# DETERMINATION OF BACKPACK MASS LIMIT FOR STUDENTS IN A UNIVERSITY IN ABEOKUTA, SOUTHWESTERN NIGERIA

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**Abstract:** The aim of this study was to use the Froude number to determine the mass of the backpack that a student should carry in tertiary institutions. A model was developed using the Froude number with leg length and power of the students as inputs. It was established that a student in tertiary institutions should carry a backpack with a mass of at most 10 % of the body mass. Similar studies are recommended for primary and secondary schools.

**Keywords:** Froude number, body mass, power, bag

## 1. INTRODUCTION

Carrying load is common to students, adolescents and adults for daily transfer of belongings, books, stationery and laptops to and from workplaces or schools. Across the use of backpacks, shoulder bags or briefcases, the most common method of load carriage is the use of backpacks [1]. Backpack uses for carrying books and other school materials are common practices among school students in primary schools, secondary schools and tertiary institutions in Nigeria as well as in developed nations [2]. In the United States of America, for instance, over 40 million students use the backpack [3]. Increase risk of musculoskeletal disorders in the lower and upper parts of the body in working and recreational populations has been associated with load carriage [4]. A study, however, found no association of backpack loading and back pain [5]. Heavy backpack carriage may cause musculoskeletal pain [6], changes in cervical and shoulder posture [7] and increased stress on spinal structures [8]. They stated that the factors responsible for these problems were: the combined effects of weight of backpack; position of the load on the body; size and shape of the load; load distribution; time spent carrying; physical characteristics and physical condition of the individuals. Many reasons have been stated for the relationship between the use of backpack and musculoskeletal disorders. Such reasons include: incorrect use of backpack [3], mass of backpack [3], length of period of backpack carriage [9] and placement of the backpack [10]. Jayaratne *et al.* [11] noted that, though the use of the backpack is the healthiest way of load carriage for school children, the global evidence showed that daily load carried by school children may have negative health implications for them.

The health effects of carrying heavy backpacks necessitated the attention given to the determination of the mass limit of backpack in the literature. Research findings showed that school-aged children carried heavy backpacks that were uncomfortable and as such, the incidences of back problems in school-aged children were high [12]. Simpson *et al.* [13] stated that carrying a load of 20 % the body mass induced significant changes in trunk posture, Ratings of Perceived Exertion (RPE) and reported shoulder discomfort compared to the unloaded condition. Some studies presented evidence to support `backpack load limits for children, but there were discrepancies in the suggested limits [14]. While some researchers proposed 10 % of the body mass [14, 15], another [16] recommended that the mass of the backpack should be between 10 and 15 % of a child's body mass. Devroey *et al*. [17] suggested that carrying loads of more than 10 % of the body mass should be avoided because they induced significant changes in the electromyography, kinematics and subjective scores. Dockrell *et al.* [18]

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reviewed the existing literature on school bag weight limit and found that the recommended load limit for school children to carry varied from 5 % to 20 % of their body weight.

Previous studies focused on a selection of either physiological [19], biomechanical parameters including electromyography (EMG) [20], posture evaluation [21], heart rate [22] and subjective ratings [22, 23] to determine an acceptable mass limit of a backpack. In another research, EMG; heart rate; Borg's RPE and perception of pain; and trunk flexion angle have all been combined to determine an acceptable backpack mass limit [14].

The Froude number is a (dimensionless) ratio of inertial to gravitational force which is used to explain the human locomotion [24]. In the inverted-pendulum model of walking [25], the exchange of kinetic energy and gravitational potential energy ensures the conservation of mechanical energy by allowing forward motion to raise the center of mass and reduce muscular work [26]. The exchange can be limited by the amount of kinetic energy available to be converted into gravitational potential energy. The ratio of these energies also reduces to the dimensionless Froude number, which may link mechanical and metabolic energy-saving aspects of the inverted pendulum mechanism across the walk to-run transition [26].

The Froude number has been used to predict the biomechanics of human movement over a distance using the body mass, gravity and speed [27]. Donelan and Kram [27] conducted a study on the effect of reduced gravity on walking kinematics and found that there were modest changes in response to the fourfold change in gravity, which confirmed that factors other than gravitational forces were the primary determinants of walking biomechanics. Moreover, Steudel-Numbers and Weaver [28] found that the cost of transport at experimentally measured optimal walking speed and Froude number were not equal across individuals, but retained a significant correlation with body mass. This study involves the development and evaluation of a new model using the Froude number in the determination of the maximum backpack mass a student in tertiary institutions should carry.

## 2. METHODOLOGY

### 2.1. Development of Model

The Froude number was employed in the study and is given by [28]:

$$F_r = \frac{Centripetal\ force}{Gravity\ force} = \frac{m \cdot v^2}{m \cdot g \cdot l} = \frac{v^2}{g \cdot l} \quad (1)$$

Where, $v$ is the velocity of walking, $g$ (9.81 $m/s^2$) is the acceleration due to gravity and $r$ (radius of curvature) has been replaced by l, the characteristic length (in this case, leg length).

The theoretical maximal walking speed occurs at a Froude number of 1.0 and bipedal animals naturally switch from a walk to a run at Froude numbers well below one [24]. It has been found that humans change from walk to run at a Froude number close to 0.5 [29]. Both children and adults have optimal walking speeds that correspond to the same Froude number of 0.25 [30] when the recovery of energy due to the pendulum mechanism is maximal, and the metabolic cost is minimal [31].

The students in the selected institutions walked very fast to be in the classroom before the lecturers and some classrooms are far from one another, therefore the transitional Froude number of 0.5 from walking to running was used in this study.

Values between 75 W and 200 W were regarded as adequate and were used in this study.

### 2.2. Development of Model

(i) For walking, = 0.50
(ii) Velocity of walking is same as the velocity at which the backpack moves.
(iii) While maximum power for intermittent uses for a young and healthy person might go up to 200W [32], for continuous power generation a workload of about 75 W would be reasonable for a young and healthy person

[33]. The following established relationship by Weyand *et al*. [34] while walking was used to obtain the energy required:

$$E_{trans} = 3.80 \times M_b \times L_b^{-0.95} \qquad (2)$$

where $E_{trans}$ is the energy required per meter length in J/m$^{-1}$, $M_b$ (body mass) in kg, and $L_b$ (body height) in m.

(iv)The leg lengths of the students were determined using the relationship established by Roebuck *et al*. [35] as follows:

$$\text{Leg length (cm)} = 0.53^{*} \text{ standing height (cm)} \qquad (3)$$

$$F_r = 0.50 = \frac{v^2}{gl} \qquad (4)$$

$$v = \sqrt{0.50 \times g \times l} \qquad (5)$$

$$\text{Power} = (\text{Force x distance}) \div \text{Time} = \text{Force x Velocity} = \text{F.}\ v \qquad (6)$$

$$\text{But, Force} = \text{mass} (m) \text{ x acceleration due to gravity (g)} = m \times g \qquad (7)$$

Assuming the only force acting is the gravitational force,

$$\text{Power (P) required to carry the backpack} = m \times g \times v \qquad (8)$$

Where $m$ is the mass of the backpack

$$m = \frac{P}{v \times g} \qquad (9)$$

Combining equations 4 and 8,

$$m = \frac{P}{\sqrt{0.50 \times g^3 \times l}} \qquad (10)$$

**2.3. Application of the Model**

Seventy-four (74) students of a Federal University in Nigeria were recruited for the study using the convenience sampling method. The students were without musculoskeletal disorder and history of spinal or shoulder injuries. Seventeen of the volunteers were females while the rests were males. Their ages were between 17 to 27 years (SD = ± 2.19 years) for males and 16 to 24 years (SD = ± 2.18 years) for females. The procedure of the experiment was explained to all participants and they gave their consent before the experiment. There was no ethics panel or Institutional Review Board when the study was conducted, which gave the study an exempt status for its conduct.

The weights of the participants, their heights and their backpacks were measured separately using weighing-stadiometer machine floor type, model-Health Scale ZT-160, Micro field, England. Students were asked to walk without backpacks for 30 minutes each [36], after which their heart rates (resting heart rates) were measured. They were asked to sit down quietly for five minutes before they carried backpacks (two-strap backpack) for 30 minutes each, after which their heart rates (working heart rates) were measured.

The Heart Rates (HR) of each participant before and after carrying backpacks were measured with the use of a digital sphygmomanometer (POLYGON YS796). Three replications of the dimensions were taken and the averages were used in the application of the model. The leg lengths were determined using the relationship between standing height and leg length provided by Roebuck *et al*. [35] as follows:

$$\text{Leg length (cm)} = 0.5*(\text{Standing height}) \tag{11}$$

The data obtained was analyzed using the SPSS 16.0 statistical package to obtain descriptive statistics and t-tests.

## 3. RESULTS AND DISCUSSION

The minimum values, maximum values, standard deviations, $5^{th}$, $50^{th}$ and $95^{th}$ percentiles of the anthropometric data obtained from the study for the female students, male students and for all students are presented in Table 1. Table 2 presents the power of the students, measured mass of the backpack and expected mass of the backpack obtained using the developed model.

There were significant differences between the ages of the male and female participants at the 5 % level of significance (p = 0.000, t = 4.614), their body heights (p = 0.007, t = 3.166), leg lengths (p = 0.007, t = 3.178), model estimated masses of the backpack (p = 0.010, t = -3.026). However, there were no significant differences between the body masses of the males and females (p = 0.371, t = 0.926); heart rates carrying backpacks, $H_W$ (p = 0.742, t = 0.337); resting heart rates, $H_R$ (p = 0.140, t = -1.574) and measured mass of the backpack (p = 0.107, t = 1.731).

There were significant differences between the values of heart rates of students that carried backpack and those that did not (p = 0.000, t = 14.312). Moreover, there were significant differences between the estimated masses of backpacks and the ones actually carried by the students both in terms of masses and percentages of body masses (p = 0.000, t = 8.514).

The students under study carried backpack of between 1 and 14 kg, which represented between 1.7 and 26.9 % of the body mass. On average, male students carried backpack of 7.5 % of their body masses while the female students carried 8.2 % of their body masses.

The calculated power of the individual has a value ranging from 106.5 Watts to 179.9 Watts as indicated by the $5^{th}$ and $95^{th}$ percentiles with the average power of the individual being 138.5 Watts as shown by the $50^{th}$ percentile (Table 2). The model estimated backpack mass that the students should carry has a value ranging from 5 kg (10% of the body mass) to 9.1 kg (13.7 % of the body mass) as indicated by the $5^{th}$ and $95^{th}$ percentiles respectively.

The 'safe' backpack mass should be the mass that virtually all students should be able to carry; therefore the $5^{th}$ percentile would be appropriate. In fact, Dianat *et al*. [37] advised that recommendation of backpack mass limit should be based on the lower percentile of the sample population. The current study, therefore proposed that students should carry a backpack of at most 6 kg, which is equivalent to 10 % of the body mass as represented by the $5^{th}$ percentile (Table 2). The developed model is carrier-specific as the carrier's body mass, body height and leg length are the anthropometric dimensions required to obtain the mass to be carried.

The model suggests that given the same power, a shorter person should carry a heavier backpack.

The heart rates increased for all participants due to backpack carriage and significant changes were recorded. This Compared to that of a taller person since the leg length is inversely proportional to the mass of the backpack. The heart rates increased for all participants due to backpack carriage and significant changes were recorded. This is in agreement with an earlier study [14] that established significant increase in heart rates when backpacks were carried walking than when participants walked unloaded. However, this observation is not consistent with the study of Bauer and Freivalds [14].

In the present study, the students carried a backpack, which was a maximum of 26.9 % of their body mass with females carrying heavier backpacks than males, which support the finding of Forjuoh [38], that females carry heavier backpacks than the males when expressed as a percentage of body mass. The 10 % of the body mass proposed in this study is in agreement with the conclusion of some studies [14, 15, 17] that recommended that backpacks should weigh at most 15 % of a child's body weight. Simon and Chow [39] using a multi-objective goal programming model recommended that the most critical backpack load should be 13 % of body weight for healthy male college students. Phonpichit et al. [40] conducted a study on the body's response to carrying a hand bag and concluded that carrying a handbag greater than 10 % BW continuously can cause musculoskeletal problems.

Table 1. Anthropometric dimensions from the study.

| Gender | Number of Participants | Statistics | Age (Years) | Height (cm) | Body Mass of participants (Kg) | BMI (kg/m$^2$) | Leg length (cm) | $H_W$ (BPM) | $H_R$ (BPM) |
|---|---|---|---|---|---|---|---|---|---|
| Male | 57 | Minimum | 17 | 153 | 49 | 15.1 | 74.4 | 63 | 53 |
| | | Maximum | 27 | 188 | 81 | 28.6 | 102.5 | 112 | 96 |
| | | 5th percentile | 18 | 163.7 | 52 | 17.4 | 83 | 69.9 | 64 |
| | | 50th percentile | 22 | 172 | 60 | 19.7 | 89.7 | 85 | 77.5 |
| | | 95th percentile | 25 | 182.2 | 78.1 | 27.2 | 97.8 | 106.2 | 93 |
| | | Standard deviation | 2.2 | 6.6 | 7.0 | 2.5 | 5.3 | 11.4 | 9.0 |
| Female | 17 | Minimum | 16 | 152 | 46 | 17.3 | 73.6 | 66 | 59 |
| | | Maximum | 24 | 173 | 76 | 25.7 | 90.5 | 109 | 99 |
| | | 5th percentile | 16 | 152.7 | 47.3 | 18.9 | 74.1 | 70.6 | 59.7 |
| | | 50th percentile | 19 | 162.5 | 58 | 21.9 | 82 | 89 | 82 |
| | | 95th percentile | 23.2 | 172.4 | 68.5 | 24.4 | 90 | 105.8 | 97.1 |
| | | Standard deviation | 2.2 | 7.6 | 8.0 | 2.0 | 6.1 | 11.8 | 12.5 |
| Total | 74 | Minimum | 16 | 152 | 46 | 15.1 | 73.6 | 63 | 53 |
| | | Maximum | 27 | 188 | 81 | 28.6 | 102.5 | 112 | 99 |
| | | 5th percentile | 18 | 155 | 49.8 | 17.8 | 76 | 69.3 | 62 |
| | | 50th percentile | 22 | 171 | 60 | 21.2 | 88.9 | 86 | 78.5 |
| | | 95th percentile | 25 | 180.7 | 77 | 26.3 | 96.7 | 107.1 | 93.7 |
| | | Standard deviation | 2.4 | 7.5 | 7.3 | 2.9 | 6.1 | 11.4 | 9.7 |

Table 2. Comparison between the values obtained using the model and the measured values.

| Gender | Number of Participants | Statistics | Power (W) | Mass of backpack from model (kg) | Mass of backpack from model as percentage of body mass (%) | Mass of backpack carried (kg) | Mass of backpack carried as percentage of body mass (%) |
|---|---|---|---|---|---|---|---|
| Male | 57 | Minimum | 106.5 | 5.0 | 9.5 | 1 | 1.7 |
| | | Maximum | 179.9 | 9.1 | 13.6 | 14 | 26.9 |
| | | 5th percentile | 122.6 | 6.0 | 10.0 | 2 | 3.2 |
| | | 50th percentile | 138.3 | 6.7 | 11.0 | 5 | 7.5 |
| | | 95th percentile | 170.6 | 8.6 | 12.0 | 8 | 13.3 |
| | | Standard deviation | 15.0 | 0.8 | 0.8 | 2.3 | 4.0 |
| Female | 17 | Minimum | 109.9 | 5.6 | 10.9 | 2 | 3.7 |
| | | Maximum | 172.5 | 8.4 | 13.7 | 7 | 10.9 |
| | | 5th percentile | 118.1 | 6.1 | 11.0 | 2 | 3.8 |
| | | 50th percentile | 140.1 | 7.1 | 12.2 | 5 | 8.2 |
| | | 95th percentile | 156.1 | 7.8 | 13.6 | 6.4 | 10.6 |
| | | Standard deviation | 14.9 | 0.7 | 1.0 | 1.8 | 2.6 |
| Total | 74 | Minimum | 106.5 | 5.0 | 9.5 | 1 | 1.7 |
| | | Maximum | 179.9 | 9.1 | 13.7 | 14 | 26.9 |
| | | 5th percentile | 121.3 | 6.0 | 10.0 | 2 | 3.3 |
| | | 50th percentile | 138.5 | 6.8 | 11.1 | 5 | 7.7 |
| | | 95th percentile | 170.9 | 8.4 | 13.2 | 8 | 12.5 |
| | | Standard deviation | 14.9 | 0.8 | 0.9 | 2.2 | 3.7 |

However, there are some limitations on the results obtained from this study. Firstly, there is no systematic study across different backpack masses which may confirm the predictability of the model. Secondly, the power required to carry the backpack was estimated using the expression obtained by Weyand *et al.* [34], which itself may contain some errors. Thirdly, the leg lengths of the students were determined from the expression developed by Roebuck *et al*. [35] which may also introduce some errors. Finally, the number of students used in the study may not be the actual representation of all students in Abeokuta. However, since the anthropometric data of the students are employed in the model, it is possible for individuals to determine the actual backpack mass that he/she should carry by incorporating the required anthropometric dimensions in the model.

## 4. CONCLUSIONS

This study was conducted to propose a model using the Froude number to determine the backpack mass limit of students in tertiary institutions. It was established that a student in tertiary institutions should carry a backpack with a mass of at most 10 % of the body mass. This is a novel approach and there is sufficient evidence to undertake a more controlled study with customized anthropometric data of students in tertiary institutions. After which similar studies may be recommended for pupils in the primary and students in secondary schools to determine the backpack mass limits.

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