



## Multi-Purpose Ergonomic Backpack for High School Students

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### ABSTRACT

**Background:** Musculoskeletal disorders (MSDs) are among the most prevalent pains which could be ignited via material handling. Backpack wearers are among those who may carry heavy loads. Since MSDs mainly originate in school-aged children, students (as the largest group of backpack wearers) are considered more important. The purpose of this study is to design a backpack based on minimization of shearing force.

**Methods:** At first the relevant patents were investigated at national and international levels. Then the appropriate ones were selected for optimization. The main selection criterion was based on reduction of pressure on the body. As an extra function we used a generator to produce electricity. The criterion for electricity generator selection was: 1) small dimension, 2) low weight, and 3) safe voltage.

**Results:** A suspending system was used to eliminate shearing forces. Since a backpack wearing student is under the shearing force caused by walking, a spring system was used as a reducing device for shearing force. Physical spring calculation revealed that springs with stiffness coefficient equal to 588 were appropriate.

**Conclusion:** In comparison with existing designs, suggested backpack design can reduce forces on upper limb during handling the backpack.

## 1. Introduction

Load carriage is frequently met during the course of normal daily activities among schoolchildren and adolescents. Students use shoulder bags, briefcases or backpacks for carrying what they need (books, stationeries, laptops, and other belongings) to and from schools. Over time most of the students have increasingly been adapted to use backpacks [1, 2]. However, there is growing concern among educators, health-care professionals, parents, and legislators that back pain is becoming a serious health issue in school-aged children due to the increased use of heavy backpacks [3].

Although these sorts of complaints are often reported among the elderly, in many cases they begin at early ages and develop to end-stage disorders during adulthood [4]. There is evidence which indicates that pain is common in adolescent populations [5] and the prevalence of musculoskeletal pain increases with age even in children and adolescents, too [6, 7]. Nowadays, carrying heavy backpacks is seriously suspected to have an important role in students' musculoskeletal disorders [8-10]. Al-Khabbaz et al., (2008) examined the effect of backpack

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the effect of backpack (weighing 10, 15 and 20% of the body weight) on trunk-lower extremity muscles and showed that by increasing backpack weight, an excessive activity occurs in some trunk-lower muscles, but backpacks with 20% of the body weight create the most significant muscular and postural tensions [11]. Based on epidemiological, physiological and biomechanical approaches, Brackley & Stevenson introduced a range between 10-15% of the body weight as a justified safe limit for backpacks [12].

The biomechanical impact of backpack load on the spine has been frequently considered in research [13, 14]. A couple of studies were carried out to find a solution. A part of these efforts is focused on defining the *safe* weight of backpack load based on the percentage of the wearer who is carrying the load [15-17]. A few studies introduced new fields about adjusting or distributing backpack load on involved muscles. For example, Sharpe et al., (2008) suggested backpacks which were accompanied with a hip belt to coordinate pelvis and thorax in motion [18].

It would be useful to consider the body movement during walking while carrying a backpack. During a walking period, the cyclic motion of the torso creates an interaction between the backpack and the human torso [19]. Comparison of carrying load on compliant poles and backpack revealed that the decrease on backpack suspension stiffness is associated with reduction of fluctuation on vertical force of torso, peak values of ground reaction forces and lower limb joint loads. Therefore, one should conclude that the back and lower limb injuries could be lessened by using a soft backpack suspension, particularly during carrying heavy-loaded backpacks [20].

However, Ren et al., (2005) expressed that a more compliant pack suspension will result in larger pack motions relative to the torso, which would affect the wearer's balance and agility. It may be possible to overcome this problem with the accurate combination of stiffness and damping, where the damping is chosen to allow a compliant suspension without excessive relative motion [19]. One may conceive that a backpack provided with a suspending system could be a solution. Because the least relative motion on torso, and at the same

the backpack can be properly fastened to achieve the least relative motion on torso, and at the same time, the backpack vertical force on the torso will be reduced.

This study was conducted to design a backpack with a suspending system for high school Students. In addition, an electricity generator was provided for backpack wearer and the possibility of notification of wearer about exceeding load weight was considered.

## 2. Materials and Methods

Developing a new backpack aiming at reduction of acting force on the torso requires investigation of existing designs, revealing the possibly of relevant pitfalls, and presenting suggestions to resolve the problems. Therefore, ergonomic backpack patents were reviewed as well as patents for extra options, and we followed the criteria of reduction of force on torso and generating safe voltage (less than 50 voltages-AC). The basic considerations were regarded as follows:

1. Making a reduction of acting force on the torso
2. Providing the possibility to inform the wearer about excessive backpack weight
3. Developing a multi-purpose backpack (with especial regard to generating safe voltage)

Then, the proposed design was drawn using Solidworks software.

## 3. Results

### 1. Reduction of acting force on the torso:

The most important innovation of proposed design is using a simple suspending system with four springs (Fig. 1) which can reduce shearing forces on upper limbs of trunk due to backpack's weight during walking. Suspending system was embedded in two holding plane frames (A, B) with similar shape, size, and area. These frames jointly act as a scaffold to hold the suspending system, as is described in the following. The holding frame (A) includes ball bearings, and holding frame (B) includes two pairs of springs (one pair on each side). Each pair of springs contain a two-centimeter and a three-centimeter (F) spring. To keep the springs stable, a rod (K) is located at its central axis which at both ends is attached to

holding frames. Holding frame (A) has one ball bearing (E) at both sides. The ball bearings cause the holding frames (A and B) to join together. Once loads are placed in backpack, the weight on ball bearings create pressure on springs and causes them to compress. From top to bottom, consequently, long springs (11 cm) accompanied with ball bearing, and then short springs (3 cm) are moved respectively.

The main criterion for determining the length of the long springs (with 11 cm length) is the range of vertical body motion during walking and the movement of the backpack (Fig. 2). Carrying backpack during walking, may pose pressure on spinal column and arteries in shoulder. Whenever the backpack wearer walks, a force is imposed on the body which is more than weight force of backpack's load; originating from Newton's second law of motion (Force = backpack mass  $\times$  acceleration). While the wearer walks and places his/her foot on the ground, the backpack tends to continue its motion with the same inertia (Fig. 3). Consequently, more burden is forced on the body. Also, at the next step, the body is lifted upward and more excessive burden is forced on the body, resulting in fatigue and musculoskeletal disorders [21]. In each step, the body fluctuates in a 4-7 centimeter vertical axis [22]. Therefore, based on the calculation described later, we chose an eleven-centimeter spring with the ability to move at an eight-centimeter interval distance. However, a longer interval distance may create another problem i.e. repeated hitting of backpack to the hip area.

Two holding frames are joined together by two rails (L). These rails prevent holding frames from separation and help them to move just in a vertical direction. The main role of balancing backpack fluctuations is bearing upon the long springs (G). They are used for justification of downward forces which are created by both load weight and walking. Short springs (F) have supplementary roles. Besides, the backpack is equipped with changeable helping compression springs (H)

which can increase the efficiency of backpack for more weight.

As previously mentioned, the long springs (G) have been considered for 15% of total mean weight of high school students. In the case of carrying heavier loads, springs with higher stiffness coefficient would be required. Therefore, a simple way for replacing springs was considered in the design.

#### *Determining stiffness coefficient for longer springs*

As discussed before, it has been proposed that total weight of backpack should not exceed 15% of students' weight [11, 12]. Based upon an anthropometric study in Zanjan, the mean weight of high school students is equal to 64 Kg [23]. By considering this mean, we concluded that gross weight (weight of the backpack itself and, the load) should not exceed 9.6 Kg. since the backpack has a spring in each side, determined stiffness coefficient should be divided in two.

According to above assumptions, Hooke law and Newton's second law of motion, following relationships could be used to determine stiffness coefficient of the spring:

$$\begin{aligned} F &= k \cdot x & F &= k \times .08 \\ F &= m \cdot g & F &= 9.6 \times 9.8 \\ m \cdot g &= k \cdot x & 9.6 \times 9.8 &= k \times .08 \\ k &= 1176 \\ k &= 1176 \div 2 = 588 & \text{for springs at each side} \end{aligned}$$

Where:

F: force (N or kg.m/s<sup>2</sup>)

k: stiffness coefficient of spring (N/m)

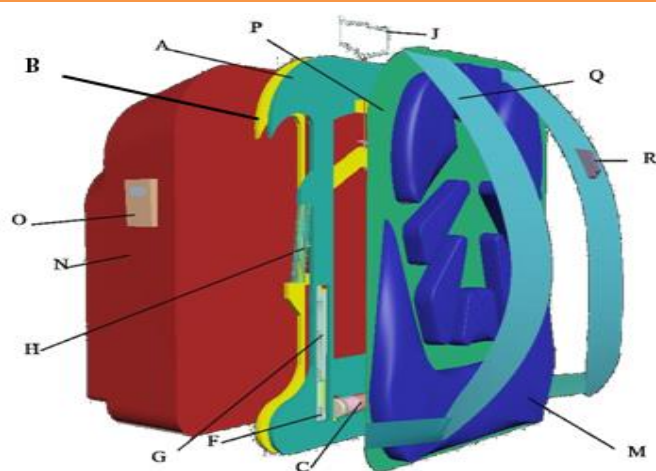
x: range of spring's motion (meter)

m: Mass (Kg)

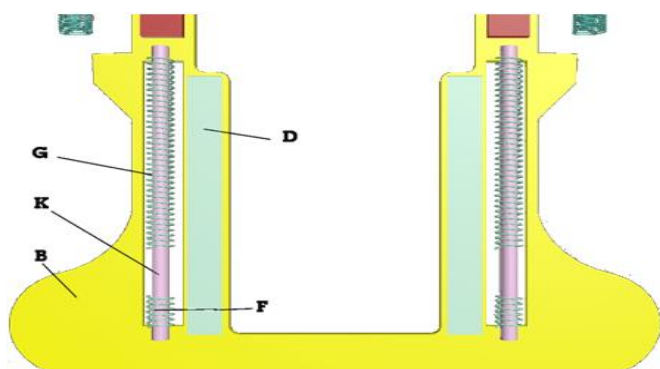
g: Earth gravity force (m/s<sup>2</sup>)

#### *Pads and strips layout*

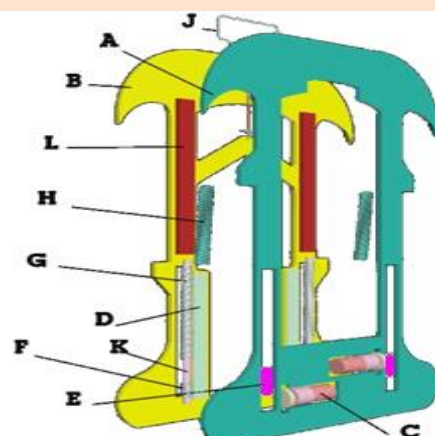
Two holding frames with their accessories are placed between the tank and the back of backpack. Soft paddings (M) will be placed on back of the backpack to reduce tension in these parts on dorsal surface, as well as allowing more parts of the body to expose to air flow.



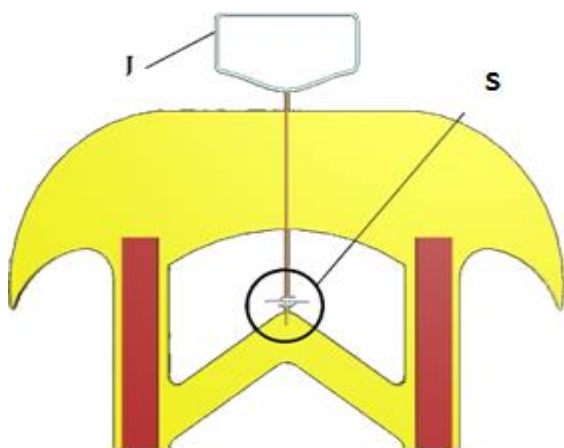
(a)



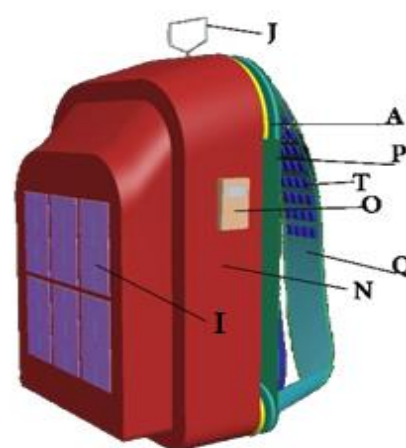
(c)



(b)



(e)



(d)

**Fig. 1:** proposed backpack in details.

A and B: backpack holding frames; C: gearbox armature (power generator); D: soft and fluffy thick plastic band; F: shorter spring; G: longer spring; H: helping spring; I: solar panels; J: weight-meter handle; K: steel rod; L: small ball-bearing rails; M: paddings placed on the wearer's back; N: backpack tank; O: weight indicator; P: part that is located on the wearer's back; Q: backpack strips; R: headphone connection place; S: a part of that weight-meter works when it is pulled; T: soft paddings at low surface of strings.

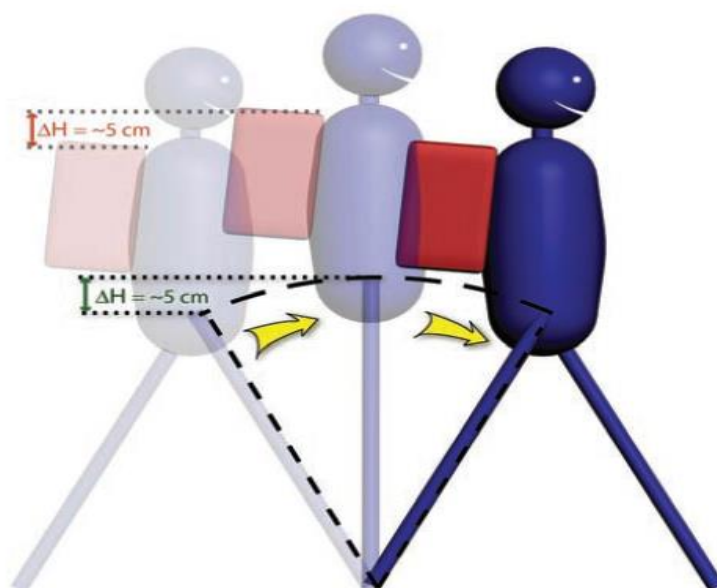


Fig. 2: Body fluctuation during walking.

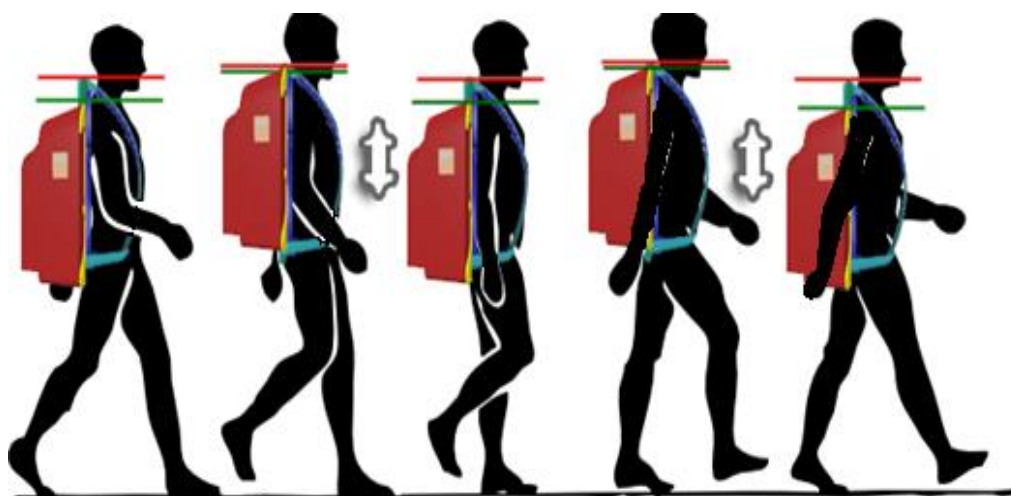


Fig. 3: Inertia of backpack movement during walking.

The strips (Q) have a crescent shape to be better matched with upper trunk. Compared to ordinary strips, the wearer's hands will meet less difficulty to move.

2. Electricity generator: over the past few decades, personal portable electronic devices have grown steadily requiring regular resupplied batteries [24].

Changing body movement to electricity was considered through a backpack combined with a suspending system [24, 25]. Thus, one of our attempts yielded in generating electricity via the mentioned suspending system. Human body motion, as a mini power plant, may create fine mechanical motion to generate electricity via appropriate devices.

The introduced backpack will generate electricity via the mentioned suspending system accompanied with a pair of gearbox armatures (C). Each gearbox armature will be placed at each side of holding frames. The gearboxes, as converters of power to speed, are attached to the armatures and directly cause them to move. This system can trap the trivial mechanical forces resulting from walking. Thus, up and down movement of the backpack will be transformed into electrical power. The power will be safe and under 50 voltages. In one of the strips, a place has been considered (R) to connect electric accessories (headphone, laptop, cellphone charger etc.) to generated electricity.

Besides, on the outer (visible) surface of the backpack, solar panels (I) will be embedded to generate electricity via sunlight, so that electric accessories will be able to work in case the wearer is not in a walking situation.

3. The possibility of notification of the wearer about exceeding load weight:

The backpack will be equipped with a weight-meter (O). The weight-meter handle (J) is connected to a lever (S) which is sensitive to extension. Whenever the handle of the backpack hangs down, the lever will be extended according to the load weight. Then, the load weight will be shown on the indicator (O). The weight-meter has three buttons: on/off, calibration, and a convertor weight units.

#### 4. Discussion and Conclusion

Musculoskeletal disorders (MSDs) are among the most common causes of disorders in Iran. Studies show that a considerable number of high school students who suffer from musculoskeletal disorders are carrying improper bags and backpacks which seem to be the main culprits for those disorders [8-10].

Alexander (1988) mentioned a surprising energy efficiency during carrying loads on the head, which is a widespread tradition for carrying loads in Africa, because the combination of muscle-tendon functions exactly like springs and

absorb, store and return energy during different parts of the gait cycle [19]. Inspiring such function, we consider equipping a backpack with a suspending system to reduce the impact of carrying backpack on MSDs. The design seems promising. However, a definite judgment on efficiency and advantages of the backpack has to be postponed until further studies such as muscular activity tests (EMG). Also, the quality of final product and the wearer convenience may be affected by the kind of material which will be used.

This backpack could be modified easily for other backpack wearers (armed forces, recreational hikers, etc.).

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