Designing a New Ergonomic Student Backpack

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ABSTRACT

Backpack is an essential tool for anyone, such as students who have to carry their daily necessities and supplies for long hours. Studies have shown that inappropriate backpack types not only cause injuries to musculoskeletal system, but also cause poor distribution of force and excessive pressure on the feet and thus discomfort for people. 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. 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.

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

1. INTRODUCTION

For people who have to carry their items daily for long hours, the 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 these 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 has been considered to reduce these complications is "backpack weight". Observations have also shown that increasing the weight of 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 a 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 kinematics of motion and electromyogram [12].

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

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

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

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

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

2. MATERIAL AND METHODS

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

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

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

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

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

By analyzing the backpacks available in the market, this study identified problems such as improper lumbar pads, improper compartmentalization of the backpack, improper shoulder pads and lack of chest strap using Schoone-Harmsen method. According to ergonomic measures, the suitable backpack was designed. The design criteria for the new backpack included:

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

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

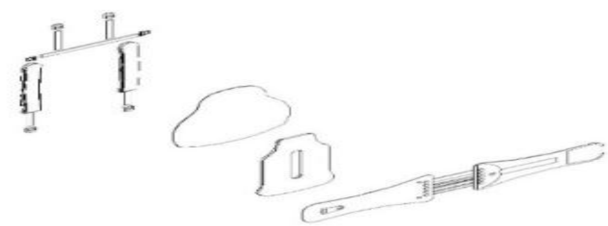

Fig. 1. Components of medical belt

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

Then, the sketch of the backpack was drawn up according to the standards. By reviewing and fixing the defects, the final design of the backpack was given to the manufacturer for implementation and construction of the backpack. The height of this backpack was 47 cm, its depth was 18 cm and its width was 27 cm, weight 2200 g with lumbar belt and 1300 g without medical belt. Some ergonomic features considered in the design included: special chest strap, special 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).

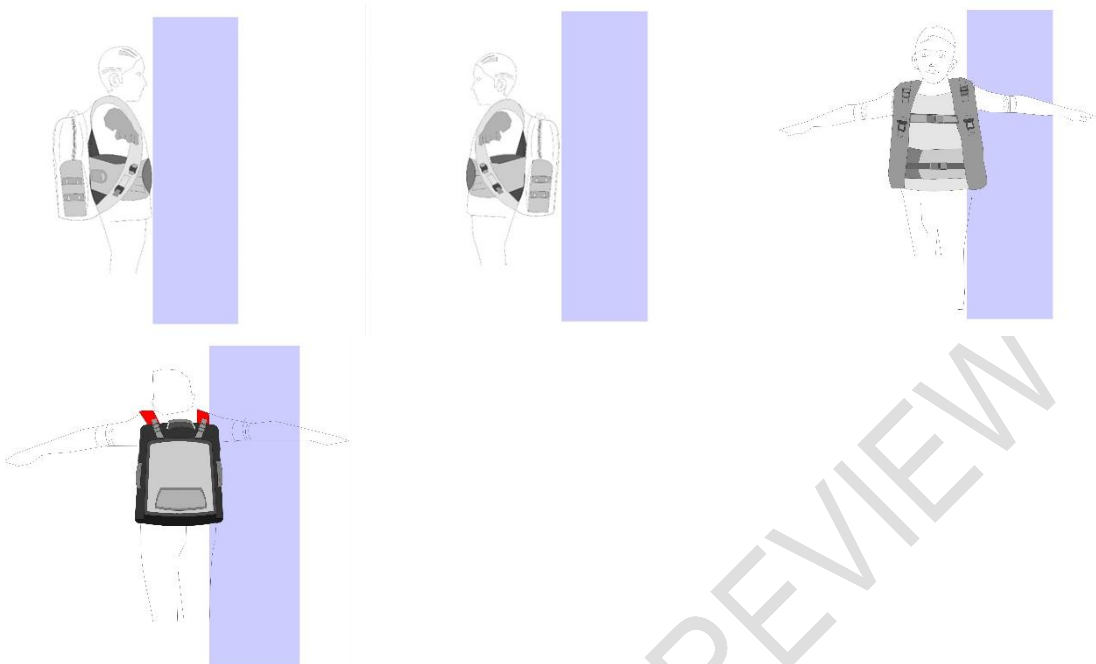

Fig. 2. The new ergonomic backpack

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 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 new ergonomic backpack and the conventional backpack ($p \geq 0.05$).

Table 3. Comparison of mean and standard deviation in feet pressure in the walking state in the new ergonomic 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

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

4. DISCUSSION

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

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

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

5. CONCLUSION

Overall, the results of this study showed that although the new backpack designed by using the medical belt based on ergonomic features did not reduce foot pressure, it had proper features with a feeling of comfort. Moreover, it was chosen more for its design and practicality. 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.

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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