Independent project (degree project), 15 credits, for the degree of Bachelor of Computer Science and Engineering
Spring Semester 2018

Improve Improper Load Distribution with Backpack

Xiao Su
Qinqing Chen

School of Health and Society or School of Education and Environment

Högskolan Kristianstad | www.hkr.se

Författare/Author
Qinqing Chen
Xiao Su

Titel/Title
Improve Improper Load Distribution with Backpack

Handledare/Supervisor
Mengistu Dawit

Examinator/Examiner
Fredrik Frisk

Sammanfattning/Abstract
This article focuses on the distribution of backpack pressure on human body. We have noticed two interesting situations: whether the length of different backpack shoulder straps will change the pressure distribution of the backpack on the human body and whether different positions of the backpack load will change the pressure distribution of the backpack on the human body. To find the answer, we designed a backpack pressure detection system to collect data and use engineering software to analyse the data. We got the range that best fits the human body and the healthiest backpack: when the distance from the top of the backpack to the shoulder is about 1/5 of the length of the shoulder and the weight of the backpack is at the bottom of the backpack. At this time, the force of the three parts of the human body (shoulders, back) is the most uniform and relatively minimal. If the user wants to minimize the pressure on the shoulder, the shoulder strap of the backpack should be as short as possible. If the user only wants the pressure on the back to be minimal, the weight in the backpack is closer to the back, which is better for the back.

Ämnesord/Keywords
Backpack, Strap length, Load distribution, Load position, Back pain

Contents

1 Introduction

1.1 Background

Backpacks are widely used in people's lives, work, and tourism, especially for students who need to load books every day. According to the statistics report of the United States in 2013, 140 million backpacks were sold in the same year and consumers' love for backpacks continued. In 2013, unit sales of backpackers increased by 4.7% and the total amount increased by 16.5% [1]. According to the network information, the growth rate of sales of Chinese backpacks in 2017 has reached more than 150.82%. It can be seen the backpacks are widely popular all over the world and have increased year by year. [2]

Due to the large amounts of backpacks used, it can also cause some adverse effects. The shoulder joint is the most complex part of the human body and consists of three bones, four joints, and the muscles connecting them, tendons and ligaments [3]. Under normal circumstances, the four joints move synchronously to ensure smooth coordination of the upper limbs. However, due to improper use of the backpack, the imbalance of the shoulders may be unstable, and even the shoulder joints may be damaged.

The most serious problem is back pain. A study in Italy was published in the "Journal of Spine Science" published in June 2016 and involves 5,318 Italian students between the ages of 6 and 19. [4] According to a series of interviews and surveys, more than 60% of students reported discomfort related to backpacks, especially for backpacks and muscles and bones. The researchers found that the time and weight of the backpack had a negative impact on the back and pain. Inseparable links; The study also found that girls are more frequent and more severe than boys, especially adolescent girls are at greatest risk of pain.

According to our further investigation, we learned that there is a study conducted in a Brazilian national school, 610 (66.59%) were primary school students and 306 (33.41%) were high school students. Of these, 496 (54.15%) were women and 420 (45.85%) were men [4]. Ages range from 10 to 19 years old. The weight range is from 23.40 to 105.50 kg and the absolute weight of the backpack is from 1.20 kg to 12.90 kg. In this study, 224 people had more obvious symptoms of back and shoulder pain. There are 166 women and 58 men. And women are more prominent.

India has a lot of academic research on the impact of schoolbag weight on the body. One of the papers points out that the average daily load of students above primary school varies from 22% to 27.5% of body weight, and one student shoulders 46.2% of body weight. Of these, 38.8% of students carried 30% of their weight [6]. As the curriculum changes and extra-curricular activities increase, the average daily weight of the body weight will increase significantly. Students sometimes carry school materials, exercise equipment or computer at the same time. Throughout the school year, more than 2.5 million pupils carry schoolbags five days a week. [19]

In summary, it is important to understand the impact of backpack weight on children's development, and it is beneficial to physical, mental and factory production. Therefore, we need to carry out research on the pressure of backpacks, aiming at the problems, finding out the root causes, overcoming shortcomings, changing shortcomings, and implementing compensation so as to achieve better and more perfect application results.

1.2 Aim and Goal

In this project, our aim is to research how physical body problem can be constructed to help users correctly locate and use the backpack system to solve the pain problem.

Our goal is to create a smart backpack with a pressure sensor to collect the pressure of the backpack under different weight distributions and the effect of different backpack lengths on the pressure distribution. By collecting different experimental data under different conditions, these data are unified and used together, and MATLAB and other statistical programs are used to compare and classify the most suitable weights for backpack position and backpack shoulder strap length.

1.3 Motivation

Studies conducted earlier show estimates of the recommended weight of backpacks for different age groups [16] [17]. The findings of these studies are summarized in Chart1.

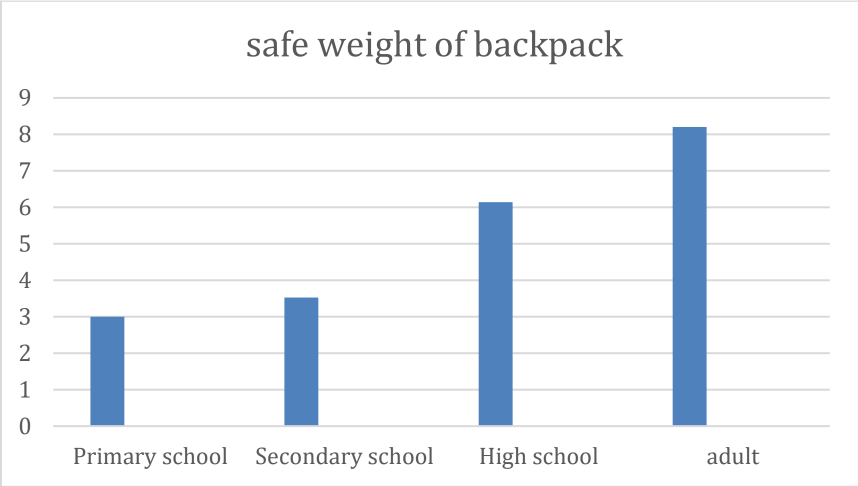


Chart.1 safe weight of backpack (kg)

But according to the survey condition of Education Bureau per year which almost everyone ignored the safety data and they exceeded the weight requirements. And for Asian countries, this situation is even more serious. In order learn better, they carry more than ten kilograms of schoolbags back and forth to school and home every day.

The weight of the backpack has a great impact on the body. In extreme cases, it may even cause serious diseases, such as rare new cases: Backpack palsy which was reported the case of a 15-year-old girl who presented with a left-side brachial palsy [6]. However, due to courses, work, etc., the weight of the backpack is difficult to reduce. Therefore, how to reduce the pressure on the shoulder and back of the school bag becomes an important and timely research topic in the case of the same weight. [7]

Here, we want to be able to measure changes in body pressure caused by heavy objects in the backpack at different locations and find out where to place the best load-bearing position for shoulder-to-shoulder pressure under the same weight.

At the same time, we believe that different shoulder strap positions result in different contact points between the backpack and the back, which can also cause pressure changes. It is hoped that the length of the shoulder strap can be found through research.

1.4 Limitations

In our project, we have many limitation factors that affect our experiment and result. The limited number of samples in the experiment did not cover all types of people. The accuracy of the experimental equipment will also affect the accuracy of the experiment.

We selected different samples to minimize errors. We also use different sensors to make sure the experimental data is reliable.

1.5 Problem identify

Researchers combine this with a variety of factors:

There are many hazards brought by backpacks. The most immediate danger is the shoulder-neck muscles. When carrying a backpack, the human body needs to perform a shoulder lift motion to resist the fall of the backpack, and the trapezius of the scapulae and the levator scapulae of the scapular shoulder (Fig.1) should be co-contracted together with the trapezius muscles being pressed. Overweight is prone to strain and pain. [5]

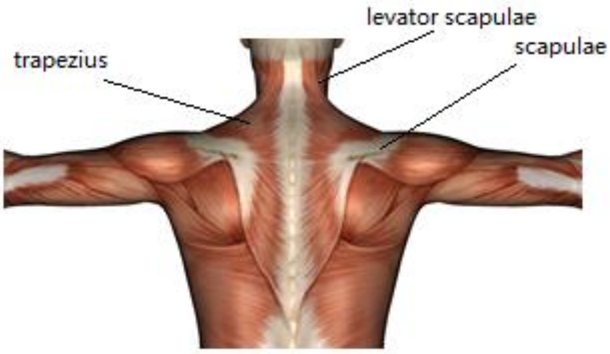


Fig.1 Human muscle structure

Such as humpback, scoliosis, spinal arthritis, etc. a series of diseases, may be caused by excessive backpacking. We can give an example: if your bag is normal weight (Here we take 5 kilogram) on your left shoulder. The muscles on the right side of the spine must produce 15-20 kilograms of force to maintain the balance of the body. This imbalance of muscular tissue force will cause the spine to bend, Causes strain and inflammation. [19]

When people use backpacks for a long time, they feel very painful in the shoulders and back. There's a sore (Fig.2), pulling feeling, and some people worry that their spine bends under the weight of the load. [11].

Fig.2 shoulder pain by backpack

In addition, the investigation of backpack disease is even more alarming. According to guidelines from the American Chiropractic Association (ACA) and the American Occupational Therapy Association (AOTA), students should carry no more than 10% of their body weight in a backpack [11]. But too much people ignoring this point, lead to serious consequences. The extra pressure placed on the spine and shoulders from the heavy loads is causing backpacks may cause disability later in life [12].

In addition to teenagers, adults also have these problems. The high prevalence of the university (85%) reported musculoskeletal discomfort and pain. 20% of participants reported physical exhaustion. A trend was also observed between musculoskeletal symptoms and the time of carrying the backpack (average asymptomatic subjects 2.3 hours, uncomfortable symptoms 3.4 hours, and pain subjects 4.8 hours) [14]. And for old people, they always wear a big backpack for travel, that's good for carrying important items. But these behave lead to too many old people suffers from cervical spondylosis, frozen shoulder, and herniated disc

The area called the shoulder includes two major bones – the Tibia or Upper arm bone, and the scapula, or shoulder blade. In addition, the clavicle or collarbone, is connected to the front part of the shoulder. All these bones Are held together and supported by tendons, ligaments and muscles. Four Muscles on the scapula also pass around the shoulder; their tendons join to create a structure called the rotator cuff. A backpack can put pressure on any of these structures and cause shoulder pain [13]. An overloaded backpack not only puts too much pressure on the shoulder, it disperses extra weight on the hip, knee and ankle. In addition, many people are hunchback because the spine was oppressed for a long time. They do not have enough power to stay upright under these very heavy loads. (Fig.3)

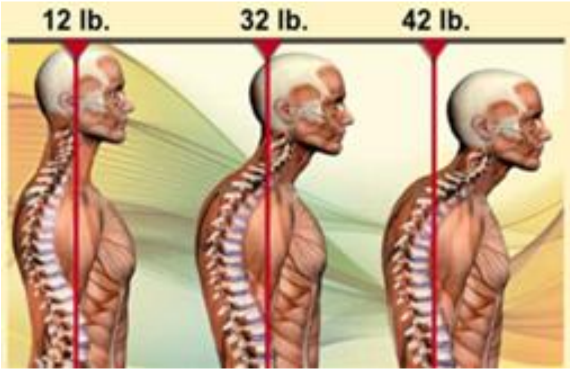


Fig.3 Heavy backpack affects the spine

1.6 Research Question

Research question 1:

What methods are used to detect that a human is using a backpack to turn on all sensors?

Research question 2:

What is the best backpack shoulder strap length for different people's shoulder?

Research question 3:

What kind of backpack position and weights position in the backpack is the best for human health?

2 Exploring the discussion (Methodology)

There are many backpacks on the market, which involve technical principles such as volume and force. If they are used correctly, they are of great benefit. If they are misused, they will have negative effects such as discomfort, soreness, disability and deformity. Therefore, it is necessary and meaningful for us to carry out multi-directional and multi-type pressure tests, find the best methods of use, and provide guidance.

2.1 Theoretical analysis Method

In the theoretical analysis, we mainly perform force balance analysis for three different conditions. That is, the first condition is when we only consider the shoulder force to analysis which backpack position (The length of backpack) is good for shoulder. The second condition is when we only consider the back force to analysis which object position in the backpack (There three position: “close to the back”, “bottom of the backpack” and “close to the outside”) is good for back. The third condition is to combine the results of the first two conditions. In order to analyze what is the position of backpack (shoulder strap length) and the position of object in the backpack is good for all part of body.

We will find the range of change of the position of the backpack and the object through the Cartesian coordinate system, and then obtain different right-angled triangles through this variation range, thereby obtaining different angles. After that, use these angles to obtain different force analysis and stress balance, and use theoretical methods to find the optimal range and relative relationship for each case.

2.2 Experiment Method

In our experiments, we used three FSR402 force sensors mounted on the back of the shoulder strap and backpack to detect pressure in three parts of the body and record data in real time. In the experiment, we conducted experiments on people with different physical characteristics. Each experimenter had to load from 0 grams to 20 kilograms to obtain force data from different parts of the body.

The experiment is divided into two big parts, the first part is to get the pressure data of the three parts of the body under the different shoulder strap length of the backpack. We set up three different shoulder strap lengths for experiments, namely "long", "short" and "standard". Among them, for the "long" shoulder strap, we set the distance from the top of the backpack to the horizontal line of the shoulder is single shoulder length for everybody. For the “short” shoulder strap, we set the distance from the top of the backpack to the horizontal line of the shoulder is $\frac{1}{10}$single shoulder length for everybody. For the “standard” shoulder strap, we set the distance from the top of the backpack to the horizontal line of the shoulder is $\frac{1}{2}$single shoulder length for everybody. In addition, we compare people with relative body characteristics, such as "fat and thin", "high and short", "male and female", to find out their results and relative relationships.

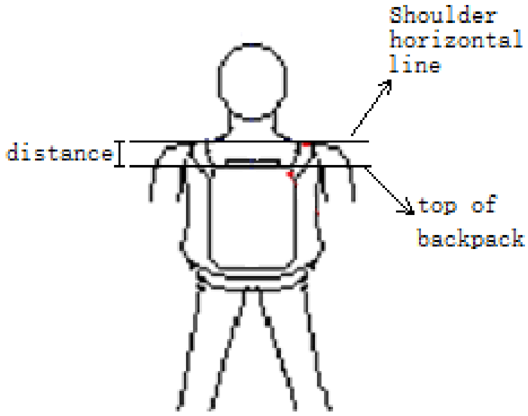


Fig. 4 shoulder strap length experiment method

The second part is to get the pressure data of the three parts of the body under the three different object position in the backpack. The three different position is “close to the back”, “bottom of the backpack” and “close to the outside”.

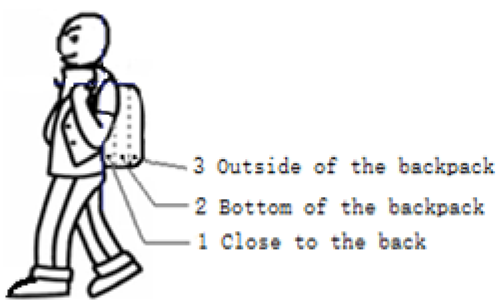


Fig.5 object position experiment method

We summarize the recorded data and use MATLAB and other software to perform statistical analysis and further calculations, such as using a line chart to record changes in pressure data and relative relationships as well as to find out the average of each conditions and use pie charts to count these averages to analyze the relative relationship between all the data and find the best data range. Finally, these data are used to verify whether the theoretical range and relative relationship of the theoretical analysis are correct.

2.4 Force analysis of backpack on each part of human body

There are also some problems with the correct way of backpacking. Where is the position of the backpack (How long the shoulder strap length) and Where the weights in the backpack to Minimizes and even forces each part of the body. We will use algebraic operations and theoretical force balance to analyze these problems.

2.4.1 Analysis of shoulder pressure force for different backpack positions

According to the internet survey of the size of the human body [29], and our own measurement of the shoulder length of 20 different body types (high, short, fat, thin, male, female) by using tools such as a soft ruler (see appendix). We can be known that for normal people, the shoulder strap position is $\frac{1}{2}$ of the length of a single shoulder.

So, as in (Fig. 6), we take two points A and B. Point A indicates the position of the shoulder strap on the shoulder.

which is

$$A\ (0, \frac{1}{2} \times \text{shoulder length})$$

And point B indicates the shoulder strap on the backpack. In addition, a two-dimensional coordinate map is made with the horizontal line of the shoulder as the x-axis and the human spine as the y-axis.

After querying the average backpack size on the market [30] and our own measurements. It is known that for each user, no matter what the shoulder strap length changes, the horizontal distance from coordinate point B to coordinate point A is almost always maintained at a constant value. Therefore, in order to control the variable, we set the horizontal distance of AB to be a constant, denoted by "z".

that is, the abscissa of B is

$$(\frac{1}{2} \times \text{shoulder length - z}).$$

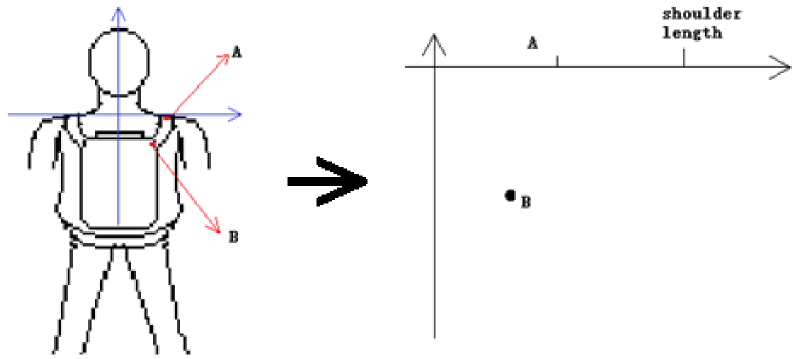


Fig. 6 Two dimensional coordinate map of human body

As the length of the shoulder strap increases or decreases, the position of the backpack will also become higher or lower, that is, the position of the coordinate point B will become higher or lower. We searched internet [31] and experimented with different samples to find that when the top position of the backpack (the position of B) is a single shoulder length relative to the shoulder (the x-axis), the backpack is located at the user's butt; when the top position of the backpack (the position of B) is The backpack is located at the upper back of the user when the shoulder (the x-axis) is $\frac{1}{10}$of a single shoulder length.

I.e. We set a standard: The minimum value is the distance between top of backpack and shoulder horizontal line is $\frac{1}{10}$ single shoulder length for everybody (When the length of the shoulder strap is the shortest). The maximum value is the distance between top of backpack and shoulder horizontal line is single shoulder length for everybody (When the length of the shoulder strap is longest).

Therefore, we take the position of the coordinate point B to change from $\frac{1}{10}$ of the shoulder length to a single shoulder length. As shown in (Fig. 7) The coordinate range of B is:

($\frac{1}{2}\times$ shoulder length -z, $\frac{1}{10}\times$ shoulder length) to ($\frac{1}{2}\times$ shoulder length -z, shoulder length)

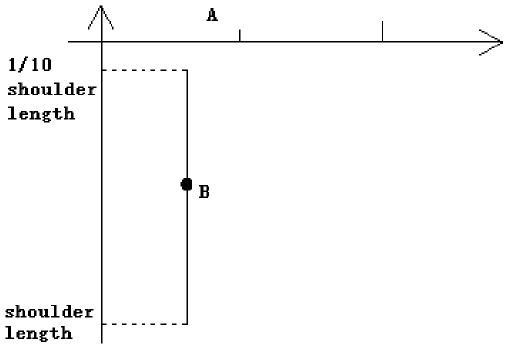


Fig.7 The range of change of coordinate point B

After a series of calculations (see appendix), we can get the range of variation of angle θ.

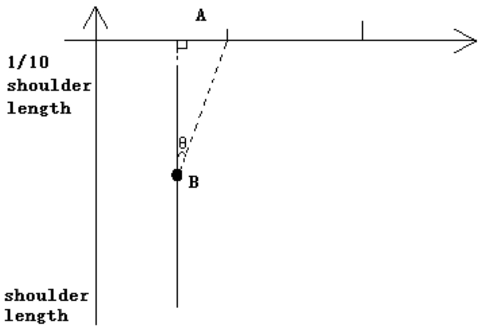


Fig.8 AB bevel angle range

Therefore, the contact point A of the shoulder strap and the shoulder line is taken as the analysis point, and the force analysis is performed (Fig.9), and Fb is the oblique downward pulling force of the coordinate point B (the shoulder strap of the backpack) on the coordinate point A (shoulder). N is the support for the shoulder strap of the backpack, which is equal to the shoulder strap pressure force on the shoulder.

After derivation, the pressure force formula of point A is obtained as follows:

$$F=N=F_b*\cos(\theta)$$

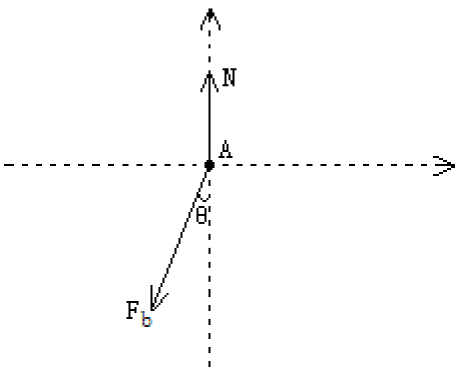


Fig.9 Force analysis chart at point A

When the weight of the backpack is constant (when the value of Fb is constant), to minimize the pressure F on the shoulder, the cos(θ) should be the smaller, so the closer the value of cos(θ) is to $\frac{\sqrt{z^2+\frac{n^2}{100}}}{z}$, the pressure force of the shoulder will change smaller. Because the denominator is P, it is represented as the AB spacing of the coordinate point B at the shoulder length of $\frac{1}{10}$.

Therefore, for shoulder forces, it can be concluded that shoulder pressure force decreases as the top of the backpack approaches the shoulder horizontal line by $\frac{1}{10}$ of the shoulder length.

However, for the backpack weight (Fb), in addition to the pressure assigned to the shoulders, there is also a part of the force allocated. And this component is just the pressure of the backpack on the back of the human body.

2.4.2 Analysis of the pressure force on the back of the backpack

What we are going to analyze now is when the total weights of the backpack is fixed, and when the position of the backpack is fixed, the weights of the backpack is at the lowest pressure on the back. After investigation and internet inquiry[32], we concluded that there are three places where the weights are generally placed. They are “close to the back”, “bottom” and “close to the outside”, which are the three positions shown in the figure below (Fig. 10). In addition, the human body's back is the y-axis, and the horizontal line at the top of the backpack is the x-axis, making a two-dimensional coordinate map. The coordinate points "1", "2", and "3" indicate three different positions of the weights in the backpack. The coordinate point "A" indicates the position of the shoulder strap of the backpack on the shoulder.

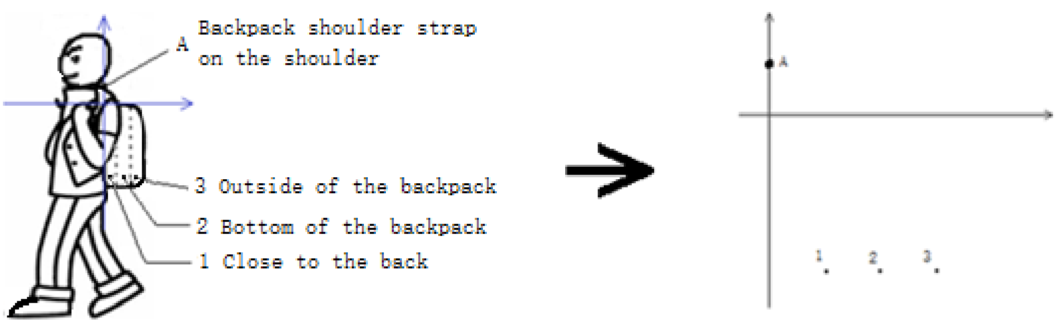


Fig.10 Two dimensional coordinate map of human body

The backpack position will not change, so the coordinate point A will remain unchanged. Take the Y axis as the right-angled edge, coordinate point A to the distance of the other three coordinate points as the oblique side, make three right-angled triangles (Fig. 11).

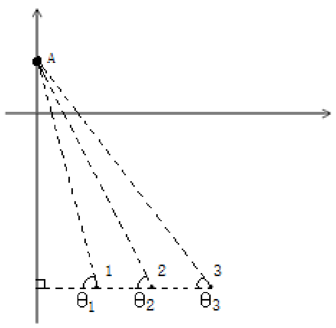


Fig.11 Three angle of coordinate point

We can intuitively see that the angles of the three coordinate points are all acute angles, and $\theta 1 > \theta 2 > \theta 3$. Therefore, we can make a force analysis graph for three points (Fig. 12). Where G is the gravity of the object; N_{back} is the support of the back of the human body to the object, which is equal to the pressure of the object on the back; $N_{backpack}$ is the support of the backpack to the object, this support is the direction of the pull of the backpack shoulder strap, because the pull of the shoulder strap provides the support for the backpack to the object.

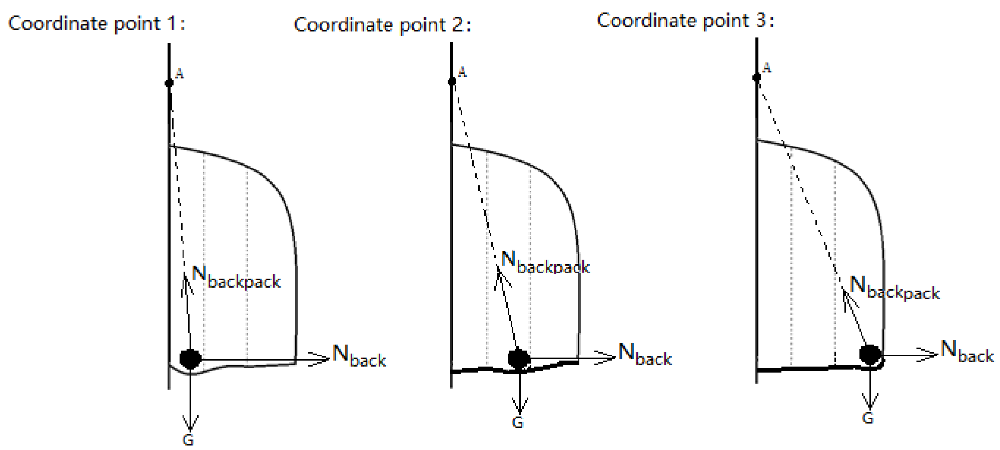


Fig.12 Three points of force analysis

In order to get the pressure on the back of the backpack, we derive the formula according to the force analysis diagram:

$$F=N_{back}=N_{backpack}*\cos(\theta)$$

Since θ1 > θ2 > θ3 for the angle between the three coordinate points, the formula is taken to be F1 < F2 < F3. So we can conclude that the closer the weights is to the back, the lower the pressure on the back of the backpack.

However, for the $N_{backpack}$, in addition to the pressure assigned to the back, a further portion of the force is assigned. And this part of the force is just the pressure of the backpack on the shoulder. Therefore, we will explore and analyze the distribution of pressure on the shoulders and back of the backpack together.

2.4.3 Unified analysis of the pressure on the back and shoulders of the backpack

For the separate analysis of the above two cases, we can see that the pressure effect of the backpack on the shoulder is a relative relationship with the pressure on the back of the backpack, that is, when the shoulder haves less pressure, the back force will be too large; When the back have less pressure, the force on the shoulder will be too large. So for this situation, we will make a unified analysis of the pressure distribution.

For the position of the weights, in order to solve the problem of excessive or too little force, we think that the position of the middle (the bottom of the backpack) is the most appropriate. Because it is in the middle position, although the pressure on the back of the human body cannot be minimized, for the entire human body to be distributed, this position is the place where the force is the most uniform and the relative pressure is the smallest.

For the position of the backpack (shoulder strap length), we make the following analysis (Fig. 13), where coordinate point B is the position of the weights in the backpack (the bottom of the backpack), and the position of point B is fixed in the two-dimensional coordinate system. The coordinate point A is the change of the coordinate point A relative to the coordinate point B under different positions of the backpack. It is worth noting that, because A changes with respect to B, when the coordinate point A is in the A1 position, the backpack position is at the bottom (the shoulder strap is the longest); when the coordinate point A is in the A2 position, the position is at the top (when the backpack strap is the shortest).

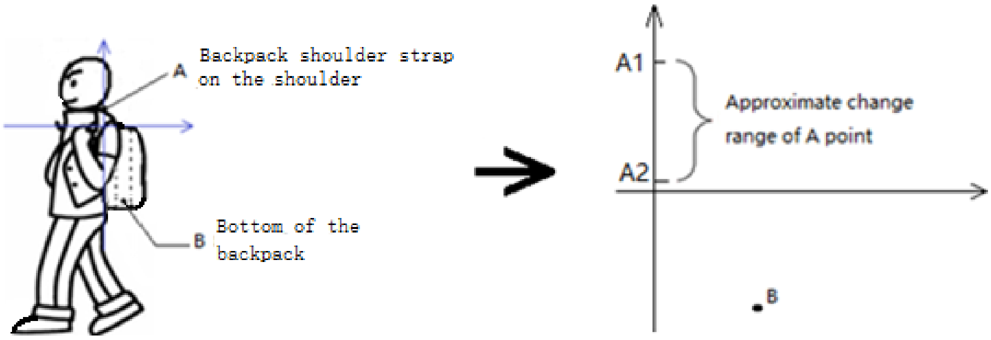


Fig.13 Two dimensional coordinate map of human body

The coordinate point A is connected with the coordinate point B, and the right-angled triangles of the A point at the positions A1 and A2 are respectively made (Fig.14), and the angle θ1>θ2 can be visually seen.

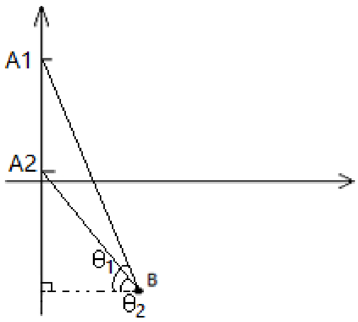


Fig.14 angle of coordinate point

So we can make a force analysis diagram (Fig.15), where G is the gravity of the object; N_{back} is the support of the back of the human body, which is equal to the pressure of the object on the back; $N_{backpack}$ is the support of the backpack to the object, this force is equal to the pull of the shoulder strap of the backpack.

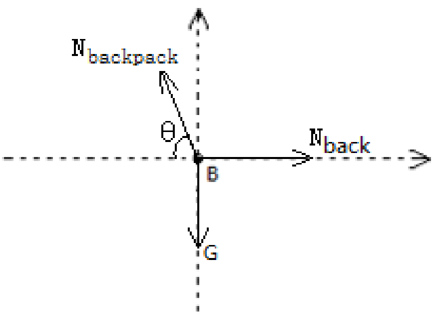


Fig.15 B point force analysis chart

In order to get the pressure on the back of the backpack, we derive the formula according to the force analysis diagram:

$$F = N_{back} = N_{backpack} * \cos(\theta)$$

Since $\theta 1 > \theta 2$ for the angle of the A1 A2, take into the formula to get $F1 < F2$. So the lower the position of the backpack (ie the longer the shoulder strap), the lower the pressure on the back of the backpack.

But the previous analysis of the shoulder pressure concluded that the higher the position of the backpack (ie the shorter the shoulder strap), the lower the pressure on the shoulder of the backpack. Therefore, in order to neutralize the results of both, and to make the force of all parts relatively small, we believe that the backpack is in the middle (ie, about $\frac{1}{2}$ shoulder length), the backpack is the most uniform force on each part of the human body, and The force is relatively minimal.

So through the above force and algebra analysis, we can get a range that can be effective for almost every user:

When the distance from the top of the backpack to the horizontal line of the shoulder is about $\frac{1}{2}$ shoulder length, and the position of the heavy object in the backpack is at the bottom of the backpack, the three parts of the human body (shoulders, back) are most uniformly and relatively minimal.

3. Experimental essentials

3.1 Literature Review

Bor-Shong Liu [8] believes that the soldiers' long-term weight-bearing action will have a certain impact on the body. In order to protect the soldier's long-term load behavior, the location of the load is an important factor. This should be taken into account when designing and loading backpacks. In order to achieve this goal, Investigators and researchers choose a military base to conduct related experiments. Five basically trained male infantrymen participated in the experiment. Experiments have shown that the loading position is an important determinant of efficient transportation, and it should be an important consideration in backpack design and subsequent load distribution. The weight should be placed on top of the backpack and close to the body. Therefore, the results of this study will have a wide practical impact on human transport on uneven walking or work surfaces and will guide the army and soldiers. [20]

Min-hee Kim and Won-gyu Yoo2 [10] focus on the spacing between the backpack traps research. They invited fourteen males participated in this study. This study investigated the effect of different distances of the backpack straps on neck muscle activity, shoulder peak and scapular position, and upper quadriceps muscles after backpack walking. Different shoulder strap spacings change the position of the backpack's weight support. Wide-pitch shoulder straps and narrow-pitch shoulder straps use different positions of muscles to withstand the weight of the backpack.

Through our investigation, we found that the current research on the weight of backpacks is basically about military soldiers. And it is also used for military backpacks with heavy weights for testing. From the actual situation, there are significant differences between the muscle lines of students and soldiers, and the burden in everyday life is far less than the backpacking weight of military operations. At the same time, the study on the influence of shoulder strap length on the pressure of the backpack on the body is absent.

3.2 Experiment Design

Our experiment consists of two parts:

(1) Test the distribution of different people's pressure on the human body under different backpack lengths. We set three backpack lengths (described in detail in 2.3.1). The load for each test is at the bottom of the backpack.

(2) Test the pressure distribution of the backpack when the load is in different positions in the backpack. We set three different backpack positions (described in detail in 2.3.2).

Experiments will use our experimental platform based on ordinary backpacks. The experimental backpack includes pressure sensors, accelerometers and Bluetooth low energy. At the same time, we will write an Android application for collecting backpack data in real time. In order to save power of the system as well as get experimental results quickly and accurately, we will find a method to detect the human who is using the backpack and active all of the sensors.

3.3 Participants

3.3.1 Shoulder strap length test

In order to verify the effect of strap length on pressure distribution, we decided to test the pressure distribution under different strap lengths. As mentioned above, the shoulders are unstable and easily injured. Therefore, the pressure of the backpack should be shared by the waist. In order to minimize the difference between different people, we chose the top of the sacrum as the reference line for the length of the shoulder strap. The base of the backpack was flat with the top of the sacrum as the standard length of the backpack. The bottom of the backpack was 10 cm above the top of the sacrum as a short shoulder strap. The bottom of the backpack was 10 cm shorter than the top of the sacrum as a short shoulder strap.

The experiment included fifteen men (height 161-185) and five women (height 152-173) with a total of ten participants.

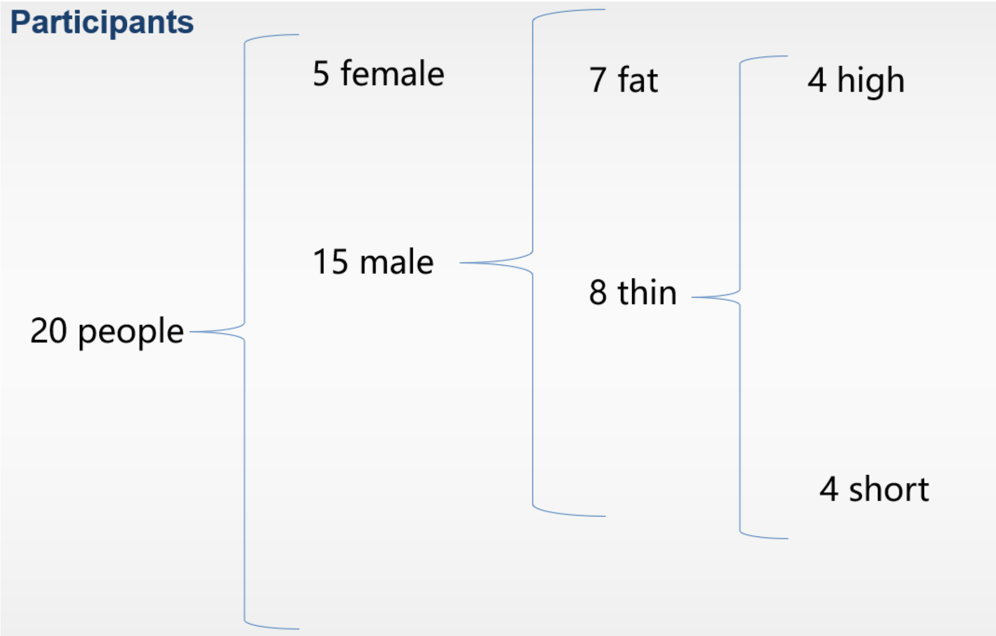


Fig.16 participants

We will use BMI to divide fat and thin people and Asian average height to divide high and short people.

3.3.2 Impact of load distribution

As mentioned in the previous, the location of the items in the backpack will also affect the distribution of backpack pressure on the human body [8]. According to the previous relevant information [20], the soldier's backpack load system has the principle of placing heavy objects as close to the back as possible. Therefore, we selected three different weights placements: near the back, the bottom of the backpack, and the outside from the back.

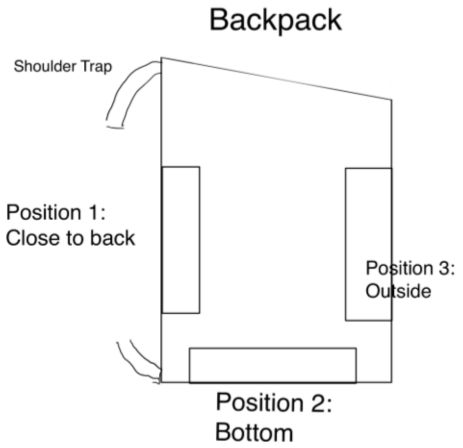


Fig.17 Load position

The three load positions: "close to back", "Bottom" and "Outside" can be seen in Fig.17

3.4 Backpack structure

We choose an already existing Backpack with known specifications and dimensions from "XD design" (The brand of the backpack) to build the experimental platform. The bag size is 44 cm x 34 cm x 20 cm with Laptop Compartment: 27 cm x 33 - 40 cm x 3,5 cm (Width x Height x Depth) and Tablet Compartment: 25,5 cm x 12 - 18 cm x 1 cm (Width x Height x Depth) which can easy to adjust the position of the load. (Fig.18)

Fig.18 backpack

3.5 Data Collecting

There are two types of data to collect: force sensor data and accelerometer data. The force data come from three force sensors on the backpack. Each of it is two bytes and the sample rate are 5 times each second. The accelerometer data is two bytes and the sample rate were set as same as the force sensor.

The statistics of all these values, and then use MATLAB and other programs to find their rules to get in different circumstances, the environment and the user's bag shoulder strap pressure on the body to find the best threshold for the user. And the backpack is portable outdoors, so we also need to do some research on the battery to find the best battery efficiency method to make the standby time longer and achieve more functionality and how to get the most accurate value with the fewest sensors. And our products are real time, users can always check the impact of the backpack on the shoulder.

4 Implementation

4.1 Testing System

There are three main parts of our testing system: Backpack, Android phone and computer. The backpack part includes the three force sensors to collect the experimental data and a accelerometer to make sure the backpack is horizontal. The Android phone part is an application to monitor the data in real time and record the data from backpack. The computer part will use MATLAB to analysis.

The details of this system can be found in our system project report [33][34].

4.2 Hardware

4.2.1 FSR Sensor

The FSR sensor is a force sensor. When an object exerts a force on its surface, its resistance will change along with it, thus changing the level of the electrical level and finally through the microprocessor Analog to Digital conversion into force data.

FSR (Force Sensing Resistor) are a polymer thick film (PTF) device which exhibits a decrease in resistance with an increase in the force applied to the active surface [10]. Force accuracy ranges from approximately ± 5% to ± 25% depending on the consistency of the measurement and actuation system, the repeatability tolerance held in manufacturing, and the use of part calibration [10]. Therefore, the measurement of this sensor is inaccurate. In addition to this, it is only a sensor that obtains a force value, so no matter how the contact area changes, the pressure value will not change.

FSR is real time force sensor. When changing the force on the sensor surface, the resistance value changes along with it. Users can more easily measure force value.

4.2.2 Sensors position

There are three force sensors in total. Two of them be mounted on the strap (one on the left and another on the right strap). The position of these two force sensors can be adjusted to match different people. And the last force sensor will be mounted on the back of the backpack. (Fig.19)

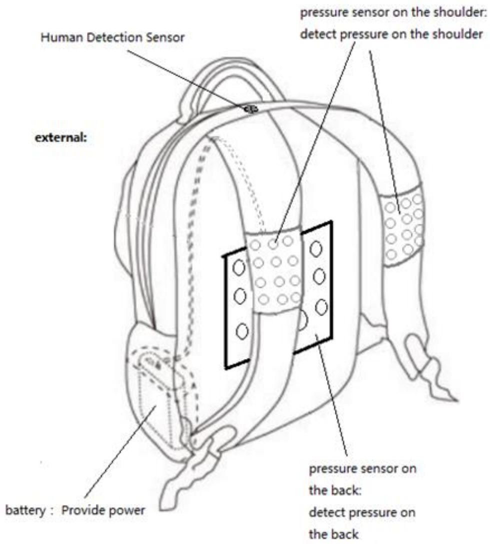


Fig.19 FSR sensors position

4.2.3 Hardware overview

All experimental chips were mounted on the printed circuit board to reduce the error. (Fig.23). Small size and light weight minimize interference with the experiment (Fig.24). [23]

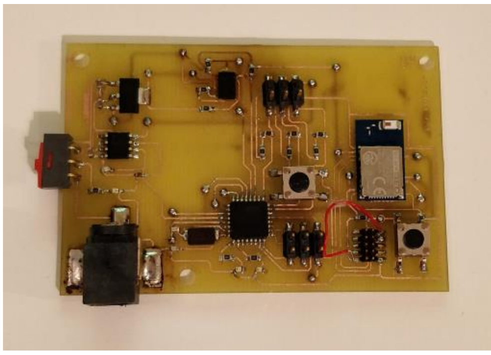


Fig.23 PCB board

Fig.24 Backpack

4.3 Software

4.3.1 MATLAB

MATLAB is a commercial mathematics software produced by MathWorks, USA. It is used for advanced technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numerical calculation. It mainly includes MATLAB and Simulink.

MATLAB is a combination of the two words matrix & laboratory, meaning a matrix factory (matrix lab). It is a high-tech computing environment that is mainly published by Mathworks in the United States and faces scientific computing, visualization, and interactive programming. It integrates many powerful functions such as numerical analysis, matrix calculations, visualization of scientific data, and modeling and simulation of nonlinear dynamic systems into an easy-to-use window environment for scientific research, engineering design, and many sciences that must be efficiently numerically calculated. [24] The domain provides a comprehensive solution, and to a large extent out of the traditional non-interactive programming language (such as C, Fortran) editing mode, representing the advanced level of international scientific computing software.

Here, the MATLAB will be used to analysis the data which collect from the experiment.

4.3.2 Android application

The developed Android application (Fig.25) can acquire pressure sensor and accelerometer data in real time through low-power Bluetooth to ensure the accuracy of experimental data. It is also convenient for experimenters to record data. The program can display the accelerometer values which use to check the backpack is horizontal or not and the values of the left shoulder, right shoulder and back pressure sensors.

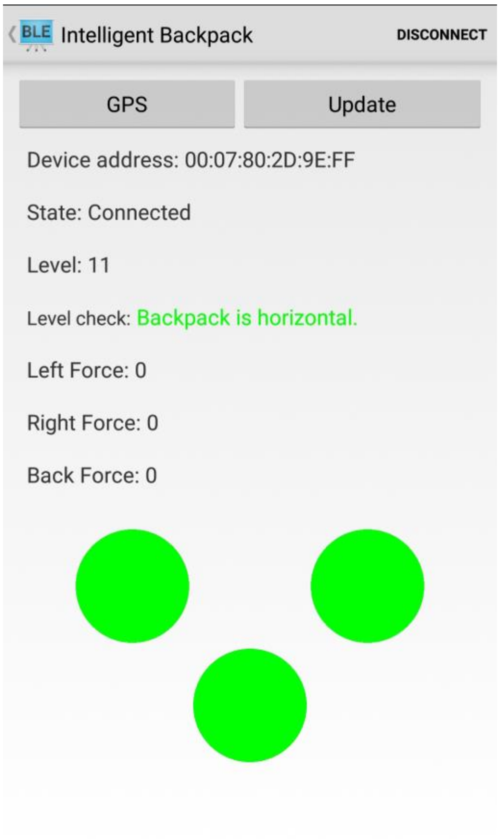


Fig.25 Android application

5 Experimental discrimination

5.1 Backpack Shoulder Strap Length Result

We measured the pressure of the three parts of the body for people of different sizes (high, short (child), fat, thin, male, female).

5.1.1 Normal Male experimental data

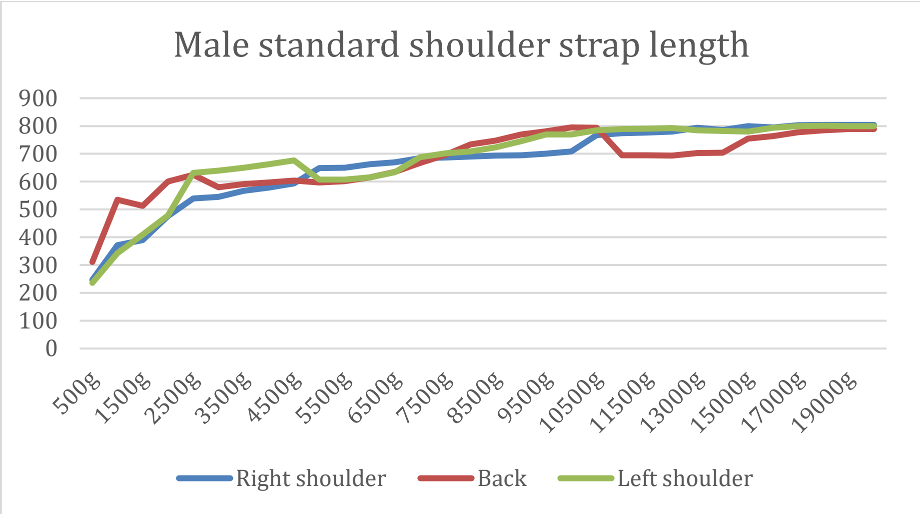


Chart.2 Male standard ($\frac{1}{5}$ shoulder length) shoulder strap length

Right shoulder average force: 665

Back average force: 673

Left shoulder average force: 680

As we can see, In the case of standard lengths, the three force parts are very uniform and effectively distribute almost the same force. And the maximum force value did not exceed the critical point of 800.

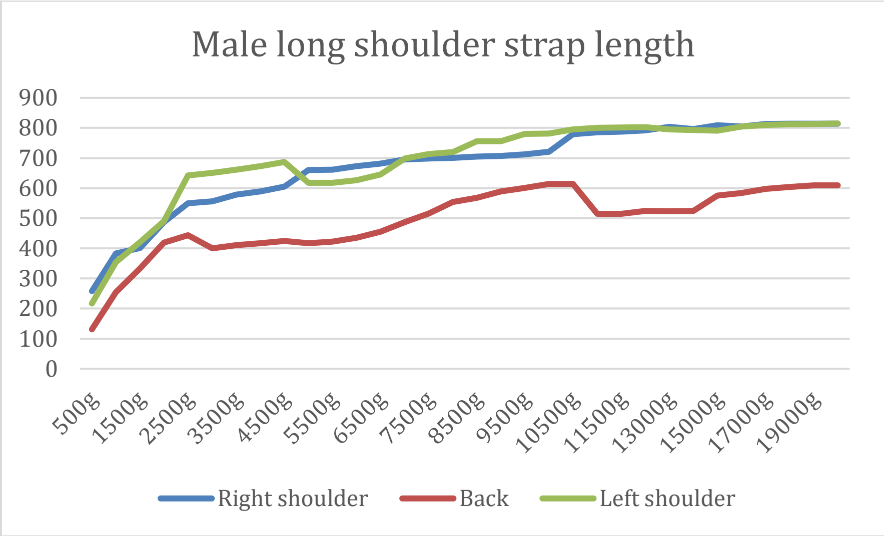


Chart.3 Male long shoulder strap length

Right shoulder average force: 676

Back average force: 490

Left shoulder average force: 691

As we can see, in the case of long lengths, the shoulders are significantly more pressure than the back, which is very bad for the distribution of human power and musculoskeletal health.

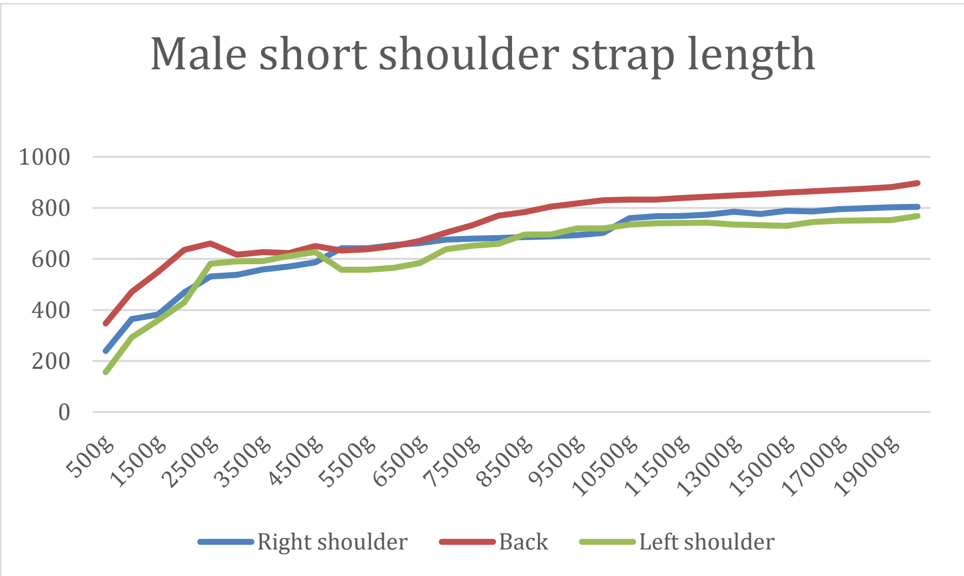


Chart.4 Male short shoulder strap length

Right shoulder average force: 657

Back average force: 734

Left shoulder average force: 631

As we can see, in the case of shorter lengths, the back is more pressure than the shoulder. And at the maximum force, the back is much larger than the critical value of 800, which is very unfavorable for the distribution of human and musculoskeletal health.

5.1.2 Female experimental data

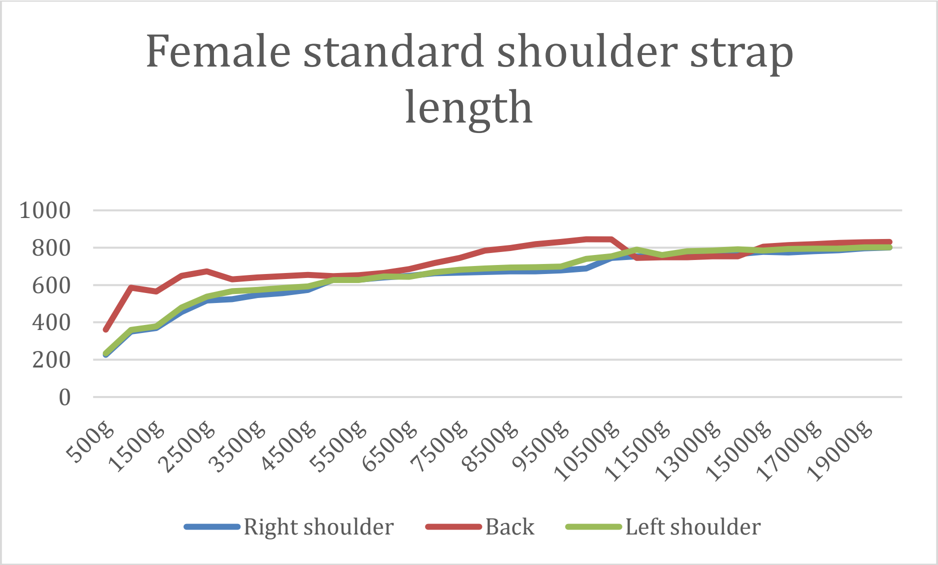


Chart.5 Female standard shoulder ($\frac{1}{5}$ shoulder length) strap length

Right shoulder average force: 645

Back average force: 722

Left shoulder average force: 660

As we have seen, for women, in the case of standard length, the three forces are very uniform, but due to the differences in the physiological structure of women and men, the pressure in the middle exceeds the critical point of 800.

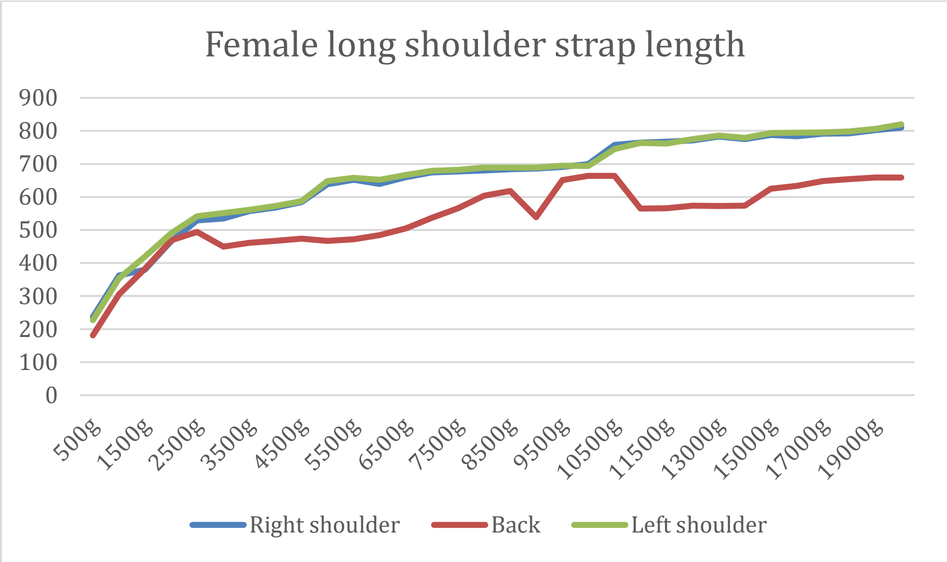


Chart.6 Female long shoulder strap length

As we have seen, for women, in the case of long lengths, the three forces are partially uneven, the back pressure is small, but the pressure on the shoulders is greater. Uneven pressure has a great impact on your health.

Right shoulder average force: 655

Back average force: 537

Left shoulder average force: 661

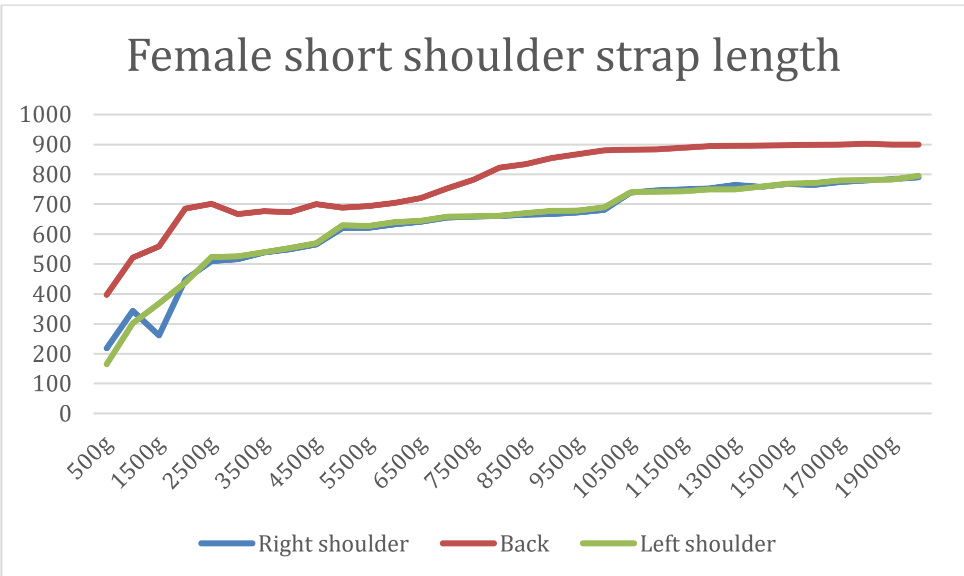


Chart.7 Female short shoulder strap length

As we have seen, for women, in the short-length case, the three forces are partially uneven, the shoulder pressure is normal, but the back pressure is very large, even reaching a sensor force data level of 900. Uneven pressure has a great impact on your health.

Right shoulder average force: 634

Back average force: 778

Left shoulder average force: 637

5.1.3 Male and Female result compare

	Male Right	Male Back	Male Left	Female Right	Female Back	Female Left
Standard	665	673	680	645	722	660
Long	676	490	691	655	537	661
Short	657	734	631	634	778	637

` Table.3 Male and Female result compare

In order to more intuitively check which area is under pressure. We have plotted pie charts and pressure profiles for each case to make a more intuitive comparison:

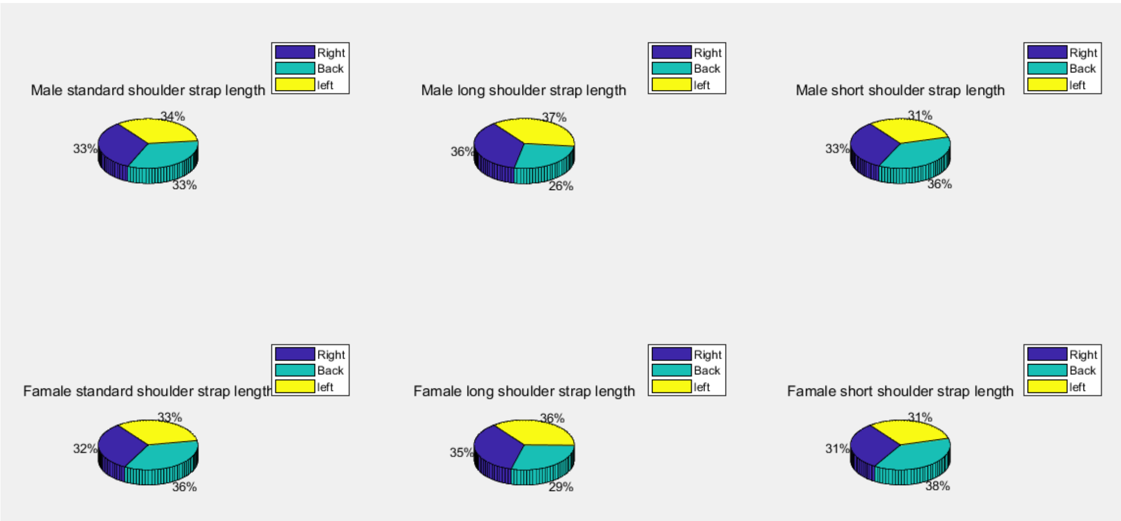


Chart.8 Male and Female result compare

It can be seen from the graph that the force distribution is different due to the difference in the size of adult male females. For longer shoulder girdle, male shoulders are more powerful. In the case of short shoulder straps, women's backs are more affected. In addition, both men and women, the shorter the shoulder strap of the backpack, the lower the pressure on the shoulder, but the pressure on the back will increase accordingly. If consider the force uniformity and relative minimum, when the standard shoulder strap length (the distance from the top of the backpack to the horizontal line of the shoulder is about $\frac{1}{5}$ shoulder length), the force on three parts of the body is the most uniform, and through the average table data can be obtained at this time when the three forces relative to the other two cases is the smallest.

5.1.4 Fat people and Thin people experimental data

We used the same method as above to measure the pressure of three fat male people and three thin male people. For the polygraph, the resulting figure is the similar as above figure. In addition, there's too much measurement data, so it's not shown here. For each part of the force average, we let the three samples (three fat people or three thin people) of the average data unified to find the most representative data as the average of this part:

	Thin Right	Thin Back	Thin Left	Fat Right	Fat Back	Fat Left
Standard	673	662	688	657	681	674
Long	684	483	699	664	499	681
Short	651	728	640	642	742	627

Table.4 Thin people and Fat people result compare

In order to more intuitively check which area is under pressure. We have plotted pie charts and pressure profiles for each case to make a more intuitive comparison:

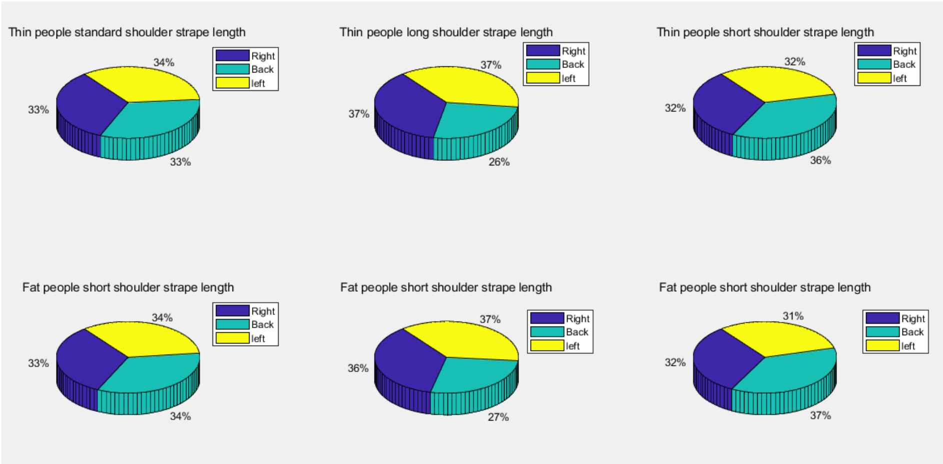


Chart.9 Thin and Fat people result compare

As can be seen from the figure, since the adult fat person is wider than the squat body type and the chest circumference is larger, the force distribution is different. For longer shoulder straps, the shoulders of the squats are subjected to greater force. In the case of a short shoulder strap, the fat person's back is more affected. However, whether it is fat or sputum, the shorter the shoulder strap of the backpack, the lower the pressure on the shoulder, but the pressure on the back will increase accordingly. If consider the force uniformity and relative minimum, the standard shoulder strap length (the distance from the top of the backpack to the horizontal line of the shoulder is about $\frac{1}{5}$ shoulder length), the force of the three parts of the human body is the most uniform, and the force available at this time is relatively minimal through the average number table.

5.1.5 High people and short people (Child) experimental data

As with the above method, we measured the pressure of three high male people (Height is greater than 170cm) and three short male people (including children) (Height less than 155) and obtained the average of all their parts:

	High Right	High Back	High Left	short Right	short Back	short Left
Standard	667	676	682	667	664	680
Long	674	496	696	678	481	691

Short	656	737	635	659	734	634

Table.5 High people and short people result compare

In order to more intuitively check which area is under pressure. We have plotted pie charts and pressure profiles for each case to make a more intuitive comparison:

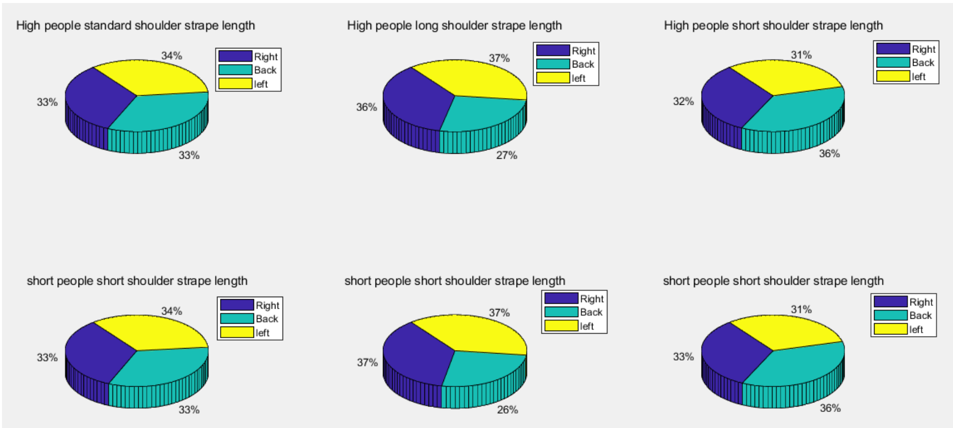


Chart.10 High people and Short people result compare

It can be known from the average table that both high and short people have similar pressure values in each case. This is because our backpack position (shoulder strap length) is adjusted for each person's height and shoulder length, so height does not affect the difference in experimental results. In addition, as can be seen from the pie chart, the shorter the shoulder strap of the backpack, the lower the pressure on the shoulder, but the pressure on the back will increase accordingly. If consider the force uniformity and relative minimum, only when the shoulder strap of the backpack is the standard length (the distance from the top of the backpack to the horizontal line of the shoulder is about $\frac{1}{5}$ shoulder length), the force on the three parts of the body is the most uniform. And relatively small.

5.2 Impact of Load Distribution Result

5.2.1 Bottom of the backpack

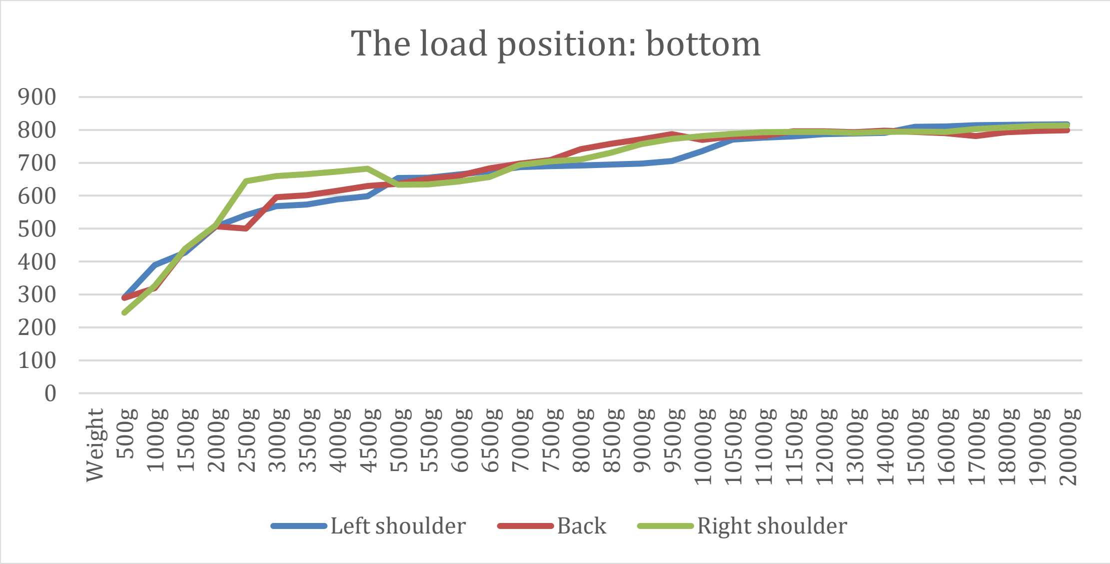


Chart.11 The load position: bottom

Right shoulder average force: 675

Back average force: 683

Left shoulder average force: 691

For bottom of backpack, the three forces are partially uneven. and there are not any sensor data more than a threshold of 800. It's relatively beneficial to the health of the body

5.2.2 Close to the back

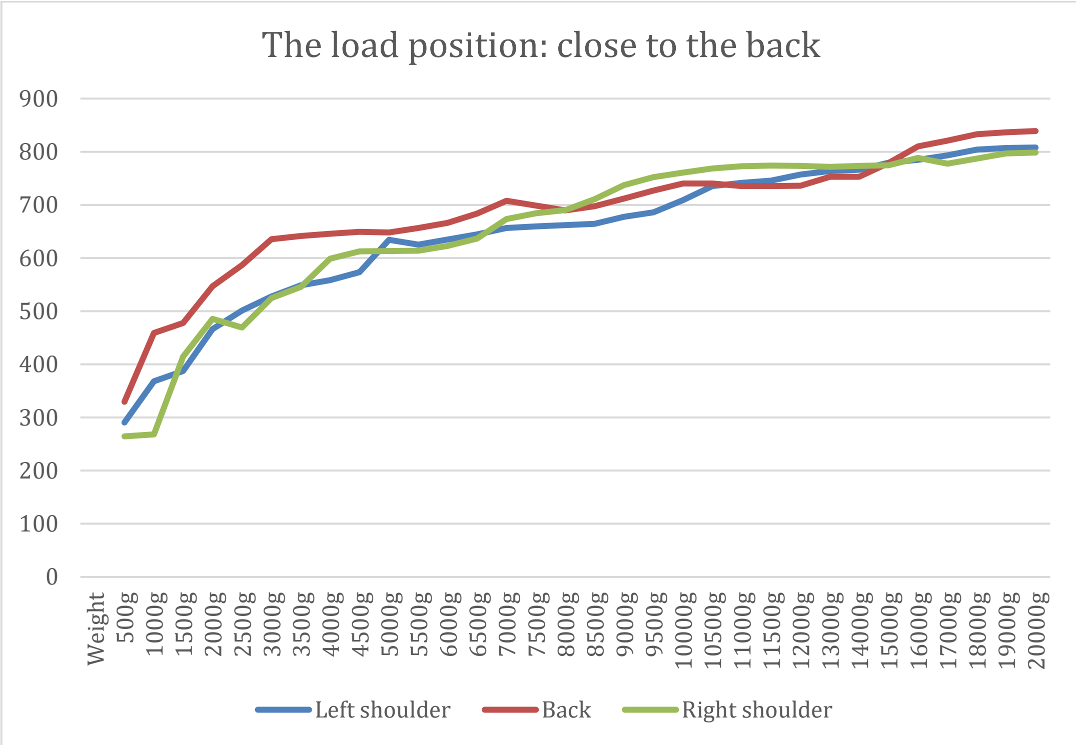


Chart.12 The load position: close to the back

Right shoulder average force: 648

Back average force: 686

Left shoulder average force: 657

As can be seen from the above chart, when the position is close the back, the three forces are partially uneven. The force on the backpack is larger than other two position and the data more than a threshold of 800. It’s good for health.

5.2.3 Outside of the backpack

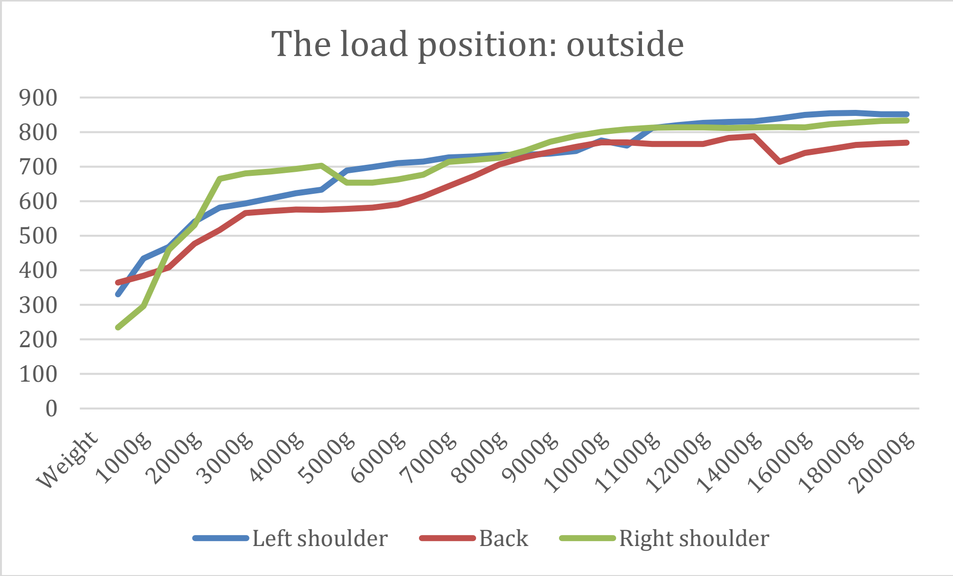


Chart.13 The load position: outside

Right shoulder average force: 712

Back average force: 655

Left shoulder average force: 708

As can be seen from the above chart, when the position is close the back, the three forces are partially uneven. The pressure on the shoulders is significant, clearly exceeding the critical value of 800. In addition, the pressure is not balanced and it affects the body's muscles and bones.

5.2.4 Force compare

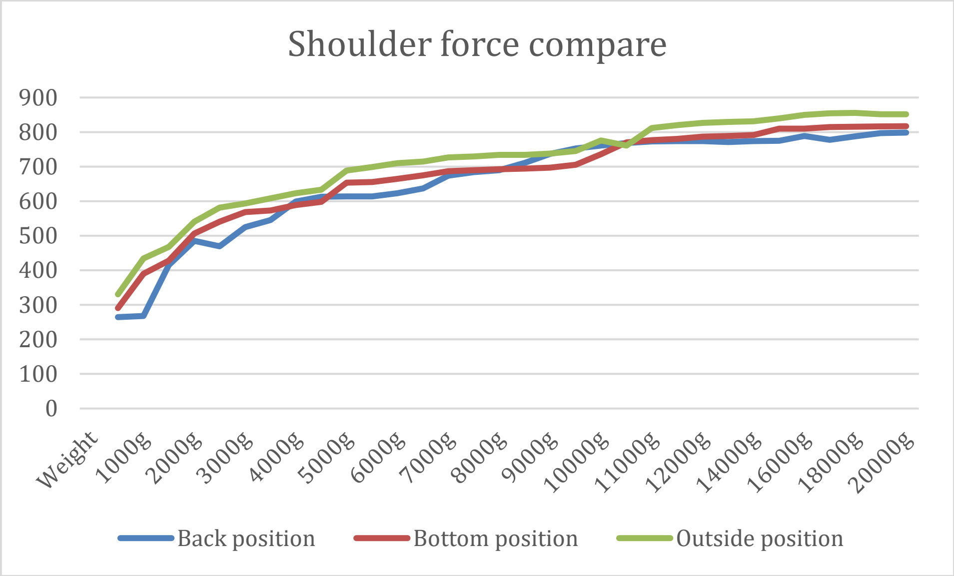


Chart.14 Shoulder force compare

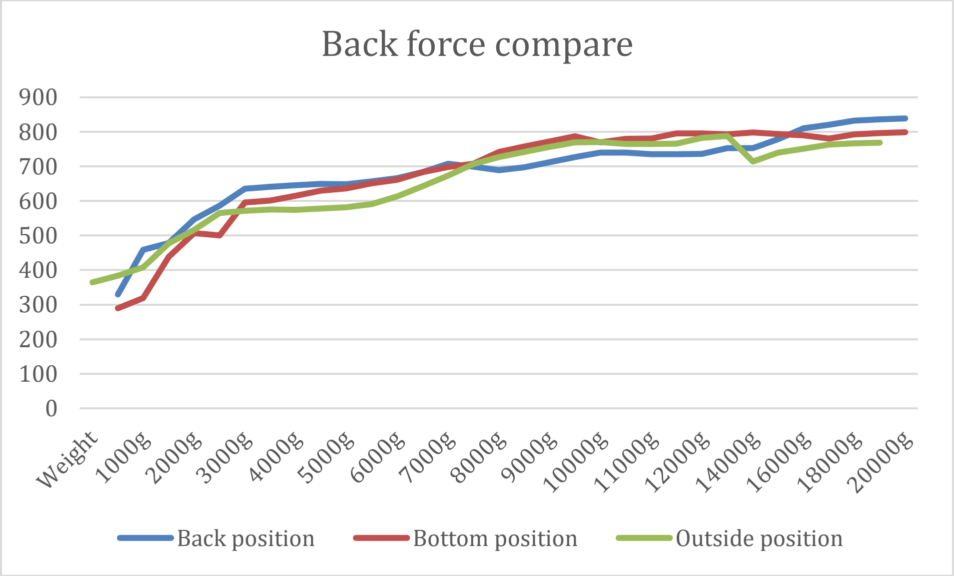


Chart.15 Back force compare

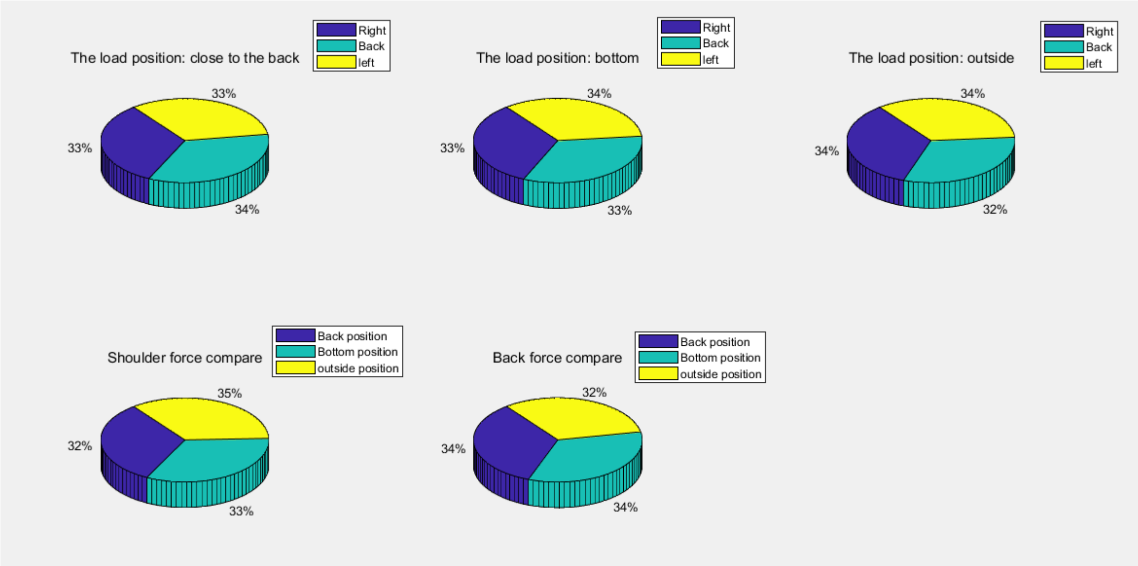


Chart.16 Force distributed percentage

As can be seen from the chart, when the load is on the outside and near the back, there is always a part that is high, resulting in uneven human pressure, and the pressure on that part exceeds the critical value, causing greater body influences. However, when the load is at the bottom of the backpack, the forces in the three parts are very uniform and not too large, and they are all within the critical value.

6 Experiment induction and discussion

6.1 Answer Research Question 1 - Human Detect Method

After research, we found that a pressure sensor is equivalent to an infinite resistance in the absence of a detected pressure. Therefore, no current will flow through it, which means that it will not consume power (Table.9). [25] In order to avoid false touches, we use a pressure sensor located on the back of the backpack as a switch to activate the detection system. When the pressure sensor on the back of the backpack detects pressure, all sensors are activated. This means that people are using backpacks. [26]

Force (lb)	Force (N)	FSR Resistance	(FSR + R) ohm	Current thru FSR+R	Voltage across R
None	None	Infinite	Infinite!	0 mA	0V
0.04 lb	0.2 N	30 Kohm	40 Kohm	0.13 mA	1.3 V
0.22 lb	1 N	6 Kohm	16 Kohm	0.31 mA	3.1 V
2.2 lb	10 N	1 Kohm	11 Kohm	0.45 mA	4.5 V
22 lb	100 N	250 ohm	10.25 Kohm	0.49 mA	4.9 V

Table.6 Force sensor power consumption

Another method here is to use an infrared pyroelectric sensor. However, the battery power is additionally consumed compared to the direct use of the pressure sensor. Also, when a person or a small animal in the house passes by, the backpack may be activated by mistake. So using pressure sensor detection directly is the best way.

6.2 Answer Research Question 2 - Shoulder Strap Length Discussion

Based on theoretical derivation in methodology, and the results of each sample experiment. If we only consider the shoulder force, the lower the distance between the top of the backpack and the horizontal line of the shoulder (ie, the closer to $\frac{1}{10}$ shoulder length), the lesser the pressure on the shoulder of the backpack.

Similarly, if we only focus on the back, when the weights position closer to the back which pressure force will be more for back.

So, if it is for a certain part or a certain situation alone. If the user wants to minimize the pressure on the shoulder, the shoulder strap of the backpack should be as short as possible. If the user wants only the least pressure on the back, the closer the weights in the backpack is to the back which is better for back.

But if we want to deal with the whole body's pressure force situation. This is related to the health of the whole part of the human body, not just in order to reduce the pressure to choose the corresponding position. But should consider the whole body's force uniform distribution and relative pressure force. For this problem, we have to look at the answer of research question3.

6.3 Answer Research Question 3 - What kind of backpack position and weights position in the backpack is the best for human health?

According to the theoretical force analysis and experimental results, we can get a relative relationship between the shoulder force and the back force. If the shoulder is less pressure, the remaining force will act on the back, which will make the back force too large; if the back force is reduced, the remaining force will act on the shoulder, causing the shoulder to be pressure increase. For human health, it is necessary to have three parts of force that are uniform and relatively small.

Therefore, in the analysis of the force of the methodology, we found that the distance from the top of the backpack to the horizontal line of the shoulder is about 1/2 shoulder length, and the position of the heavy object in the backpack is at the bottom of the backpack. Only in this case, the force applied to each part is at a medium level, and no extra force is attached to another part, the three parts of the human body (shoulders, back) are most uniformly and relatively minimal.

In addition, we can also validate the conclusions of the theoretical analysis by measuring and experimenting the samples of different body types.

6.4 Difference in body structure

In the course of the experiment, we noticed that differences in body structure would have a significant impact on the distribution of backpack pressure on humans. According to the differences in fat, thin, high, short and gender of the testers, their feelings about backpack pressure are also different.

The backpack bearer status for female testers and male testers. The angle formed by the shoulder strap and the shoulder of the subject is significantly different. Male subjects are generally thin and strong with a small angle between the shoulder strap and the shoulder. Therefore, the pressure sensor and the shoulder of the contact surface show about 45 degrees, and the height of the leg, the length of the shoulder strap is longer, the backpack is also above the buttocks, the pressure is still guaranteed and does not cause too much pressure. Due to the different physiological structure, the female's chest and back are full and round, and the shoulder strap of the tester is tightly attached to the shoulder, so that the pressure sensor is closer to the level of the shoulder, resulting in shoulder pressure less than men, but Back pressure is greater than men's.

For fat people, their body size is wider than that of the squat, and the bust is larger, which makes the chest and back full and round, and the backpack will be more tightly attached to their body, making the shoulder pressure less. And the back pressure will be greater

The above measurements indicate the length of the shoulder strap and its choice of use in different body parts. How to reduce gravity can give practical guidance. [27]

7 Conclusion

We have tested and verified the pressure conditions of backpacks, found out the differences in force, and gave summary guidance. This will enable people to use backpacks more correctly and have a wide range of significance.

7.1 Summary of Findings

Through the theoretical analysis of algebraic operations and force balance, we get the most suitable range for the human body and the healthiest backpack:

“When the distance from the top of the backpack to the horizontal line of the shoulder is about $\frac{1}{2}$ shoulder length as well as the position of the heavy object in the backpack is at the bottom of the backpack, the three parts of the human body (shoulders, back) are most uniformly and relatively minimal.”

And we also get, if it is for a certain part or a certain situation alone. If the user wants to minimize the pressure on the shoulder, the shoulder strap of the backpack should be as short as possible. If the user wants only the least pressure on the back, the closer the weights in the backpack is to the back which is better for back.

In order to verify the reliability and scope of this range. We have done a lot of experiments and measurements on people of different body types, heights and genders, and compared the experimental results with the theoretical analysis results. It is found that the scope of this theoretical analysis is very reliable and can be satisfied by different users.

7.2 Recommendations

We recommend that users minimize the weight of the backpack. If the user is unable to reduce the weight, the user should adjust the position of the backpack and the position of the object in the backpack based on our conclusions, so that the body can be the healthy way.

7.3 Future Work

As mentioned above and some experimental results, we can see that our project has not been perfect. And we have a very big space for improvement in terms of technology, experimentation, and as products enter the market.

7.3.1 Technical aspects

(1) Pressure sensor: The pressure sensor is an important test device for this project. The force sensor we use at present is a basic laboratory equipment, not an accurate pressure sensor, and the experimental data obtained are subject to some errors, and are easily influenced by resistance, voltage, and other external factors. For the future, we will seek more accurate and stable pressure sensors as experimental equipment to obtain accurate experimental results.

(2) Micro-controller: The micro-controller used by us is a basic chip, which is not that fast and accurate in performance as other advanced chips. The real-time nature of handling multiple events is also weak, so it will cause some errors. In the future work, we will select better chips to continue to improve the collection of data

(3) Power supply: Due to the need to provide effective voltage and power for each sensor. We are currently selecting a battery set with a larger total volume and weight, which will cause the net weight of the school bag to be affected. Therefore, in the future work, we will select a small, high power advanced power supply

(4) Algorithm: Due to the influence of time, the code design and PCB design are more complicated, and do not consider too many algorithms to simplify and improve the operating efficiency. In future work, will add some algorithmic analysis that needs improvement to make the system work more efficiently and get more accurate results.

7.3.2 Experimentation aspects

In the experiment, we tried to carry out many types of testing work according to the project plan and procedures. However, due to the limitations of the conditions, there are still deficiencies that need to be improved. Such as:

(1) Test deficiency: Due to the influence of time and other conditions, we found fewer experimenters and could not perform experiments for each age group or individual body type. Only representative volunteers were selected as experimental subjects. However, these experimental topics are far from meeting the needs of all users. In the future work, we will pick more experimenters to obtain more information in order to obtain data suitable for all users.

(2) More conditions: Our current project is still lacking in exploring the effects of backpacks on the human body in many different situations. For example, the direction of

power, whether the user is acting, etc. In the future, we will explore more possible changes in the situation and make the experimental results more valuable.

7.3.3 Promotion testing system

The pressure test system used in our study is not expensive. We hope that the pressure monitoring of the backpack can be implemented through this system, and then the expansion of the information interaction function of the mobile phone will help the backpack to prevent loss, prevent theft, prevent students from going to school and return home on time. The role is even greater and more obvious. If manufacturers and related groups use these products, they will produce very good economic and social benefits.

8 Epilogue

In summary, we focus on the research project of rationally distributing backpack pressure, using sensor sampling, combining hardware and software technologies, making test equipment, implementing various types, different positions, and changing the length of the shoulder strap. The form of pressure test has obtained useful and scientific data to guide people, especially elementary and middle school students, on the correct use of backpacks, effectively reducing the negative effects of discomfort, soreness, disability, and even deformity.

Backpacks all over the world, the correct, high-quality use of the method, has a common practical significance and the role of public welfare, the tester alarm with related functions, it is worth a wider range of promotion and application.

9 Reference

[1] Chris Allen.How many backpacks are sold every year in the United States. co-founder of Historical Emporium; Jan 21, 2015; Available from: https://www.quora.com/How-many-backpacks-are-sold-every-year-in-the-United-States

[2] Kelty, Marmot Mountain, Sierra Designs, Gelert. Backpack Sales Global Market 2017; May 29th, 2018; Available from: https://www.marketersmedia.com/backpack-sales-global-market-2017-key-players-arcteryx-equipment-kelty-marmot-mountain-sierra-designs-gelert/273461

[3] Rockville Pike, Bethesda.Shoulder Injuries and Disorders. USA ; 6 March 2018; Available from: https://medlineplus.gov/shoulderinjuriesanddisorders.html

[4] *Kelly Rehan*. Packing Pain: Study Reveals New Insights About Backpack Pain. *Jan 31,2017;* Available from: https://www.spineuniverse.com/wellness/packing-pain-study-reveals-new-insights-about-backpack-pain

[5] The influence of load imposed by the backpack school in children and teens in Brazil,

6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015

[6] Back Problems Due to Heavy Backpacks in School Children, IOSR Journal of Humanities and Social Science (IOSR-JHSS) Volume X, Issue X (May. - Jun. 2013), PP 01-00, e-ISSN: 2279-0837, p-ISSN: 2279-0845. Available from: www.Iosrjournals.Org

[7] "Backpack load positioning and walking surface slope effects on physiological responses in infantry soldier, International Journal of Industrial Ergonomics, Volume 37, Issues 9 – 10, September – October 2007, Pages 754-760.

[8] KatyRose, AnneDavies, MatthewPitt, DidiRatnasinghe, LuigiDArgenzio. Backpack palsy: A rare complication of backpack use in children and young adults – A new case report. May 6 2015; Available from:
https://www.sciencedirect.com/science/article/pii/S1090379816300307

[9] Bor-ShongLiu. Backpack load positioning and walking surface slope effects on physiological responses in infantry soldiers; September–October 2007 Available from: https://www.sciencedirect.com/science/article/abs/pii/S0169814107000996

[10] Min-hee Kim, Won-gyu Yoo. Effect of the Spacing of Backpack Shoulder Straps on Cervical Muscle Activity, Acromion and Scapular Position, and Upper Trapezius Pain. 2013 Jul 23; Available from:
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3805011/

[11] Camarillo. FSR® Integration Guide & Evaluation Parts Catalog with Suggested Electrical Interfaces. 546 Flynn Road.

[12] WEBMD ARCHIVES. Pain in the Backpack.

[13] Spine Correction Center. Heavy Backpacks Can Cause Shoulder & Back Pain. August 30, 2017.

[14] BETH GREENWOOD. Exercises to Prevent Shoulder Pain from a Backpack. AUG. 14, 2017.

[15] June Mung Yuing Hu, Karen Jacobs. Backpack usage and self-reported musculoskeletal discomfort in university students. Boston University; 2008.

[16] Retail sales value of the global backpack market from 2006 to 2015, by segment (in million U.S. dollars) Release date July 2011.

[17] S.O. Ismaila. Safe backpack weight limit for secondary school students in Ibadan, Southwestern Nigeria. Department of Mechanical Engineering, Federal University of Agriculture, P.M.B. 2240, Abeokuta, Ogun State, Nigeria. 9 January 2017.

[18] Steven Dowshen, MD. Backpack safety. August 2016.

[19] Peng B1, Pang X, Li D, Yang H: Cervical spondylosis and hypertension: a clinical study of 2 cases; 2015 Mar; Available from:

https://www.ncbi.nlm.nih.gov/pubmed/25761188

[20] PETER GRICKEJ: 5 Negative Effects of Bad Posture on Your Body and Mind; JUNE 20, 2014; Available from: http://posturebly.com/5-negative-effects-of-bad-posture-on-your-body-and-mind

[21] Thomas Lewandowski: How much weight does the average US Army soldier carry on each part of their body; May 18, 2017. Available from: https://www.quora.com/How-much-weight-does-the-average-US-Army-soldier-carry-on-each-part-of-their-body

[22] P.O. Box 9106, Norwood, MA 02062-9106, U.S.A. Available from: https://www.sparkfun.com/datasheets/Sensors/Accelerometer/ADXL345.pdf

[23] EDWinXP – An Integrated EDA Software Package. Available from: https://zh.scribd.com/document/101615635/Datasheet-EDWINXP

[24] MAYLAB; Wikipedia. 26 April 2018. Available from:

https://en.wikipedia.org/wiki/MATLAB

[25] Android Studio; Wikipedia. 3 May 2018. Available from:

https://translate.google.cn/#en/zh-CN/3%20May%202018

[26] lady ada. Using an FSR. 2015-11-19 at 06.27.23 PM. Available from: https://learn.adafruit.com/force-sensitive-resistor-fsr/using-an-fsr

[27] BU-104a: Comparing the Battery with Other Power Sources; Available from:

http://batteryuniversity.com/learn/article/comparing_the_battery_with_other_power_sources

[28] Ramprasad M1, Alias J, Raghuveer AK. Effect of backpack weight on postural angles in preadolescent children. Epub 2009 Oct 14, Indian Pediatr. Available from: https://www.ncbi.nlm.nih.gov/pubmed/20019396

[29] lady ada. PIR Motion Sensor. Available from: https://learn.adafruit.com/pir-passive-infrared-proximity-motion-sensor?view=all

[30] June Mung Yuing Hu, Karen Jacobs. Backpack usage and self-reported musculoskeletal discomfort in university students. Boston University; 2008.

[31] Treanor, Brian, *Aspects of alterity: Levinas, Marcel, and the contemporary debate*, Fordham University Press, 2006

[32] Engle, Eric, *Lex Naturalis, Ius Naturalis: Law as Positive Reasoning & Natural Rationality*, The Rlias Clark Group, Melbourne, 2010

[33] Qinqing Chen, Xiao Su. Hardware Design Document.

[34] Qinqing Chen, Xiao Su. Software Design Document.

10 Appendix

Relative position of the shoulder strap

People	Single shoulder length	Shoulder strap position (relative to the spine)
Adults (including different body types)	20cm to 26cm	10cm to 14cm
Children 9 to 12 years old	11cm to 15cm	5cm to 8cm
Teenagers 13 to 16 years old	15cm to 22cm	7.5cm to 11cm

Table.1 relative position of the shoulder strap

Force analysis calculation

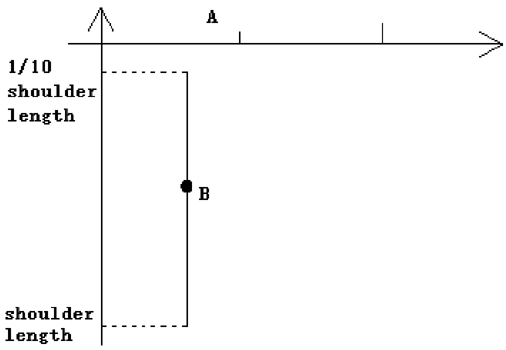


Fig.9 The range of change of coordinate point B

Set the shoulder length be n, then the coordinate of A is $(0,\frac{n}{2})$, as well as the coordinate range of B is $(\frac{n}{2}$-z, 1/10n) to $(\frac{n}{2}$-z, n)

Since the coordinate point B forms a right triangle with respect to the coordinate point A (Fig. 10), the length of the AB can be changed by the Pythagorean theorem:

$$\sqrt{z^2+(\frac{1}{10}n)^2}=\sqrt{z^2+\frac{n^2}{100}} \quad \text{to} \quad \sqrt{z^2+n^2}$$

Therefore, the variation range of sin(θ) can be obtained from the sine theorem:

$$\frac{z}{\sqrt{z^2+\frac{n^2}{100}}} \text{ to } \frac{z}{\sqrt{z^2+n^2}}$$

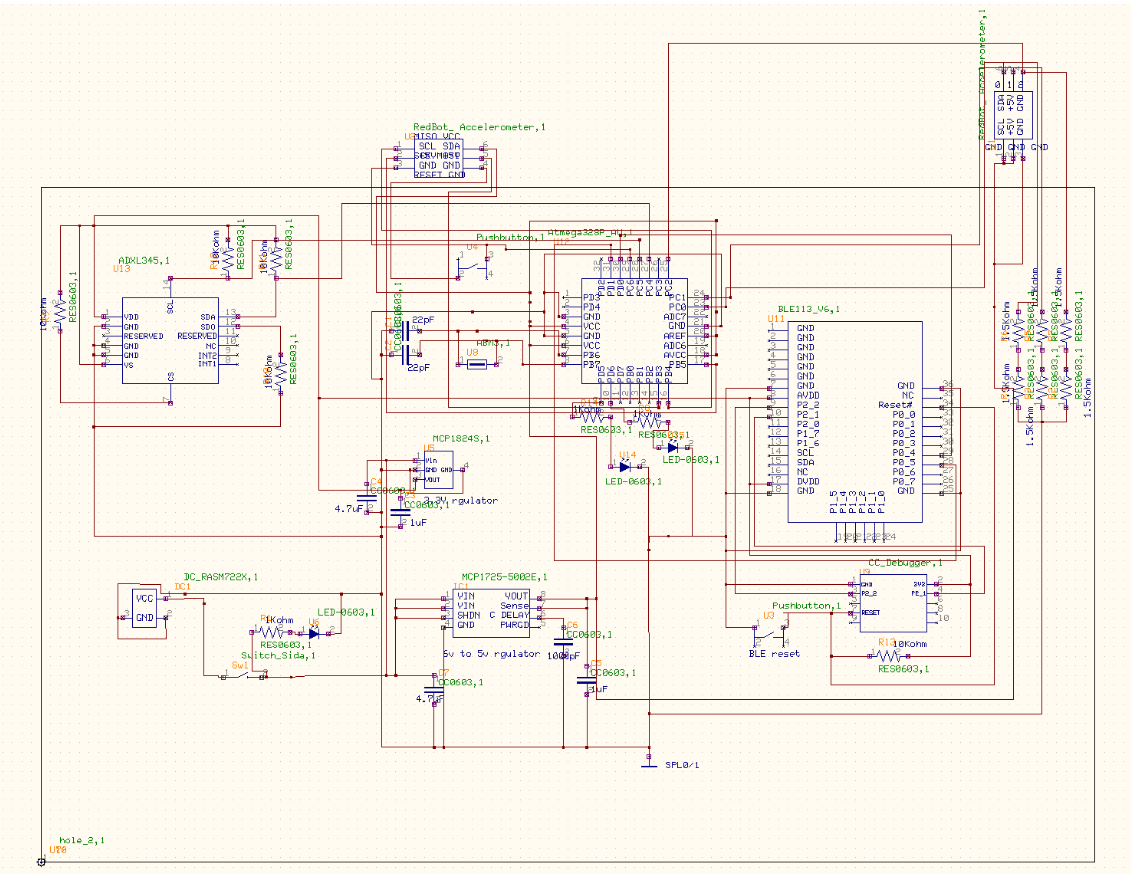
Which is,

$$\sin(\theta) \in [\frac{z}{\sqrt{z^2+n^2}}, \frac{z}{\sqrt{z^2+\frac{n^2}{100}}}]$$

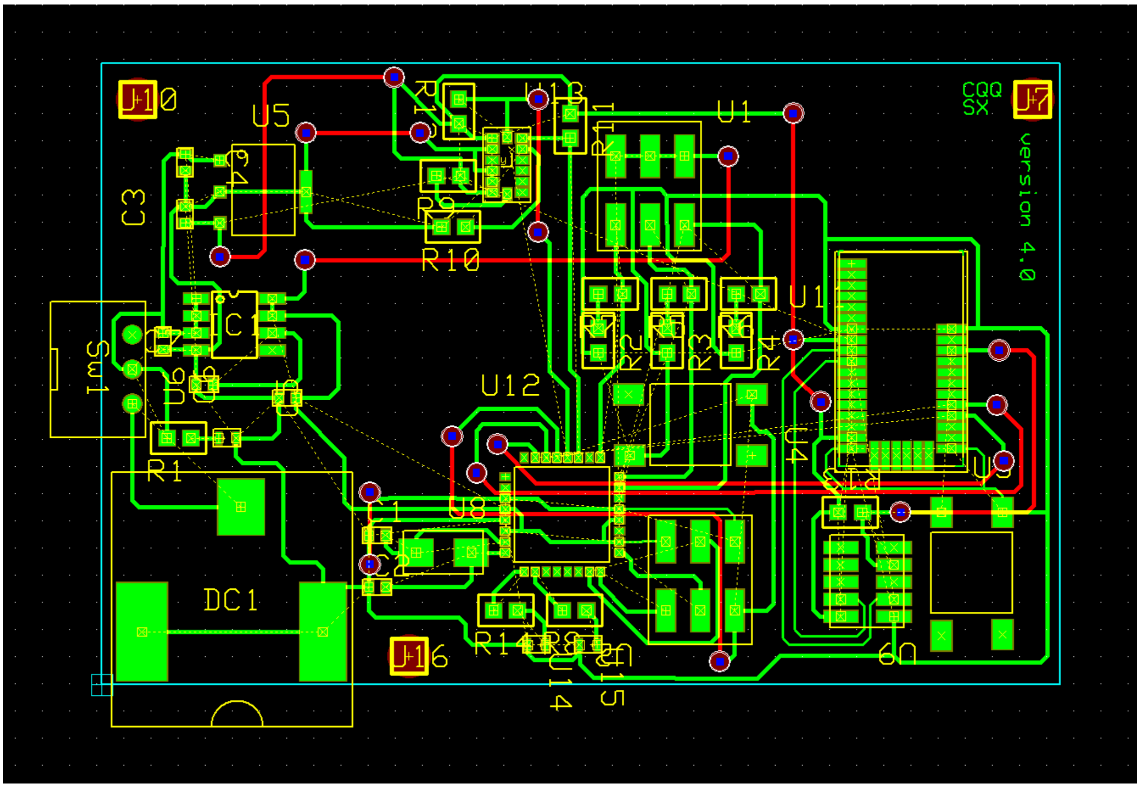
From the cosine theorem: “$\cos(\theta)=\frac{1}{\sin(\theta)}$”

$$\cos(\theta) \in [\frac{\sqrt{z^2+\frac{n^2}{100}}}{z}, \frac{\sqrt{z^2+n^2}}{z}]$$

System Schematic



PCB Layout



FSR sensor data sheet:

Delay=200ms, only connect 3KΩ resistor:

Heavy	sensor value
200.6g≈200g	482 to 487
400.5g≈400g	571 to 575
601.5g≈600g	624 to 631
800.5g≈800g	626 to 633
1001g≈1000g	706 to 710
1202g≈1200g	729 to 731
1400g≈1400g	757 to 761
1598g≈1600g	790 to 795
1802g≈1800g	795 to 800
2001g≈2000g	810 to 813

2201g≈2200g	814 to 816
2402g≈2400g	844 to 849
2599g≈2600g	868 to 872
2798g≈2800g	869 to 872
3001g≈3000g	873 to 875
3201g≈3200g	892 to 893
3402g≈3400g	894 to 895
3601g≈3600g	895 to 896
3798g≈3800g	896 to 897
4001g≈4000g	897 to 898
4201g≈4200g	899 to 900
4401g≈4400g	900 to 902
4602g≈4600g	902 to 903
4803g≈4800g	903 to 904
5001g≈5000g	904 to 907
5002g≈5200g	908 to 910
5401g≈5400g	910 to 913
5601g≈5600g	914 to 916
5801g≈5800g	916 to 918
6001g≈6000g	919 to 921
6201g≈6200g	921 to 923
6402g≈6400g	923 to 925
6601g≈6600g	925 to 928
6802g≈6800g	929 to 930
7001g≈7000g	931 to 933
7203g≈7200g	934 to 935

7401g≈7400g	936 to 937
7602g≈7600g	949 to 940
7803g≈7800g	941 to 942
8002g≈8000g	942 to 944
8201g≈8200g	944 to 945
8401g≈8400g	944 to 945
8602g≈8600g	945
8800g≈8800g	945 to 946
9002g≈9000g	946 to 947
9201g≈9200g	947 to 948
9401g≈9400g	947 to 948
9602g≈9600g	948 to 949
9803g≈9800g	950 to 951
9998g≈10000g	952 to 954

Load position experimental data

Load Position: Bottom of the backpack

Weight	sensor value	sensor value2	sensor value3
500g	247 to 334	311 to 268	206 to 183
1000g	372 to 407	535 to 503	343 to 210
1500g	390 to 465	513 to 563	409 to 470
2000g	476 to 536	599 to 615	479 to 542
2500g	539 to 543	624 to 669	631 to 658
3000g	545 to 591	580 to 611	640 to 680

3500g	567 to 580	591 to 612	650 to 681
4000g	578 to 599	597 to 614	662 to 684
4500g	594 to 603	604 to 615	676 to 689
5000g	649 to 659	597 to 619	607 to 660
5500g	650 to 660	602 to 621	607 to 661
6000g	662 to 668	615 to 627	615 to 671
6500g	670 to 679	635 to 652	634 to 679
7000g	684 to 689	667 to 689	688 to 699
7500g	687 to 692	696 to 720	702 to 706
8000g	690 to 694	734 to 749	709 to 712
8500g	694 to 695	748 to 767	724 to 738
9000g	695 to 700	769 to 775	745 to 769
9500g	700 to 710	781 to 793	769 to 776
10000g	709 to 762	795 to 805	770 to 792
10500g	767 to 774	794 to 807	784 to 793
11000g	774 to 779	695 to 696	789 to 796
11500g	776 to 785	695 to 696	790 to 798
12000g	780 to 794	694 to 698	792 to 795
13000g	794 to 784	703 to 723	784 to 799
14000g	786 to 796	704 to 732	782 to 805
15000g	799 to 820	755 to 773	780 to 809
16000g	795 to 825	764 to 776	794 to 793
17000g	803 to 826	778 to 784	799 to 806
18000g	804 to 827	784 to 802	801 to 814

19000g	804 to 829	789 to 804	800 to 824
20000g	804 to 830	789 to 809	800 to 827

Load Position: Close to the back

Weight	sensor value	sensor value2	sensor value3
500g	257 to 324	351 to 308	176 to 153
1000g	352 to 384	575 to 543	286 to 250
1500g	360 to 415	553 to 603	369 to 460
2000g	446 to 486	639 to 655	429 to 542
2500g	509 to 493	664 to 709	481 to 658
3000g	515 to 541	620 to 651	570 to 680
3500g	547 to 550	631 to 652	610 to 681
4000g	558 to 559	637 to 654	582 to 684
4500g	564 to 583	644 to 655	636 to 689
5000g	609 to 659	637 to 659	567 to 660
5500g	610 to 640	642 to 671	567 to 661
6000g	622 to 648	655 to 677	575 to 671
6500g	630 to 659	675 to 692	594 to 679
7000g	644 to 669	707 to 729	648 to 699
7500g	647 to 672	736 to 760	662 to 706
8000g	650 to 674	774 to 789	669 to 772
8500g	654 to 675	788 to 807	684 to 738
9000g	675 to 680	809 to 815	705 to 769
9500g	682 to 690	821 to 833	729 to 776

10000g	686 to 732	835 to 845	730 to 792
10500g	737 to 734	834 to 847	744 to 793
11000g	744 to 739	735 to 736	749 to 796
11500g	746 to 745	735 to 736	750 to 798
12000g	750 to 764	734 to 738	752 to 795
13000g	764 to 764	743 to 763	744 to 799
14000g	756 to 776	744 to 762	742 to 805
15000g	769 to 790	795 to 763	740 to 809
16000g	775 to 795	804 to 816	774 to 803
17000g	786 to 800	818 to 824	749 to 806
18000g	794 to 814	824 to 842	761 to 814
19000g	799 to 815	829 to 844	770 to 824
20000g	800 to 816	829 to 849	770 to 827

Load Position: Near the outside of the backpack

Weight	sensor value	sensor value2	sensor value3
500g	287 to 374	271 to 658	246 to 223
1000g	412 to 457	495 to 473	383 to 210
1500g	430 to 505	483 to 533	449 to 470
2000g	516 to 566	569 to 585	519 to 542

2500g	579 to 583	594 to 639	671 to 658
3000g	585 to 601	550 to 581	680 to 680
3500g	607 to 610	561 to 582	690 to 681
4000g	618 to 629	567 to 584	702 to 684
4500g	634 to 633	564 to 585	716 to 689
5000g	689 to 689	567 to 589	647 to 660
5500g	690 to 708	572 to 591	647 to 661
6000g	702 to 718	585 to 597	655 to 671
6500g	710 to 719	605 to 622	674 to 679
7000g	724 to 729	627 to 659	728 to 699
7500g	727 to 732	656 to 690	732 to 706
8000g	730 to 739	694 to 719	739 to 712
8500g	734 to 735	718 to 737	754 to 738
9000g	735 to 740	739 to 745	775 to 769
9500g	740 to 750	751 to 763	801 to 776
10000g	759 to 792	765 to 775	810 to 792
10500g	717 to 804	764 to 777	824 to 793
11000g	804 to 819	665 to 666	829 to 796
11500g	816 to 825	665 to 666	830 to 798
12000g	820 to 834	664 to 668	832 to 795
13000g	824 to 834	673 to 693	824 to 799
14000g	826 to 836	674 to 702	822 to 805
15000g	829 to 850	725 to 703	820 to 809
16000g	835 to 865	734 to 746	834 to 793

17000g	843 to 866	748 to 754	839 to 806
18000g	844 to 867	754 to 772	841 to 814
19000g	844 to 859	759 to 774	840 to 824
20000g	844 to 860	759 to 779	840 to 827