

Safe Backpack Mass 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, 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

1. 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 (Brackley et al., 2009). 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 (Negrini and Carabalona, 2002; Sheir-Neiss et al., 2003). Heavy backpack loads may cause musculoskeletal pain (Iyer, 2001) changes in cervical and shoulder posture (Chansirinukor et al., 2001) and increased stress on spinal structures (Vacheron et al., 1999).

Many reasons have been stated for the relationship between use of backpack and musculoskeletal disorders. Such reasons include incorrect use of backpack (Goodgold and Nielsen, 2003), mass of backpack (Puckree et al., 2004; Siambanes et al., 2004), length of period of backpack carriage (Trevelyan and Legg, 2006) and placement of the backpack (Frank et al., 2003).

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 (Mackenzie et al., 2003). 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 (Chow et al., 2005; Bauer and Freivalds, 2009), another (Hong and Cheung, 2003) proposed 15 % of body mass. Brackley and Stevenson (2004) recommended that backpacks weight should be between 10–15% of a child's body mass. Mackenzie et al. (2003) established a relationship between back pain and backpack load exceeding 15% to 20% of body mass. Backpack limit may not be a function of weight only but other anthropometric data may be necessary. Ismaila and Charles-Owaba (2012) used the strain energy principles at the spine 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 safe backpack mass limit that

students should carry to be safe with due consideration of their anthropometric characteristics using strain energy principles at the spine of Ismaila and Charles-Owaba (2012).

2. Methodology

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 (Nussbaum et al., 1999; Mc Gill, 1997)
2. Each of the endplate of the spine consists of hyaline and fibro cartilage (Cenar, 2007) and may be modeled as an isotonic elastic material (Joshi, 2004).
3. An Elliptical truncal cross sectional area of the human subject is assumed (Glickman, 1998)

$$\text{Elliptical Truncal Area, } A = \frac{\pi \times l_f \times l_s}{4} \quad (\text{Marshek, 1987}).$$

where l_f is the chest breadth measured across the chest at the nipple; l_s 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 (Fick and Espino, 2011) and a factor of safety of 1.25 (Shigley and Mischke, 2001) was adopted. Therefore, $E = 5.6 \text{ MN/m}^2$

5. The strain energy at the spine is the sum of the potential energy and kinetic energy of the load being lifted (Leskinen et al., 1983)

6. The normal walking of the backpack carrier occurs when Froude number $= 0.25 = \frac{u^2}{g \times l}$ (Leurs et al., 2011)

Where u = velocity of movement, $g = 9.81 \text{ m/s}^2$ and l = leg length

7. The Leg length, $l = 0.53 \times \text{Height of the backpack carrier}$ (Roebuck et al., 1975)

8. The maximum permissible spinal shrinkage, $x = 0.021 \text{ m}$ (Ismaila and Charles-Owaba, 2008)

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)

$$\text{Strain Energy, } SE = \frac{Fx}{2} \quad (\text{Ryder, 1969}) \quad (1)$$

where $F = \text{Load on the spine}$

$x = \text{spinal shrinkage}$

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

$$\text{Potential Energy, P.E.} = mg (SH) \quad (3)$$

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:

$$k = F/x = AE/L \quad (\text{Marshek, 1987}) \quad (4)$$

Combining equations (1) and (4) we have

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

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 backpack

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,

$$\begin{aligned} SE_c &= (M_o + M_b)g(SH) + (M_o + M_b)u^2/2 - [M_b g(SH) + M_b u^2/2] \\ &= M_o g(SH) + M_b g(SH) + M u^2/2 + M_b u^2/2 - M_b g(SH) - M_b u^2/2 \\ &= M_o g(SH) + M u^2/2 \end{aligned} \quad (14)$$

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

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

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

Substituting for $u^2 = 0.25 \times g \times l$; $A = \frac{\pi \times l_f \times l_s}{4}$; $SH = L + 0.53 \times H$ and $g = 9.81$

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

Model Application

Ten students from a Federal university participated in the study. 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 safe backpack mass to be carried by the students.

3. Results and Discussion

Table 1 shows the anthropometric data of the students and the obtained values of the measured backpack mass and the estimated percentage of body weight (safe backpack mass) for the 5th, 50th and 95th percentiles.

Table 1: 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)	Determined Mass of backpack (kg)	Percentage of body mass (%)
5 th	18.9	54.5	1.63	0.16	0.23	5.23	8.29
50 th	23.5	59.0	1.73	0.18	0.25	5.86	9.72
95 th	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.

This is in agreement with the work of (Brackley and Stevenson, 2004) 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 (Hong and Brueggemann, 2000; Mackie et al. 2005; Steele et al., 2003). However, Simpson et al. (2011) 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 (Chow et al., 2005; Bauer and Freivalds, 2009; Hong and Brueggemann, 2000; Hong et al., 2000) that proposed a backpack load limit of 10% of body mass. Carrying heavier backpack than the safe limit generates high forces against the body (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.

4. 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.

References

Bauer, D. H., Freivalds, A., Backpack load limit recommendation for middle school students based on physiological and psychophysical measurements, *Work*, vol. 32, pp. 339–350, 2009.

- Brackley, H. M., Stevenson, J. M. Stevenson, Selinger J. C., Effect of backpack load placement on posture and spinal curvature in prepubescent children, *Work*, vol. 32, pp. 351-360, 2009.
- Brackley, H. M., Stevenson, J. M., Are Children's Backpack Weight Limits Enough? A critical review of the relevant literature, *Spine*, vol. 29, pp. 2184-2190, 2004.
- Cenar, Y., Mechanical Characterization of a Simple Gel in a Prototype Device that models a Degenerative Intervetral Disc, *Msc Thesis of Oregon State University*, United States, 2007.
- Chansirinukor, W., Wilson, D., Grimmer, K., Dansie, B., Effects of backpacks on students: Measurement of cervical and shoulder posture, *Australian Journal Physiotherapy*, vol. 47, pp. 110-116, 2001.
- Chow, D. H. K., Kwok, M. L. Y., Au-Yang, A. C. K., Holmes, A. D., Cheng, J. C. Y., Yao, F. Y. D., Wong, M. S., The effect of backpack load on the gait of normal adolescent girls, *Ergonomics*, vol. 48, no. 6, pp. 642-656, 2005.
- Fick, M. J., Espino, M. D., Articular cartilage surface rupture during compression: Investigating the effects of tissue hydration in relation to matrix health, *Journal of the Mechanical Behavior of Biomedical Materials*, vol. 4, pp. 1311-1317, 2011.
- Frank, E., Stevenson, J. M., Stothart, P., *The Effect of Load Placement on Static Posture and Reaction Forces in Youth*, 2003, S21.
- Glickman, J., The NASI Report: Toward a Resolution of the Bigfoot Phenomenon from <http://www.bigfootencounters.com/biology/nasi.htm>. Accessed on 6/2/09, 1998.
- Goodgold, S. A., Nielsen, D., Effectiveness of a school-based backpack health promotion program: Backpack intelligence. *Work*, vol. 21, pp. 113-123, 2003.
- Holt, K. G., Wagenaar, R. C., LaFiandra, M. E., Kubo, M., Obusek, J. P., Increased musculoskeletal stiffness during load carriage at increasing walking speeds maintains constant vertical excursion of the body center of mass. *Journal of Biomechanics*, vol. 36, no. 4, pp. 465-471, 2003.
- Hong, Y., Brueggemann, G., Changes in gait patterns in 10-year old boys with increasing loads when walking on a treadmill, *Gait & Posture*, vol. 11, pp. 254-59, 2000.
- Hong, Y., Cheung, C., Gait and posture responses to backpack load during level walking in children, *Gait & Posture*, vol. 17, pp. 28-33, 2003.
- Hong, Y., Li, J. X., Wong, A. S. K., Robinson, P. D., Effects of load carriage on heart rate, blood pressure and energy expenditure in children, *Ergonomics*, vol. 43, no. 6, pp. 717-727, 2000.
- Hutton, W. C., Malko, J. A., Fajman, W. A. (2003). Lumbar disc volume measured by MRI: effects of bed rest, horizontal exercise, and vertical loading. *Aviation Space and Environmental Medicine*, vol. 74, no. 1, pp. 73-78, 2003.
- Ismaila, S. O., Charles-Owaba, O. E., A quantitative approach for establishing safe weight of lift, *Engineering Review*, vol. 32, no. 1, pp. 1-8, 2012.
- Ismaila, S. O., Charles-Owaba, O. E., Determination of The Highest Permissible Spinal Shrinkage, *Australian Journal of Basic and Applied Sciences*, vol. 2, no. 4, pp. 872 - 875, 2008.
- Iyer, S. R., An ergonomic study of chronic musculoskeletal pain in Schoolchildren. *Indian Journal of Pediatrics*, vol. 68, no.10, pp. 937-941, 2001.
- Joshi, A. B., Mechanical Behaviour of the Human Lumbar Inter vertebral disc with Polymeric Hydrogel Nucleus Implant: An Experimental and Finite Element Study, *An Unpublished Dissertation Submitted to Drexel University*, 2004.
- Leskinen, T. P. J., Stalhammer, H. R., Kuorinka, I. A. A., Troup, J. D. G. The effect of inertial factors on spinal stress when lifting, *Engineering in Medicine*, vol. 12, pp. 87-89, 1983.
- Leurs, F., Ivanenko, Y. P., Bengoetxea1, A., Cebolla, A., Dan, B., Lacquaniti, F., Cheron, G. A., Optimal walking speed following changes in limb geometry, *The Journal of Experimental Biology*, vol. 214, pp. 2276-2282, 2011.
- Mackenzie, W. G., Sampath, J. S., Kruse, R. W., Sheir-Neiss, G. J., Backpacks in Children, *Clinical Orthopaedics and Related Research*, vol. 409, pp. 78-84, 2003.
- Mackie, H. W., Stevenson, J. M., Reid, S. A., Legg, S. J., The effect of simulated school load carriage configurations on shoulder strap tension forces and shoulder interface pressure, *Applied Ergonomics*, vol. 36, pp. 199-206, 2005.
- Marshek, M. K., *Design of Machine and structural parts*, John Wiley and Sons Inc. New York, 1987.
- Mc Gill, S. M., The biomechanics of low back injury: implications on current practise in industry and the clinic, *Journal of Biomechanics*, vol. 30, pp. 465-475, 1997.
- Negrini, S., Carabalona, R., Backpacks on! Schoolchildren's perceptions of load, associations with back pain and factors determining the load. *Spine*, vol. 27, pp. 187-195, 2002.
- Nussbaum, M. A., Chaffin, D. B., Baker, G., Biomechanical analysis of materials handling manipulators in short distance strength, spine forces and muscular antagonism, *Ergonomics*, vol. 42, no. 12, pp. 1597-1618, 1999.
- Puckree, T., Silal, S. P., Lin, J., School bag carriage and pain in school children. *Disability and Rehabilitation*, vol. 26, no.1, pp. 54-59, 2004.

- Roebuck, J. A., Kroemer, K. H. E., Thomson, W. G., *Engineering anthropometry methods*, New York: Wiley Intersciences, 1975.
- Ryder, G. H., *Strength of materials*, Macmillan Publishers Ltd. London. Safety and Health, Cincinnati, OH. 1969.
- Sheir-Neiss, G. I., Kruse, R. W., Rahman, T., Jacobson, L. P., Pelli, J. A., The association of backpack use and back pain in adolescents. *Spine*, vol. 28, pp. 922-930, 2003.
- Shigley, E. J., Mischke, R. C., *Mechanical Engineering Design*, 6th Edition, Tata McGraw Hill: New Delhi, 2001.
- Siambanes, D., Martinez, J. W., Butler, E.W., Haider, T., Influence of school backpacks on adolescent back pain *Journal of Pediatric Orthopedic*, vol. 24, no. 2, 211–217, 2004.
- Simpson, K. M., Munro, B., Steele, J. J. R., Effect of load mass on posture, heart rate and subjective responses of recreational female hikers to prolonged load carriage, *Applied Ergonomics*, vol. 42, pp. 403-410, 2011.
- Steele, E., Bialocerkowski, A., Grimmer, K., The postural effects of load carriage on young people - a systematic review, *BMC Musculoskeletal Disorders*, vol. 4, no. 1, pp. 12-17, 2003.
- Trevelyan, F. C., Legg, S. J., Back pain in school children – Where to go from here?, *Applied Ergonomics*, vol. 37, pp. 45– 54, 2006.
- Vacheron, J. J., Poumarat, G., Chandezon, R., Venneville, G., Changes of contour of the spine caused by load carrying, *Surgical Radiology Anatomy*, Vol. 21, pp. 109–113, 1999.

Biography

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