03	0.046	-	Out of Range
	5	LCHL>=LCBP	22	30.8	-	Not Matched
	6	LCBSS>=LCBP	30	30.8	-	Within Range
28	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	7.9	0.714	11.85	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.16	0.37	1.32	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.08*2= 0.16	0.17	-	Matched
	4	MDBSS>=HNW	0.05	0.045	-	Within Range
	5	LCHL>=LCBP	21	30.7	-	Not Matched
	6	LCBSS>=LCBP	27	30.7	-	Not Matched
29	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	9.1	0.792	13.65	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.16	0.41	1.32	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.07*2= 0.14	0.16	-	Not Fully Matched
	4	MDBSS>=HNW	0.05	0.05	-	Within Range
	5	LCHL>=LCBP	20	28.58	-	Not Matched
	6	LCBSS>=LCBP	25	28.58	-	Not Matched
30	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	8.5	0.618	12.75	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.08	0.39	1.23	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.07*2= 0.14	0.17	-	Not Matched
	4	MDBSS>=HNW	0.045	0.048	-	Within Range
	5	LCHL>=LCBP	21	28.31	-	Not Matched
	6	LCBSS>=LCBP	28	28.31	-	Within Range
31	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	9.5	0.691	14.25	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.10	0.41	1.25	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.07*2= 0.14	0.18	-	Not Matched
	4	MDBSS>=HNW	0.045	0.05	-	Out of Range
	5	LCHL>=LCBP	24	33.7	-	Not Matched
	6	LCBSS>=LCBP	30	33.7	-	Not Matched
32	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	6.6	0.669	9.9	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.03	0.37	1.18	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.09*2= 0.18	0.19	-	Matched

	4	MDBSS>=HNW	0.04	0.045	-	Out of Range
	5	LCHL>=LCBP	19	28.6	-	Not Matched
	6	LCBSS>=LCBP	25	28.6	-	Not Matched
33	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	5.6	0.551	8.4	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.06	0.38	1.21	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.08*2= 0.16	0.20	-	Not Matched
	4	MDBSS>=HNW	0.04	0.042	-	Within Range
	5	LCHL>=LCBP	24	33.3	-	Not Matched
	6	LCBSS>=LCBP	30	33.3	-	Not Matched
34	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	5.9	0.566	8.85	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.17	0.41	1.33	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.09*2= 0.18	0.18	-	Matched
	4	MDBSS>=HNW	0.055	0.044	-	Within Range
	5	LCHL>=LCBP	25	34.56	-	Not Matched
	6	LCBSS>=LCBP	31	34.56	-	Not Matched
35	1	0.10*(SBW) ≤ BPW ≤ 0.15*(SBW)	7.2	0.798	10.8	Safe
	2	1.07*(BPH+ CT) < STL < 1.22*(BPH+CT)	1.11	0.39	1.27	Matched for upper range
	3	SCSL= V / (BPH * BPW)	0.08*2= 0.16	0.18	-	Not Fully Matched
	4	MDBSS>=HNW	0.035	0.046	-	Out of Range
	5	LCHL>=LCBP	20	29.16	-	Not Matched
	6	LCBSS>=LCBP	26	29.16	-	Not Matched

4. Results and Discussion

4.1. Analysis of Result

The primary aim of this research was to evaluate the ergonomic suitability of backpacks among thirty-five students using six distinct formulas based on body dimensions and backpack measurements. Each formula had specific criteria for determining the ergonomic safety and fit of the backpacks for the students.

Formula 1 focused on a basic safety measure, assessing whether the backpacks were generally safe for all students. The findings showed that every one of the thirty-five pupils satisfied the requirements for Formula 1, indicating a 100% compliance rate. This result implies that, at a basic level, the students' backpacks are safe and do not present an immediate ergonomic risk.

Formula 2 presented a more sophisticated assessment with two ranges: an upper and a lower range. Once again, the data showed that all 35 students met the upper-range requirements, demonstrating 100% compliance. None of the pupils, meanwhile, fit the lower range. This finding may indicate that although the backpacks successfully fit a wider or more permissive safety range, they fail to meet strict ergonomic standards.

Formula 3 assessed the fit of the backpacks using three distinct criteria: matched, not matched, and not fully matched. According to the findings, 14 students (or 40%) had backpacks that completely complied with the ergonomic standards, 15 students (or 43%) did not, and 6 students (17%) did not. The distribution of these backpacks' ergonomic compatibility suggests a wide range in the backpacks' suitability for different body proportions. This underscores the need for a customized approach when choosing a backpack.

Formula 4 explored ergonomic suitability through three ranges: within range, out of range, and not matched. According to the findings, three students (9%) had no matching backpacks, 16 students (46%) had backpacks outside of the suggested ergonomic range, and 15 students (46%) had backpacks inside the range. This almost even split between those within and out of range suggests a wide range in the ergonomic suitability of the backpacks, supporting the conclusions from Formula 3 that a one-size-fits-all strategy might not work.

Formula 5 addressed the Load Caring Capacity of the Hanging Loop (LCHL) and Load Caring Capacity of the Backpack (LCBP) comparison. Based on the data taken for the 35 students, only 4 out of 35 students (11.4%) had results where LCHL was greater than or equal to LCBP, indicating compliance with this criterion. On the other hand, 31 out of 35 students (88.57%) did not meet this requirement, showing that LCHL was less than LCBP. This suggests a significant number of students' backpacks may need to improve in this area.

Formula 6 analyzed the taken data based on another comparison between the Load Caring Capacity of Both

Shoulder Straps (LCBSS) and the Load Caring capacity of a Backpack (LCBP). Among thirty-five students, 14 students (40%) met the criterion, where LCBSS was greater than or equal to LCBP. This indicates that a comparatively larger group of students met this requirement compared to formula 5. However, 21 out of 35 students (60%) did not meet this requirement, with LCBSS being less than LCBP, indicating a need for improvement for most of the backpacks in this area to meet ergonomic student guidelines.

4.2. Suggestions and Recommendations

4.2.1. Re-Evaluation of Criteria for Lower Range in Formula 2 for Different Data Sets

Given that no students met the lower range criteria for Formula 2, it may be beneficial to re-evaluate this aspect of the formula for different students. This could involve adjusting the parameters to better reflect realistic backpack usage or redefining what constitutes a safe lower range to ensure it aligns with the student's body dimensions and typical posture.

4.2.2. Customized Backpack Solutions

The findings from Formulas 3 and 4 suggest a wide variability in backpack fit and ergonomic safety among students. This indicates the need for more personalized backpack options considering individual body dimensions. Schools or parents should consider ergonomic assessments before purchasing backpacks to ensure they meet the specific needs of each student.

4.2.3. Educational Programs on Backpack Safety

Introducing educational programs that focus on backpack ergonomics and proper wearing techniques can help students understand the importance of choosing the right backpack and wearing it correctly. This could potentially reduce the number of students who fall into the "not matched" or "not fully matched" categories.

4.2.4. Further Research in this Area

It would be valuable to conduct further studies to explore why certain formulas are more effective for some students than others. This could involve a more detailed analysis of body dimensions, backpack design features, and how these interact. Additionally, expanding the sample size and including a diverse range of body types could provide a more comprehensive understanding of backpack ergonomics.

4.2.5. Manufacturer Collaboration

Collaborating with backpack manufacturers to develop designs that cater to a wider range of body dimensions and ergonomic needs could help in creating products that are safer and more comfortable for students.

5. Conclusion

This study emphasizes how crucial it is to incorporate anthropometric data into backpack designs in order to enhance student ergonomic safety. Thirty-five backpacks were analyzed. Although all of them satisfied the minimum safety standards, none of them satisfied the more exacting ergonomic norms. In particular, they frequently met upper-range requirements but not lower-range requirements, suggesting that these rules need to be updated. Significant differences in fit were found in the analysis, confirming the inadequacy of a one-size-fits-all strategy. Moreover, very few backpacks fulfilled the required load-bearing capacities for shoulder straps and hanging loops, indicating significant space for development. According to the result, the following measures should be taken to solve these problems: updating ergonomic safety regulations, creating customized backpacks that fit each user's exact specifications, and initiating responsible usage education campaigns. With manufacturers working together, further study is necessary to improve designs and gain a deeper understanding of fit variability, with the goal of improving the ergonomic safety of backpacks for a wide range of students.

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