

## Backpack Effects on Two-Dimensional Gait Spatiotemporal and Kinematic Parameters

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### ABSTRACT

Loads could affect the body gait in various ways. Backpacks, sling bags, suitcases, and even trolleys could hugely affect human gait without us realizing it. The effects of these loads have been scientifically researched in biomechanics and sports science for the past few years. For instance, the comparison of walking with and without a backpack could easily reveal significant differences in body segments, which could be utilized for therapy and medicine development. The aim of this research is to determine the differences of the spatiotemporal kinematic parameters between a conventional human gait and a backpack-loaded gait. Some parameters to be highlighted are stride lengths, stride duration, joint angles, linear and angular segment positions, velocities, and accelerations. The method used for marker data acquisition is based on the 2-dimensional Direct Linear Transformation. The results demonstrate that the backpack increases stride lengths and reduces stride duration, contrast to the expected where backpacks would reduce stride lengths. It was observed that the angle between the bag and the body posterior affects the abdomen relative angle, which directly translates to stride lengths as well. During unloaded walking, increases in pelvic rotation contribute to increases in stride length with increasing walking speed. However, in loaded walking, the back angle is also a factor in determining kinematic parameters.

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**Keywords:** Comparison, Direct Linear Transformation, gait, kinematic parameters, loads, spatiotemporal, stride

## I. Introduction

The smallest difference in the body behavior, external or internal, could be observed from the human gait. Studies in psychophysics reveal that humans are capable of recognizing people from impoverished displays of gait, indicating the presence of identity information in the gait signature [1]. Carriage of backpacks applies a substantial load to the spine [2],[3].

Backpack weights carried by students are at least 10% of their body weight [2]. According to Paez-Moguer et al., their experimental study showed that increased backpack loads alter gait parameters [4]. The stance load response and swing phases had a significantly greater duration for the 15 and 20% weight children than those with baseline weight. Adding weight to the body using a backpack will shift the centre of gravity toward the rear of the base of support (feet). This combination of increased load and postural change can alter gait patterns. Paez-Moguer et al. found increased value in both double limb support and stance phase, single support, swing, and contact phase, from baseline to loads of 15% and 20%



body weight. Their results indicated that carrying a backpack requires children to increase the time spent on both feet to manage this load during gait. Some children walked more slowly to manage the weight, yet secondly, and by way of contrast, other children increased their speed in response to loading.

In contrast, Pau et al. found that spatiotemporal parameters were unaffected by backpack carriage from two hundred-eighteen school children's gait. However, they also reported that there are significant increases (up to 25%) in plantar pressures found during both static standing and walking, especially in the forefoot by carrying a mean mass in their backpacks of 5.2 kg (at least 10% of their weight) [5]. Based on the results of Dames and Smith [6] on the effects of load carriage on human gait, it mentioned that lower limb kinematic differences were noted in response to both loading and footwear. Changes in spatiotemporal parameters observed when walking barefoot were not exacerbated by the addition of a backpack load.

Demia et al., which studied walking with a heavily loaded carriage, show significant effects of loading in joints that influenced subjects' walking kinematic parameters [7]. Zaheer et al. also found a significant association between heavy bag lifting and poor posture with related pain in regions of the cervical followed by upper back in secondary school students [8]. Dockrell et al. stated that the recommended load limit for schoolchildren to carry varies from 5% to 20% of their body weight, and the evidence linking backpack weight and back pain is inconclusive [9].

The present study focused on the gait of a 20-year-old student as a subject. The gait being examined are subject's gait while carrying a bag containing the general needs of lectures, such as books, laptops, stationery, and drinks, or while not carrying a bag. The present study aims to determine the difference in spatiotemporal kinematic parameters between a natural conventional gait and a natural backpack-loaded gait. Camera calibration is based on markers and 2-dimension Direct Linear Transformation. Parameters to be observed are stride lengths, stride duration, joint angles, linear and angular segment positions, velocities, and accelerations. Therefore, this study will help develop studies on biomechanics, sports science, medicine, or therapies in developing their own specialties for a backpack-loaded gait.

## II. Material and Methods

The tools utilized were LED lights as markers, a video camera, a tight black suit, and software capable of tracking objects in a video. There are 5 LED lights needed to mark the subject's joints while the subject wore a tight black suit. These joints were: Right shoulder (1), torso (2), right hip (3), right knee (4), and right foot ankle (5), as shown in Fig. 1.

With these markers, the observation was made at the sagittal plane because the author expects that the significant influence due to backpack usage on the subject's movement would occur in this plane. Using the LED lights as markers, the experiment was conducted inside a dark room and recorded by a 60-frame-per-second video camera. Figure 2 illustrates the schematic of the recording.

The experiment was done within 2 conditions. For the first condition, the subject walked for 3 meters straight wearing a backpack of 4.76 kilograms, and then for the next condition, the subject walked straight for 3 meters without wearing the backpack. Before recording the movement, the subject was asked to practice walking following the path for a few moments until he got used to it. The purpose of these methods was to get the result as similar as a

normal walking movement. But, prior to the data collection, camera calibration needs to be performed first. First, measure the length of objects in real life and then compare it to what is detected in the image that being captured by the camera. The quality and the shutter speed for calibration's video recording must be the same as in the data's video recording. The calibration's recorded video will be extracted into frames (pictures), and then select one of the pictures to detect points as a camera calibration reference. Figure 3 shows the camera calibration reference.

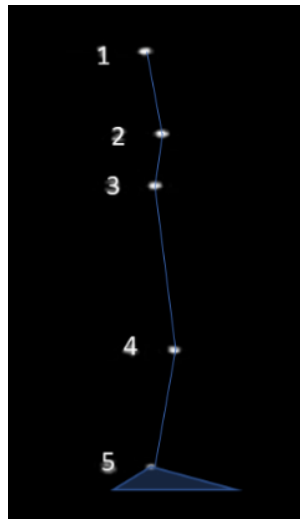


Fig. 1. Marker Placement

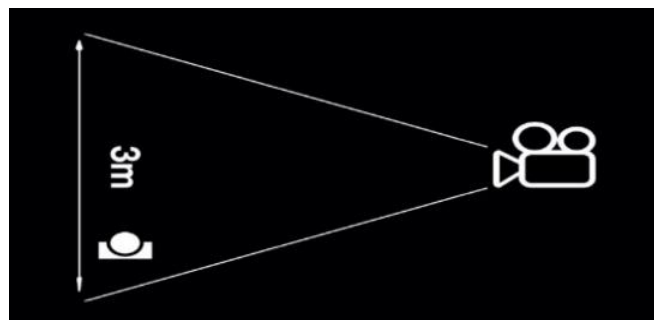


Fig. 2. Schematic of motion capture data acquisition

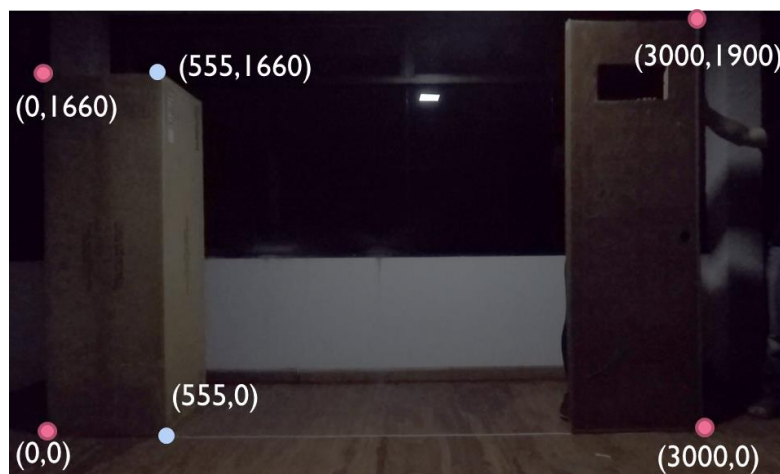


Fig. 3. Camera calibration reference

The rest of the process was done in MATLAB. The first step was to calibrate the reference picture from camera's pixel to obtain a metric scale. Calibration was done using the DLT method [10, 11]. The process in recording images using a camera is equivalent to mapping object point  $O$  in the object space to image point  $I'$  in the film plane, as shown in Figure 4 (a). This recorded image would be projected again to image  $I$  in the projection plane for digitization, as shown in Figure 4 (b). DLT method has a collinearity condition basis. The optical system of the camera/projector maps point  $O$  in the object space to image  $I$  in the image plane.  $[x, y, z]$  was the object-space coordinates of point  $O$ , while  $[u, v]$  was the image-plane coordinates of the image point  $I$ . Points  $I, N$  &  $O$  thus are collinear, as shown in Figure 4(c) [12].

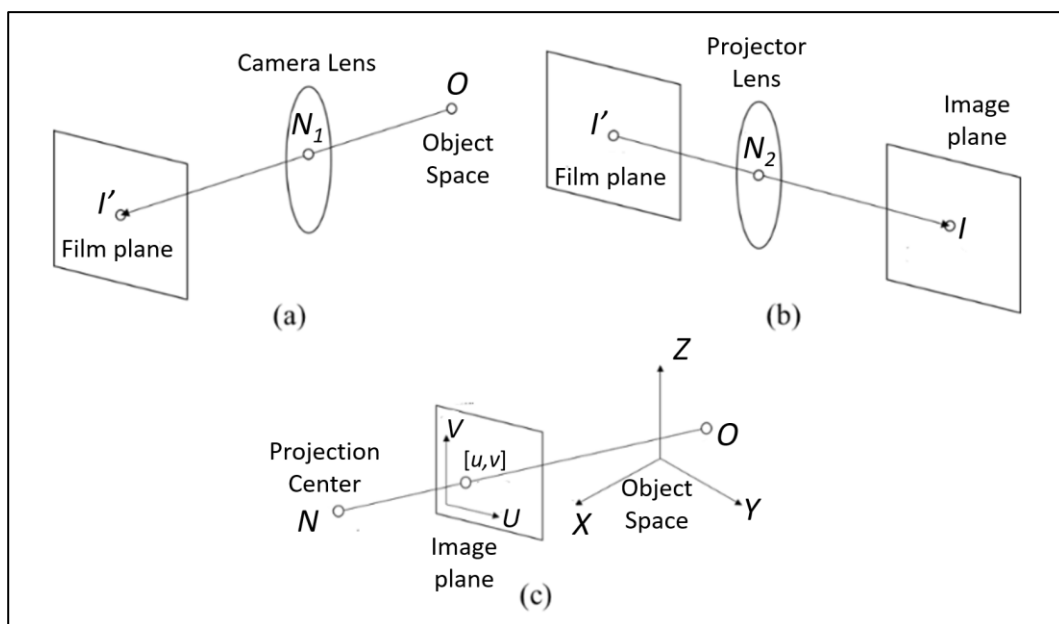


Fig. 4. (a) mapping object point  $O$  in the object space to image point  $I'$  in the film plane, (b) projection from  $I'$  in the film plane to image  $I$  in the projection plane, and (c) illustration of the relation projected image and the object [12].

After using DLT methods, the root mean square function [13] was used to calculate the error in image detection of points in Figure 3 that have been measured before.

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (X_i - X'_i)^2}{n}} \dots \dots \dots (1)$$

Where  $X_i$  refers to the point that we measure,  $X'_i$  refers to the point detected using the DLT method, and  $n$  is the number of data. After performing the calculation, we obtained the errors of the image processing in the  $X$  direction was 5.148 mm and in the  $Y$  direction was 4.9 mm.

The next step was video extraction and processing. The recorded video was extracted into frames, then the frames were converted into black and white pictures with a 0.7 threshold level so that there would be no other light source in the frame other than the LED marker lights. The function region properties were then used to detect the position of the white points (light) centroid for every frame. These centroid data then would be named based on their position from top to bottom. However, some frames had one or more markers blocked by the subject's limb while recording the movement. Therefore, to acquire the

missing data, the regression method was used. Since the coordinates obtained in the previous step were pixelated, these coordinates were converted into GCS (Global Coordinate System) coordinate by using the scale calculated from the calibration frame. From this point, the position coordinates were obtained. The next step was to calculate the velocity data smoothing. Data smoothing utilizing the spline method was used to smooth the position coordinates so it would be easier to differentiate the position of the coordinates numerically. The method was done as such in order to obtain the velocity and acceleration when the velocity data was smoothed and differentiated numerically again. The linear velocity and acceleration were calculated using a finite difference equation [14]. This method was selected because of its simplicity. The requirements of linearity were already satisfied due to small time step between each data point.

$$Velocity = \frac{(Change\ in\ displacement)}{(Change\ in\ time)} \dots\dots\dots (2)$$

$$Acceleration = \frac{(Change\ in\ velocity)}{(Change\ in\ time)} \dots\dots\dots (3)$$

Spatiotemporal parameters, such as stride duration and stride length, are obtained from the GCS coordinate data.

Segment angles were defined as the angle of the segment with respect to a right-horizontal line originating from proximal end of the segment [15]. The illustration in segment angles is shown in Figure 5.

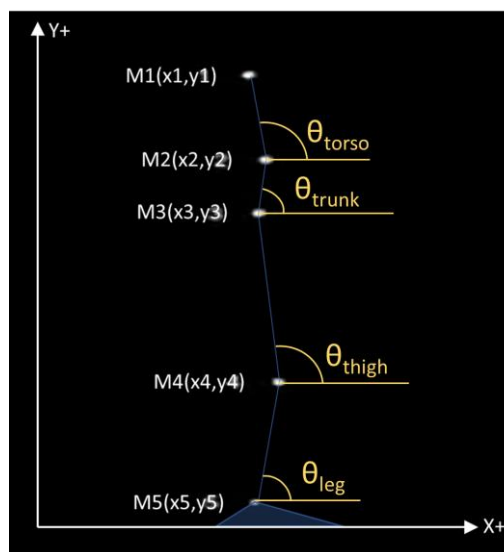


Fig. 5. Angular kinematics parameter modeling

Angular velocity ( $\omega$ ) and acceleration ( $\alpha$ ) were calculated using a finite difference equation [15].

$$\omega_i = \frac{\theta_{i+1} - \theta_{i-1}}{2 (\Delta t)} \dots\dots\dots (4)$$

$$\alpha_i = \frac{\omega_{i+1} - \omega_{i-1}}{2 (\Delta t)} \dots\dots\dots (5)$$

$$\text{or } \omega_i = \frac{\theta_{i+1} - 2 \theta_i + \theta_{i-1}}{2 (\Delta t)} \dots\dots\dots (6)$$

where  $\theta$  represents the angular position and  $\Delta t$  represents the time duration between adjacent data points which in this case one over frame per second used in the camera during recording.

### III. Results and Discussions

From the data processing that has been done, the results such as right shoulder (M1), torso (M2), right hip (M3), right knee (M4), and the right foot ankle (M5) markers' linear kinematics have been found. The results then plotted into graphs such as markers' position which plotted X coordinate in mm respected to Y coordinate in mm, then markers' velocity and acceleration which plotted respected to time domain (seconds). The graph example is shown in Figure 6. There are two lines in Figure 6 (a), (b), and (c) for knee linear kinematic parameters, where the red line represents data when the subject did not carry backpack and blue line represents data when the subject carried backpack. Phase shift noticed in Figure 6 (a) was  $x$ -directional differences between "with bag" and "without bag" subject's initial contact due to overground walking movement that was not captured at the same time.

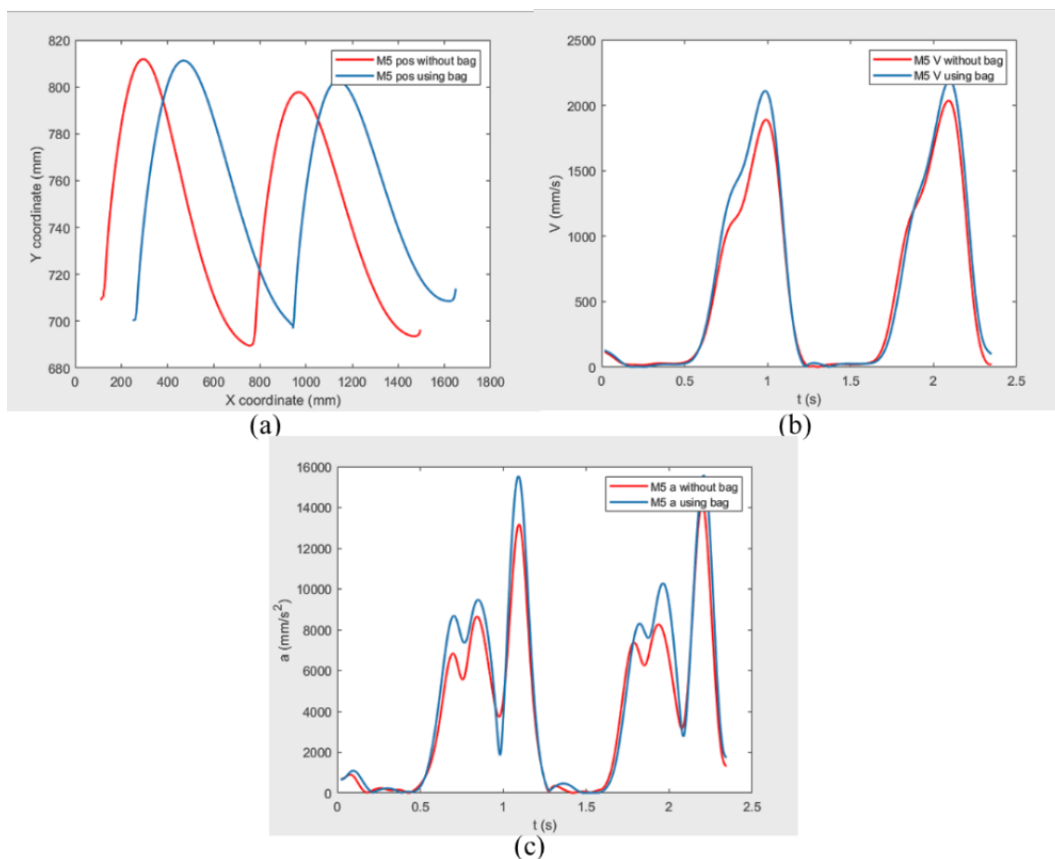


Fig. 6. Ankle marker (M5) (a) position, (b) velocity, (c) acceleration

The result also shows angular kinematics of back, hip and knee condition. It shows an angular position in degree, velocity and acceleration graphs which plot respected to the time domain (seconds). The graph example is shown in Figure 7. There are two lines in Figure 7 (a), (b), and (c) for knee angle angular kinematics parameters, where the red line represents data when the subject did not carry backpack, and the blue line represents data when the subject carried backpack.

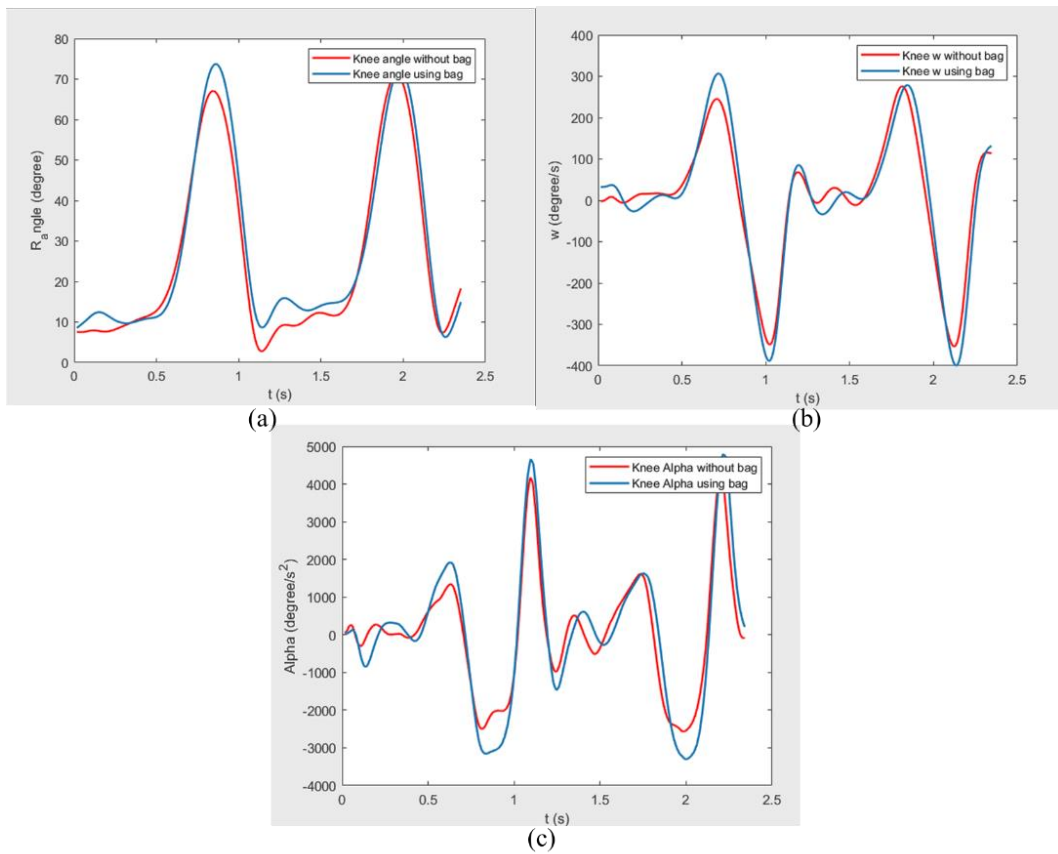


Fig. 7. Knee angle (a) position, (b) velocity, (c) acceleration

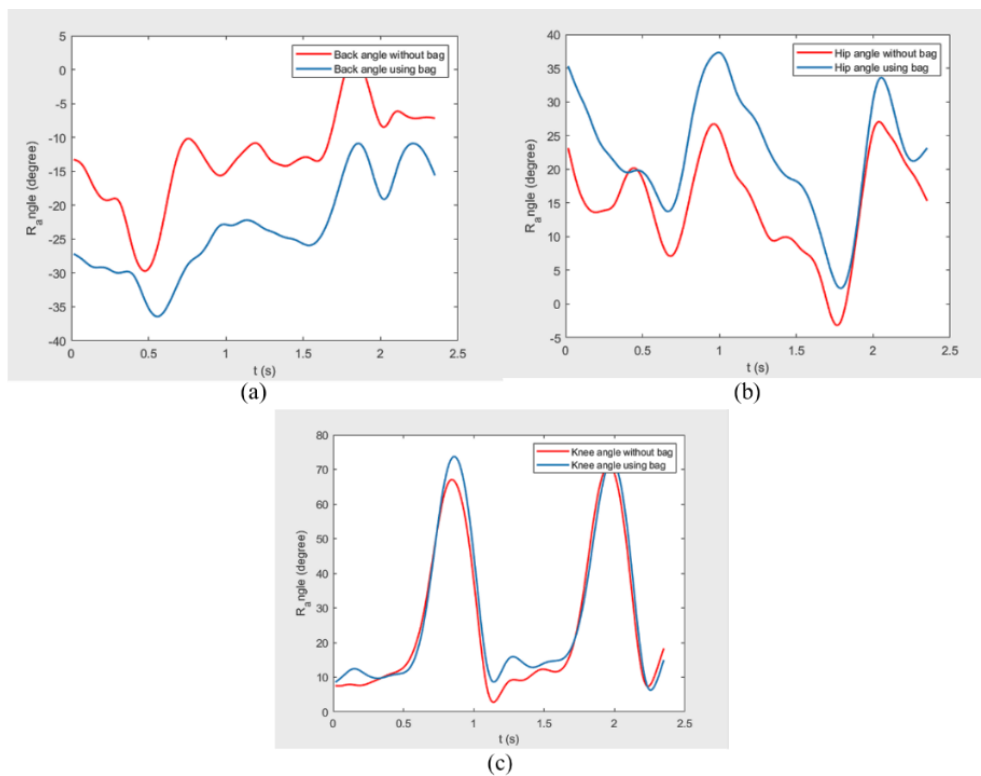


Fig. 8. Angle (a) back, (b) hip, and (c) knee

From data in Figure 6, the spatiotemporal parameters for the walking condition while using backpack or not are also obtained. The subject while walking without using backpack has 1347 mm step length, 673.5 mm stride length, 1.17 seconds period, and 0.86 seconds cadence. While walking using a backpack, the subject has a longer step length, which is 1365 mm, and a longer stride length, which is 682.5 mm, but a shorter period and cadence, which are 1.15 seconds and 0.87 seconds. Those differences were about 1.34% relative difference for step length and stride length, 1.74% relative difference for period, respectively.

Subject back angle, hip angle, and knee angle are plotted in a graph with respect to time is shown in Figure 8 (a), (b), and (c), where the red line represents the data while the subject was not using backpack and the blue line where the subject was using a backpack. It appears in Figure 8 (a), (b), and (c). The trends are the same, although the values are different for “with bag” and “without bag”.

Subject’s upper body posture while using backpack is pulled backward compared to the posture without a backpack. It can be seen in the negative value of the angle and the illustration figure from data processing that is shown in Figure 9.

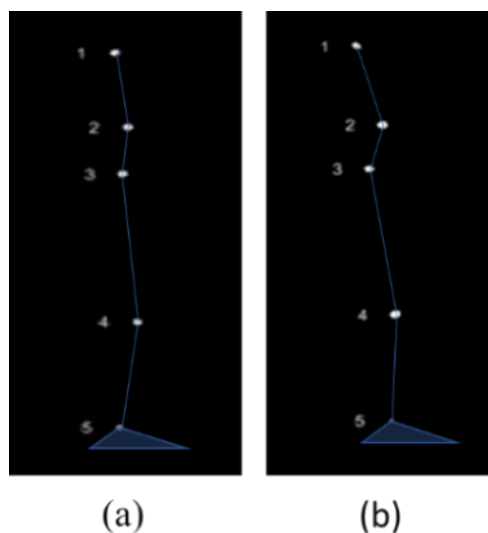


Fig. 9. Subject illustration (a) without using a backpack and (b) using a backpack

#### IV. Conclusions

Based on the results that have been obtained, loaded walking increases stride frequency and stride length. In most cases, stride length would decrease. The project found out that the back angle is also a determining factor in spatiotemporal kinematic parameters. The subject with the bag tightened up to the body, which minimizes the angle between the bag and the body posterior, increasing pelvis rotation and directly translates to the increment of the stride length.

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