Determination of Safe Mass of Backpack for Students in Tertiary Institutions

Salami O. Ismaila
Department of Mechanical Engineering
Federal University of Agriculture
P. M. B 2440, Abeokuta, Ogun State, Nigeria

Kolawole T. Oriolowo
Department of Mechanical Engineering,
The Polytechnic, Ibadan, Oyo State, Nigeria

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, and 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, \( A = \frac{\pi \times l_1 \times l_2}{4} \) [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/m² [24] and a factor of safety of 1.25
[25] was adopted. Therefore, \(E = 5.6\) MN/m²

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

\[
Froude\ number = 0.25 = \frac{u^2}{g \times l} \tag{27}
\]

Where \(u = \) velocity of movement, \(g = 9.81\) m/s² 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 length of
length of the spine from the first thoracic to the last lumbar
vertebrae of the trunk \((L)\), chest breadth \((lf)\) and chest depth
\((ls)\).

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, \(SE = \frac{F_x x}{2} \tag{30} \)

where \(F_x = \) Load on the spine

\(x = \) spinal shrinkage

Kinetic Energy, K.E. = ½ \(mu^2\) \tag{2}

Potential Energy, P.E. = \(mg \times SH\) \tag{3}

Where \(SH = \) Shoulder Height of the backpack carrier, \(m = \) Length of spine less that of cervical, \(L \times \) Leg
length

\(m = \) mass of backpack, kg

\(u = \) velocity of movement of the backpack carrier

The spring constant, \(k\), is given by:

\[
k = \frac{F_x}{x} = AE/L \tag{4}
\]

Combining equations \(1\) and \(4\) we have

\[
SE = \frac{AEx^2}{2L} \tag{5}
\]

From energy conservation principle

\[
SE = PE + SE \tag{6}
\]

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,

\[
SE_T = SE_b + SE_c \tag{7}
\]

where,

\[
SE_T = \text{Strain energy due to upper body weight and weight of lift}
\]

\[
SE_b = \text{Strain energy due to upper body weight}
\]

\[
SE_c = \text{Strain energy due to backpack carrying}
\]

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

Hence,

\[
SE_T = PE_T + KE_T \tag{8}
\]

From equations \(2\) and \(3\)

\[
KE_T = M_Tu^2/2 \tag{9}
\]

\[
PE_T = M_Tg(SH) \tag{10}
\]

Where

\(M_T = M_0 + M_b\)

\(M_0 = \) weight of backpack

\(M_b = \) weight of upper body

\[
SE_T = M_Tg(SH) + M_Tu^2/2 \tag{11}
\]

Similarly,

\[
SE_b = M_bg(SH) + M_bu^2/2 \tag{12}
\]

But,

\[
SE_b = SE_T - SE_c \tag{13}
\]

Therefore,

\[
SE_c = (M_0 + M_b)g(SH) + (M_0 + M_b)u^2/2 - [M_bg(SH) + M_bu^2/2]
\]

\[= M_bg(SH) + M_bu^2/2 + M_0u^2/2 - M_bu^2/2 \tag{14}\]

\[= M_bg(SH) + 1/2M_bu^2 \]

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

\[
AEX^2/2L = M_bg(SH) + 1/2M_bu^2 \tag{15}
\]
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 about 12% (11.87%) of body mass. This current study has added to the model is valid and showed that the maximum backpack load 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.

### REFERENCES


BIOGRAFY

Salami O. Ismaila is a Senior Lecturer in the Department of Mechanical Engineering, Federal University of Agriculture, Abeokuta, Nigeria. He received BSc. Degree in Mechanical Engineering from Obafemi Awolowo University, Ile Ife, Osun State, Nigeria in 1990; MSc. and Ph.D. in Industrial Engineering from University of Ibadan, Ibadan, Nigeria in 2000 and 2006 respectively. His research interests are Ergonomics, Human Factors and Safety. He has published up to 50 articles in highly referred journals and conference proceedings. He is reviewer of several international journals. He was nominated to be a Session Chair at the International Conference on Industrial Engineering and Operations Management (IEOM), Istanbul, Turkey, July 3-6, 2012. He is a member of Nigerian Society of Engineers, Nigerian Institute of Industrial Engineers, Nigerian Institution of Mechanical Engineers and a Registered Engineer with Council for the Regulation of Engineering in Nigeria.

Kolawole T. Oriolowo is a Lecturer in the Department of Mechanical Engineering, The Polytechnic, Ibadan, Nigeria. He received BSc. and MSc. Degrees in Industrial Engineering from from University of Ibadan, Ibadan. He is currently a Ph.D. student in the department of Industrial and Production Engineering, University of Ibadan, Ibadan, Nigeria. His research interests are Ergonomics, Human Factors and Safety. He is a member of Nigerian Society of Engineers a Registered Engineer with Council for the Regulation of Engineering in Nigeria.