Determination of Safe Mass of Backpack for Students in Tertiary Institutions

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***Abstract*— Load carrying using backpacks is common among students from primary schools to tertiary institutions in Nigeria. Backpacks are used for carrying books and other school materials. The aim of this study is to determine the mass of backpack that students in tertiary institutions using strain energy principles of the spine. Ten students in a selected tertiary institution participated in the study. A model was developed using strain energy in terms of chest width, chest depth, Young Modulus of Elasticity of articular cartilage, maximum permissible spinal shrinkage, length of spine and body height of the students. The 5th, 50th, ands 95th percentiles of the data obtained were computed using a SPSS 16.0 statistical package. The study confirmed that the model is valid and showed that the maximum backpack load limit for students in tertiary institutions should be 12% of body mass. Similar studies were recommended to be carried out in primary and secondary schools.**

Keywords*— *Spinal shrinkage; backpack; load carriage; tertiary institutions.

I. INTRODUCTION

Load carrying using backpacks is common among students from primary schools to tertiary institutions in Nigeria. Backpacks are used for carrying books and other school materials.

This is likely to be a practice adopted from the developed nations as the use of backpack amongst pupils and students has been recognized as the most popular means of transporting belongings to and from school in those nations [1]. Findings have showed that school-aged children carried heavy backpack loads that were uncomfortable to carry, and as such the incidence of back problems in school-aged children was high [2, 3]. Heavy backpack loads may cause musculoskeletal pain [4], changes in cervical and shoulder posture [5] and increased stress on spinal structures [6]. Many reasons have been stated for the relationship between use of backpack and musculoskeletal disorders. Such reasons include incorrect use of backpack [7], mass of backpack [8, 9], length of period of backpack carriage [10] and placement of the backpack [11]

The health effects of carrying heavy backpack loads necessitated the attention given to the determination of the load limit of backpack in the literature. Students sometimes carry as much as 30% to 40% of their body weight at least once a week [12]. Many studies present evidence to support backpack load limits for children, but the suggested limits have been based on percentage of the body weight with discrepancies. While some researchers proposed 10 % of body mass [13, 14], others [15] proposed 15 % of body mass. Brackley and Stevenson [16] recommended that backpacks weight should be between 10–15% of a child's body mass. Mackenzie *et al*. [12] established a relationship between back pain and backpack load exceeding 15% to 20% of body mass. Therefore, there is no consensus among researchers as to the actual percentage of body weight that the backpack should be, necessitating further research. Backpack limit may not be a function of weight only but other anthropometric data may be necessary. Ismaila and Charles-Owaba [17] used the spinal shrinkage principles to determine the weight of a load that a worker should lift to be safe. The aim of this study is therefore to determine the backpack mass limit that students can carry to be safe with due consideration to their anthropometric characteristics.

II. METHODOLOGY

A. Model Development

In the formulation of the model, the following assumptions were made:

1. The spine is the most important aspect of the lifting structure and therefore it is given serious consideration [18, 19]
2. Each of the endplate of the spine consists of hyaline and fibro cartilage [20] and may be modeled as an isotonic elastic material [21].
3. An Elliptical truncal cross sectional area of the human subject is assumed [22]

Elliptical Truncal Area, $A = \dfrac{\pi \times l_f \times l_s}{4}$ [23]

where *lf* is the chest breadth measured across the chest at the nipple; *ls* is the chest depth measured at the chest from front (sternum) to back (spinal groove).

4. The Modulus of elasticity of articular cartilage, E is assumed to be 7.0 MN/m^2 [24] and a factor of safety of 1.25 [25] was adopted. Therefore, E = 5.6 MN/m^2

5. The strain energy at the spine is the sum of the potential energy and kinetic energy of the load being lifted [26]

6. The normal walking of the backpack carrier occurs when Froude number = 0.25 = $\frac{u^2}{g \times l}$ [27]

Where u = velocity of movement, g = 9.81 m/ s^2 and l = leg length

7. The Leg length, $l = 0.53 \times$ Height of the carrier [28]

8. The maximum spinal shrinkage, $x = 0.021$ m [29]

The anthropometric dimensions introduced into the model and regarded as variables are: height shrinkage (x), the value of length of the spine from the first thoracic to the last lumbar vertebrae of the trunk (L), chest breadth (l_f) and chest depth (l_s).

The parameters used in the model are young modulus of elasticity of the articular cartilage (E) and velocity of movement of the backpack carrier (u)

Strain Energy, $SE = \frac{Fx}{2}$ [30] (1)

where *F=Load on the spine*

x= spinal shrinkage

Kinetic Energy, K.E. = $\frac{1}{2} mu^2$ (2)

Potential Energy, P.E. = $mg\,(SH)$ (3)

Where SH = Shoulder Height of the backpack carrier, m

= Length of spine less that of cervical, L + Leg length

m = mass of backpack, kg

u = velocity of movement of the backpack carrier

The spring constant, k, is given by:

$k=F/x=AE/L$ (Marshek, 1987) (4)

Combining equations (1) and (4) we have

$$SE=\frac{AEx^2}{2L} \quad (5)$$

From energy conservation principle

$$SE = PE + SE \quad (6)$$

The strain energy due to backpack carrying and that due to the upper body (i.e. head, trunk and arms) weight must be equal to the sum of strain energy due to upper body weight only and that due to backpack carrying.

Therefore,

$$SE_T = SE_b + SE_c \quad (7)$$

where,

SE_T= Strain energy due to upper body weight and weight of lift

SE_b= Strain energy due to upper body weight

SE_c= Strain energy due to backpack carrying

But strain energy is the sum of potential and kinetic energies,

Hence,

$$SE_T = PE_T + KE_T \quad (8)$$

From equations 2 and 3

$$KE_T = M_T u^2/2 \quad (9)$$

$$PE_T = M_T g(SH) \quad (10)$$

Where

$M_T = M_o + M_b$

M_o = weight of backpack

M_b= weight of upper body

$$SE_T = M_T g\,(SH) + M_T u^2/2 \quad (11)$$

Similarly,

$$SE_b = M_b g\,(SH) + M_b u^2/2 \quad (12)$$

But,

$$SE_l = SE_T - SE_b \quad (13)$$

Therefore,

$$SE_c = (M_o + M_b)\,g\,(SH) + (M_o + M_b)\,u2/2 - [M_b g\,(SH) + Mbu2/2]$$

$$= M_o g\,(SH) + M_b g\,(SH) + M\,u^2/2 + M_b u^2/2 - Mbg\,(SH) - M_b u^2/2$$

$$= M_o g\,(SH) + M\,u^2/2 \quad (14)$$

Hence, combining this with equation (5), then:

$$AEx^2/2L = M_o g\,(SH) + 1/2 M_o u^2 \quad (15)$$

$$M_o = \frac{A \times E \times x^2}{2L\left(g(SH) + \frac{u^2}{2}\right)} \quad (16)$$

Substituting for $u^2 = 0.25 \times g \times l$; $l = 0.53 \times H$

$SH = L + 0.53 \times H$ and $g = 9.81$

$$M_o = \frac{\pi \times l_s \times l_f \times E \times x^2}{78.48 \times L^2 + 46.69 \times H \times L} \quad (17)$$

B. Model Application

Ten students from a Federal university participated in the study. The mean age of the students was 22.9 years (SD = ± 2.47 years) and height of 1.71 m (SD = ± 0.06 m). The consents of the students were obtained before the commencement of the study. The chest breadth and chest width were measured with a vernier calliper. The standing height was measured with a stadiometer while L (length from the first thoracic to the last lumbar) was measured with a meter rule. The obtained values were used in the proposed model to obtain the maximum allowable weight to be carried by the students.

III. RESULTS AND DISCUSSION

Table 1 shows the anthropometric data of the students and the obtained values of the backpack mass limit for the 5th, 50th and 95th percentiles.

TABLE I. ANTHROPOMETRIC DATA OF THE PARTICIPANTS AND VALUES OF PROPOSED BACKPACK MASS LIMIT

Percentiles	*Age (years)*	*Weight (kg)*	*Height (m)*	*Chest depth (m)*	*Chest width (m)*	*Mass of backpack (kg)*	*Percentage of body weight (%)*
5th	*18.9*	*54.5*	*1.63*	*0.16*	*0.23*	*5.23*	*8.29*
50th	*23.5*	*59.0*	*1.73*	*0.18*	*0.25*	*5.86*	*9.72*
95th	*25.6*	*69.8*	*1.77*	*0.20*	*0.28*	*6.66*	*11.87*

The mean age of the students was 22.9 years (SD = ± 2.47 years) and height of 1.71 m (SD = ± 0.06 m). Using the developed model, the students with a mean chest depth of 0.18m and mean chest width of 0.25m are expected to carry a mean safe backpack mass of 5.86 kg with a maximum of 6.66kg. The mean percentage of body mass was 9.72% and a maximum of about 12 % (11.87%) of body mass.

The present study proposed a maximum backpack mass of 6.66 kg which is about 10% of the body mass of the carrier. This is in agreement with the work of [16] which stated that backpacks should weigh no more than between 10 and 15% of a child's body weight. Some other researchers also recommended load mass guidelines for school backpack load carriage in schoolchildren of between 10% and 15% body mass [31-33]. However, Simpson *et al*. [34] concluded that a backpack load limit of 30% of body mass should be recommended for female recreational hikers during prolonged walking. The work is at variance with earlier studies [13, 14, 31, 35] that proposed a backpack load limit of 10% of body mass. To minimize musculoskeletal problems, a schoolbag weight limit of 10–15% of body weight has been recommended as a maximum load for school students [16].

Hong and Brueggemann [31] examined the gait pattern, heart rate, and blood pressure in 10-year-old boys carrying backpacks of 0% (control), 10%, 15%, and 20% of their own body weight while walking on a treadmill. They did not notice any significant difference in the measured parameters between the 10% and 0% load conditions, however a significant difference was found between the 0% and 15% or 20% load conditions with a significant increase of forward trunk bending. They therefore concluded that backpack weight should not exceed 10% of body weight in 10- year-old boys.

Backpack loads of more than 10% of body weight increase trunk forward lean [31], increase energy consumption [35] and result in decreased lung volumes [36]. A backpack mass of 10% of the body weight is supported by this study. Carrying heavier backpack than the safe limit generates high forces against the body [37, 38]Holt et al., 2003; Hutton et al., 2003).The main advantage of the model is that it is backpack carrier specific, with the anthropometric data of the carrier known, the safe backpack mass could be determined. The main limitation of this study is the number of participants as the sample size was relatively small due to the convenient sampling technique employed. Also, only the male students were used in the study.

IV. CONCLUSIONS

This study was conducted to propose a model using strain energy principles to determine the maximum backpack mass limit for students in tertiary institutions. The study confirmed that the model is valid and showed that the maximum backpack load limit for students in tertiary institutions should be 12% of body mass. This current study has added to the studies on the use of backpacks for use of students. Similar studies are recommended for pupils in primary and students in secondary schools to determine their backpack load limits.

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