

Designing a New Ergonomic Student Backpack

ABSTRACT

Introduction: a Backpack is an essential tool for anyone, such as students who have to carry their daily necessities and supplies for long hours.

Aims: Studies have shown that inappropriate backpack types not only cause injuries to the musculoskeletal system but also cause the poor distribution of force and excessive pressure on the feet and thus discomfort for people.

Methods: In order to improve the comfort of backpack users and reduce the pressure on the foot, 18- to 25-year-old female students with normal body mass were selected for the study. The backpack was designed and made according to the Schoone-Harmsen method and ergonomic criteria. The sample was compared with current and existing backpacks in the market in terms of design and ergonomic features.

Results: The results showed that the new backpack using a medical belt based on ergonomic features with appropriate features provides a greater sense of comfort for users and it is improved compared to existing backpacks which are available in the Iranian market and designs based on previous studies.

Conclusion: For designing a backpack for people with different anthropometric sizes, a more accurate assessment of the larger sample, particularly measurements on the lumbar region and back, is required. It is recommended to evaluate the results in a larger sample and its effect on the dimples of Venus. However, the results had a positive evaluation at this stage.

Keywords: backpack, ergonomic design, students, comfort, foot pressure

1. INTRODUCTION

For people who have to carry their items daily for long hours, a backpack is a practical tool [1, 2, 3]. Backpacks are widely used by most people, including climbers and cyclists [4] and students [5]. This load carrying tool is placed in a state of balance and close to the body and seems to be a good tool for carrying load [6]. However, concerns over the increasing prevalence of undesirable side effects are increasing [5, 7]. The results of the studies show that prolonged use of the backpack not only worsens the musculoskeletal system and damages this system but also leads to improper distribution of force and excessive pressure on the foot as the lowest body part, followed by a feeling of discomfort [9, 8]. Although previous studies have related the consequences to backpacking habits [10], they also relate the use of inappropriate and non-standard backpack types to this [8, 9]. One of the important problems which have been considered to reduce these complications is "backpack weight". Observations have also shown that increasing the weight of the backpack from 10 to 15% of body weight leads to a significant increase in trunk flexion along with step length and walking frequency changes [11].

A study by Devroey et al. on 20 college students at different positions and different load weights in standing and moving state showed that carrying a backpack weighing more than 10% of the body weight caused an increase in discomfort, negative changes in the kinematics of motion and electromyogram [12].

29 Daneshmandi et al also showed that the use of backpacks with 8% body weight had a significant difference in physiologic
30 indexes of heart rate, systolic and diastolic blood pressure, respiratory rate and pulmonary ventilation compared to 10.5%
31 and 13% of body weight in students and backpacks weighing less than 8% of body weight can be safe for students [13].

32 While backpack weight loss is one of the most important recommendations for reducing the complications, Heather et al.
33 reviewed the relevant biomechanical, epidemiological and physiological studies to reduce the adverse effects of
34 backpacking, confirming the need for backpack weight loss by approximately 10-15% of body weight and emphasizing the
35 necessity of designing and using ergonomic backpacks [14]. The use of inappropriate and non-ergonomic backpacks
36 causes changes in body position, such as increased trunk forward flexion (as a response to a change in position from the
37 centre of gravity), Lordosis and kyphosis reduction [8, 15], and changes in the distribution of foot pressure [8]. Backpack
38 position on the back and design aspects such as shoulder straps and lack of waist strap which add more pressure on
39 muscles also contribute to problems or reduce them [8, 16]. However, backpacks with a framework with a pelvic strap can
40 reduce the risk of developing backpack palsy syndrome. **Backpack palsy is a rare but well-established cause of brachial**
41 **plexus injury, arising as a result of heavy backpack use [27].** Load-lightening, equipment optimization, improvement of
42 load distribution and preventive measures can be considered in order to achieve the goal of reducing the damage caused
43 by backpack load [17].

44 Considering the anthropometric characteristics of the backpack design, such as the position of the backpack at the top of
45 the pelvis, widespread padded backrest, waist region belts and shoulder straps, are standard backpack features. There
46 are two shoulder straps to help reduce the discomfort in the waist, knees, feel less pressure in the shoulder region, reduce
47 percentages of weight, reduce ventilatory disorders in the lung function [18].

48 It is expected that backpack design and optimization based on ergonomic principles and standards prevent and reduce
49 injuries to the musculoskeletal system and lead to more feeling of comfort for users and more proper distribution of
50 pressure on the feet. Despite the variety of load carrying tools, there is still no fully optimized system [19]. Although a
51 variety of backpack designs have been marketed, it seems that new backpack designs focus more on artistic aspects
52 such as materials used to satisfy customers and standard anthropometric features for users such as climbers, soldiers
53 and students, but it should be noted that students as a significant group of young adults have backpacks for carrying their
54 books and their daily necessities [20, 21, 22].

55 Based on resources, excessive backpack weight [8] and individual user characteristics such as more than 12 years of age
56 and female gender also increase the chance of damage caused by backpack load. Neglecting the factors such as
57 comfort, loss of leg muscle pressure, proper weight distribution at the foot, improvement of proper lumbar position to
58 prevent musculoskeletal disorders are due to improper use of a backpack, which should be given more attention [23].
59 Therefore, this study considers the design of a backpack with ergonomic and artistic criteria for female students.

60 2. MATERIAL AND METHODS

61
62 In order to increase the comfort and reduce the pressure on the foot in female students aged 18 to 25 years with normal
63 body mass index, a new backpack was designed based on the Schoone-Harmsen method [24]. This method is intended
64 to support designers in designing products which are safe to use. Moreover, it can also help ergonomists when analyzing
65 the use of a product. This method consists of four steps:

66 1. **Analysis:** At this stage, defects and problems of backpacks available in the market are identified.

67 2. **Identification of critical factors:** If the activity or mode of the consumer or features of the device plays a role in the
68 injury, the designer must apply those product features which can have an effect on the ease or reduce damage to be
69 effective on the use of the product.

70 3. **Synthesis:** At this stage, the designer is looking for solutions for the problems found in the product.

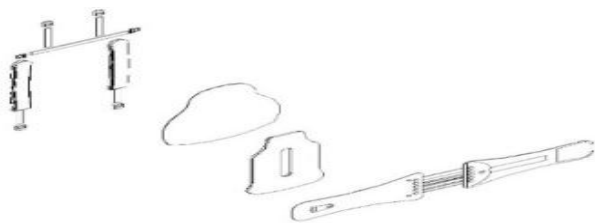
71 4. **Procedure:** The success in finding a solution for design is defined by a combination of different aspects such as
72 production capability, technical performance, ease of use, and physiological efficiency. At this stage, the effect of attention
73 to the safety of the product is also measured. Limitations such as safety standards and rules should also be included in
74 the evaluation. The design idea can lead to certain levels of development, before proving the effect that this idea could
75 pose. Evaluation in the early stages of the design process also allows better intervention wherever it is needed.

76 By analyzing the backpacks available in the market, this study identified problems such as improper lumbar pads,
77 improper compartmentalization of the backpack, improper shoulder pads and lack of chest strap using Schoone-Harmsen

78 method. According to ergonomic measures, a suitable backpack was designed. The design criteria for the new backpack
79 included:

- 80 • Maximum permitted load was 10 to 15% of the body weight.
- 81 • There were two spaced shoulder straps with a raised pad to reduce pressure on the shoulders and allow free
82 movement of the arms.
- 83 • Compact backpack straps for stability
- 84 • The volume was compacted to get the backpack compartments as close as possible to the body
- 85 • Pelvic and chest belts were used for transferring part of the backpack weight from the shoulder and back to the
86 pelvis and chest for further stability of the backpack.
- 87 • The bottom of the backpack was placed in the lower back and in the middle of the body properly to prevent
88 bending to the buttocks.
- 89 • Two strategies for lowering the feeling of weight on the shoulders and the back is shifting shoulder straps from
90 back to front and compartmentalizing the backpack internally. By changing the location of the straps to the front of
91 the backpack, force is applied to a greater surface of the body. As a result, the force applied on the shoulders will
92 be reduced [24].
- 93 • Internal compartmentalization of the backpack improves the load distribution in the backpack; in addition, it moves
94 the centre of gravity of the backpack closer to the centre of gravity of the body, which is a significant factor in
95 reducing the effective load on the shoulders, the back and neck. The results show that the shoulder straps
96 support the heaviest part of the backpack when they are placed in the middle of the backpack in front of the back
97 of the backpack. The heaviest part of the backpack should be close to the back and upper backpack [25].

98 According to these criteria and reviews conducted, it was decided to use a special medical belt with a spine and pelvic
99 support pad for better distribution of the pressure and force on the back and weight transfer from the shoulders to the
100 pelvis (Figure 1). This belt has an advanced and ergonomic design of polymer pads in different sizes. The goals in its
101 application are to immobilize the spine, correct the shape of the spine and keep the muscles and vertebra warm.
102 Considering the advantages of using this belt, in addition to a better distribution of backpack weight and lower foot
103 pressure and a greater sense of comfort, incorrect habits of standing and walking during long-term load carrying will also
104 be corrected [25].



105
106 **Fig. 1. Components of medical belt**

107 Establishing the right pressure to hold back the abdomen to balance the center of gravity, keeping the waist warm and
108 keeping the spine in a standing position are the effects of the medical belt chosen in this study. Moreover, the belt is sized
109 based on the waist circumference; because the sample included female students, the average size was in the range of 75
110 cm to 89 cm.

111 Then, the sketch of the backpack was drawn up according to the standards. By reviewing and fixing the defects, the final
112 design of the backpack was given to the manufacturer for the implementation and construction of the backpack. The
113 height of this backpack was 47 cm, its depth was 18 cm and its width was 27 cm, weight 2200 g with a lumbar belt and
114 1300 g without a medical belt. Some ergonomic features considered in the design included: special chest strap, special
115 medical belt, supporting pads for the back and dimples of Venus (lordosis/lumbar curve), small straps on the shoulder

straps to close the top of the backpack to the top of the trunk and shoulders. The internal backpack compartmentalization and multiple pockets on the outside of the backpack were made to divide the load in different places and reduce pressure. In the backpack, the medical belt was embedded in the backpack that is easily removable from the back of the backpack, so that the backpack can be used either with a medical belt or without it, and this is also an advantage of the backpack (Figure 2).

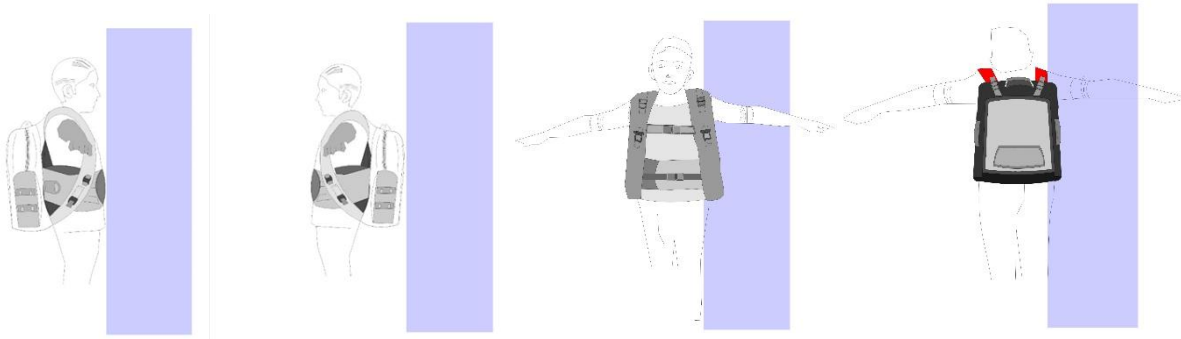


Fig. 2. The new ergonomic backpack

3. EVALUATION

At this stage, the ergonomic backpack designed and built was compared with a conventional backpack available on the Iranian market in terms of artistic design and ergonomic features, as well as comfort and pressure on the foot in a small sample of five female students or body mass index, while the backpack weight and its contents (including academic books, water container and pencil case), which was equivalent to 10% of their body weight. The conventional backpack was chosen from four different types of backpacks available on the market. The selection criterion was the highest number of ergonomic features based on standards. Features of this backpack included waist strap, back pad, dimples of Venus(lordosis/lumbar curve) support pad, standard shoulder straps, and multiple pockets on the backpack for categorizing the gadgets (length 47 cm, depth 13 cm and width 31 cm, weight 1300 g). Table 1 lists anthropometric features of a small sample of five people with normal BMI (Body Mass Index) participating in the evaluation (Table 1).

Table 1: Anthropometric features of the primary sample (5 people) participating in the evaluation

Variable	mean±SD	Min/max
Age	20.4±1.74	18-22
Height	160.6±2.23	157-164
Weight	55±0.63	54-56
BMI	21.2±0.44	21-22

BMI: Body Mass Index

Table 2 reports the comfort felt by the samples relative to components of the backpack and backpack carrying. Obviously, score of the comfort felt was significantly higher in the ergonomic backpack than the conventional backpack ($p < 0.05$).

Table 2: Comparison of mean and standard deviation in score of the comfort of components and carrying state in the new ergonomic and conventional backpack

Comfort	Ergonomic Mean Rank	Conventional Mean Rank	U Mann Whitney	p
Wrist strap	8.00	3.00	<0.001	0.008
Shoulder strap	8.00	3.00	<0.001	0.007
Back pad	7.80	3.20	<0.001	0.015
Carrying	8.00	3.00	<0.001	0.008

According to Table 3, there was no significant difference in the pressure imposed on the feet between the new ergonomic backpack and the conventional backpack ($p \geq 0.05$).

145 **Table 3. Comparison of mean and standard deviation in feet pressure in the waking state in the new ergonomic**
146 **and conventional backpack**

Pressure on the foot areas	Ergonomic Mean Rank	Conventional Mean Rank	U Mann Whitney	P
Back	5.40	5.60	12.00	0.917
Front	6.80	4.20	6.00	0.175
Total	5.80	5.20	11.00	0.754

147
148 With regard to artistic design and practicality of the backpack, while the participants were unaware of the new or
149 conventional type of the backpack and could closely check them out, they chose the ergonomically designed backpack.

150 **4. DISCUSSION**

151
152 In order to design and build a backpack prototype using ergonomic criteria to reduce the pressure on the foot and
153 increase comfort in 18 to 25 year old female students, a backpack was designed, taking into account the design of
154 previous studies and samples existing in the Iranian market and attempts were made to resolve the problems reported in
155 previous studies.
156

157 In the present study, back position, lumbar and shoulder straps were considered as standard features of the backpack.
158 Mackie et al. designed a backpack considering ergonomic criteria with two large compartments, sturdy back pads, and
159 lateral compact straps [26].

160 In another study on ergonomic backpack design for students aged 7-9, the widespread padded back, lumbar belt and
161 shoulder straps were used as standard backpack features in design based on a user-centric design approach. However,
162 they considered shifting the shoulder strap from back to front of the backpack and internal compartmentalization to reduce
163 backpack weight; according to their report, the shift of shoulder straps from back to front was confusing for the users [20].
164 Instead of shifting the shoulder straps, the present study used small straps to roll up the upper part of the backpack and
165 get the load closer to the upper part of the trunk. Although age differences in two studies should be considered, however,
166 this change was acceptable to our users. Shakoori et al. designed a relief backpack for military use which can be used for
167 long hours and its compartments were based on medical need; compartments of the backpack were based on colour and
168 size of substances and drugs and easy access to various backpack compartments. Suitable materials and the same
169 colour of military uniforms used in the backpack, pelvic pad and waist strap, numerous small straps to bring the backpack
170 closer to the body and easier carriage were evident ergonomic features. However, the height of the backpack, lack of a
171 wide pad and back support were negative aspects of this design [18]. Solving these problems in backpack design was
172 considered in this study. As with the new backpack, the tips mentioned in fashion design, as well as a medical belt, was
173 also considered to be embedded in the backpack, which can easily be removed from the backpack. In this way, the user
174 can use the backpack with or without the medical belt; these features did not exist in previous designs [26, 20, 18]. This
175 medical belt used in the backpack added 900 g weight to the backpack, in contrary to recommendations for reducing
176 backpack weight as a standard in design; thus, load carrying ability was reduced by the same amount. However,
177 comparisons showed that comfort felt by using this backpack, despite the higher weight, was better, which is probably due
178 to positive effects of the medical belt on the waist, including the effect on dimples of Venus (lordosis/lumbar curve), based
179 on features considered by the belt manufacturer.

180 **5. CONCLUSION**

181
182 Overall, the results of this study showed that although the new backpack designed by using the medical belt based on
183 ergonomic features did not reduce foot pressure, it had proper features with a feeling of comfort. Moreover, it was chosen
184 more for its design and practicality. For designing a backpack for people with different anthropometric sizes, a more
185 accurate assessment of the larger sample, particularly measurements on the lumbar region and back, is required. It is
186 recommended to evaluate the results in a larger sample and its effect on the dimples of Venus. However, the results had
187 a positive evaluation at this stage.

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ETHICAL APPROVAL

This project is approved by the Postgraduate Council and the Ethics Committee of the Iran University of Medical Sciences (IR.IUMS.REC 1395.9413467002).

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