EFFECT OF CARRYING SYMMETRIC AND ASYMMETRIC WEIGHTS ON GAIT PARAMETERS AND LATERAL SPINAL FLEXION

RAHUL DAS
IIT Kharagpur, Department of Mechanical Engineering
Kharagpur, 721302 India
rahuldas.email@gmail.com

ROHIT DHUME
IIT Kharagpur, Department of Mechanical Engineering
Kharagpur, 721302 India
rohit.dhume@gmail.com

SRIDHAR IYER
IIT Kharagpur, Department of Mechanical Engineering
Kharagpur, 721302 India
sridhar.iyer90@gmail.com

Abstract:

This paper attempts to document the variations in step length, step frequency and spinal lateral flexion for persons carrying a load (e.g. grocery bags) in one or both arms against those for no load condition over one gait cycle. The variation in the said parameters was obtained from six test subject in the age group 19 – 21 years as they carried different weights. A MATLAB code was developed to obtain the coordinates of key points using image processing and to calculate the flexion angles. A significant reduction in step length and a corresponding increase in step frequency were observed while carrying a weight as compared to without any weight. Similar lateral flexion variation was observed for each subject and the maximum value of the angle was obtained for asymmetric loading and occurred at the beginning of the swing phase of the foot on the loading side.

1. Introduction

1.1 Present literature

A large amount of literature is available regarding the measurement of gait and its associated parameters. In particular the changes in gait on carrying heavy weights have been well analysed in the papers of A Rohlmann *et al* (2012) and J.Kapnik *et al* (1996).

However most of the research has been concentrated on the effect of loading while carrying heavy bags on the shoulders or the back. Attention was drawn mostly to this area because the effect of school bags on children was found to be of utmost interest as well as in case of soldiers who carry heavy backpacks.

This paper aims to address the question about changes in important gait parameters when weight is carried on the arms. This is a common scenario that is seen while lifting heavy shopping bags or suitcases while travelling.

We attempt to use a novel video capture system akin to the system used by G. Bergmann *et al* (2001). which used infrared markers and a series of cameras to record motions of subjects and developing biomechanical models.

1.2 Introduction to gait and lateral flexion

Gait is defined as the manner of walking. The human gait cycle consists of mainly the Stance phase and the Swing phase as shown in figure 1. The stance phase makes up about 60% and the swing phase makes up 40% of the gait cycle. The basic gait parameters most frequently used are velocity, step length and step frequency.

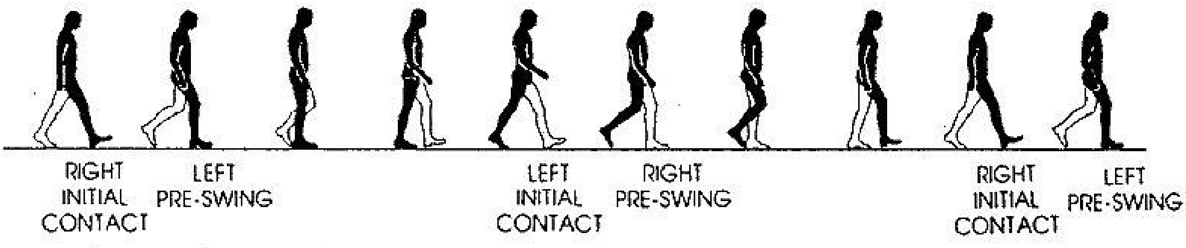

Figure 1Phases of the Gait Cycle

Step Length is defined as the distance from the heel print of one foot to the heel print of the other foot as shown in figure 2.

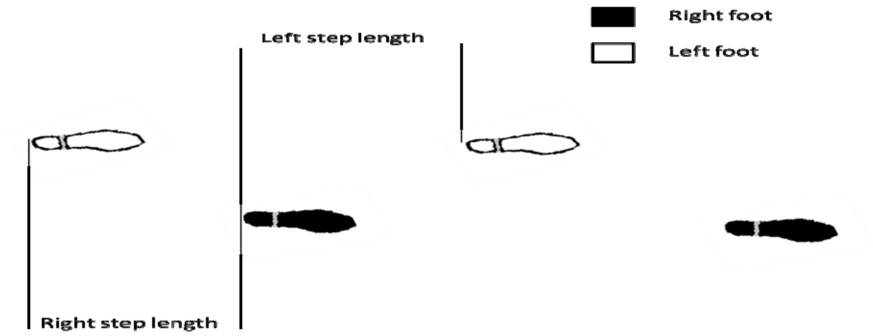

Figure 2 Measurement of Step Length

Lateral flexion refers to the bending of the spine to one side away from the midline of the body.

Changes in three key parameters were recorded for persons carrying varying load, i.e. Step length, frequency and lateral flexion. Previous research suggests that the step length decreases with increase in the load that a person carries. Moreover this is accompanied an increase in the double support time and also an increase in the step frequency.

The variation in lateral flexion has not been extensively documented in the literature and this paper attempts to rectify the same.

2. Methodology

Six male test subjects were selected between the ages of 19 and 21 years with no physical impairments.

2.1 Outer clothing

Subjects wore normal outer clothing secured with pins to prevent significant warping due to motion and atmospheric disturbances. To simulate a realistic experience we used weights placed within similar receptacles with handles, mimicking a person carrying heavy bags.

2.2 Markers

Fluorescent markers were attached to key locations on the subjects' outer clothing to obtain motion of joints and limbs. Markers were made of 1.5 inch green crosses superimposed on a black background to enhance the contrast for easy extraction from the image.

2.3 Measurements

Subjects wore commercially available sports shoes whose soles were stained with ink. During motion, a trail was left behind on the walkway for each of the strides. The markings were then used to calculate the step lengths for each of the subjects. Individual step lengths for right and left steps were measured from the markings for the entire cycle and then averaged to get the step length of the subject. The lateral flexion angle was measured by taking four key points, two on the lower torso and two on the upper torso. The points were subsequently paired and a line was drawn through each of these pair of points. The acute angle formed between these lines was taken as the lateral flexion of the spine.

2.4 Motion Capture

Motion was captured using two SONY Cybershot DSC-W510 cameras. Cameras were placed at two mutually orthogonal positions to the front and side of the subject. A custom test rig with rotating base was used to maintain uniform distance throughout each trial to negate the effect of the forward motion of subject. The side camera was used to calculate step and stride frequency throughout the gait cycle. Frontal camera was used to observe lateral deviation in the spine and other key locations.

Figure 3 Test Subject (Markers have been highlighted in green for clarity)

2.5 Trials

Test subjects performed four trials each, under no loading, with 10KG on left arm, 10KG on right arm and with 10KG symmetrically distributed between both arms. Subjects carried measured weights in receptacles as seen in figure 3.

2.6 Software Processing

The videos were processed using a custom developed MATLAB code. Initially the videos were split into a series of frames using commercially available third party software. The frames were split with a time difference of 0.04 seconds. However the volume of images proved to be too large to allow easy data extraction. Out of the available frames, the steady state gait cycle was taken from the middle of each of the trials to minimize aberrations occurring during starting or stopping of motion. From this set of images, frames with a difference of 0.16 seconds were selected to extract marker co-ordinates.

The software enhanced contrasts between markers and surroundings and extracted the key points' co-ordinates. A biomechanical model of the subject was built by joining the key points as per the limb configurations of the subject. The motion of the subject over the entire gait cycle was interpolated from the co-ordinates obtained. Cubic spline interpolation was used to create a smooth walking motion of the subject. The resulting model was used to calculate the deflection of pertinent angles.

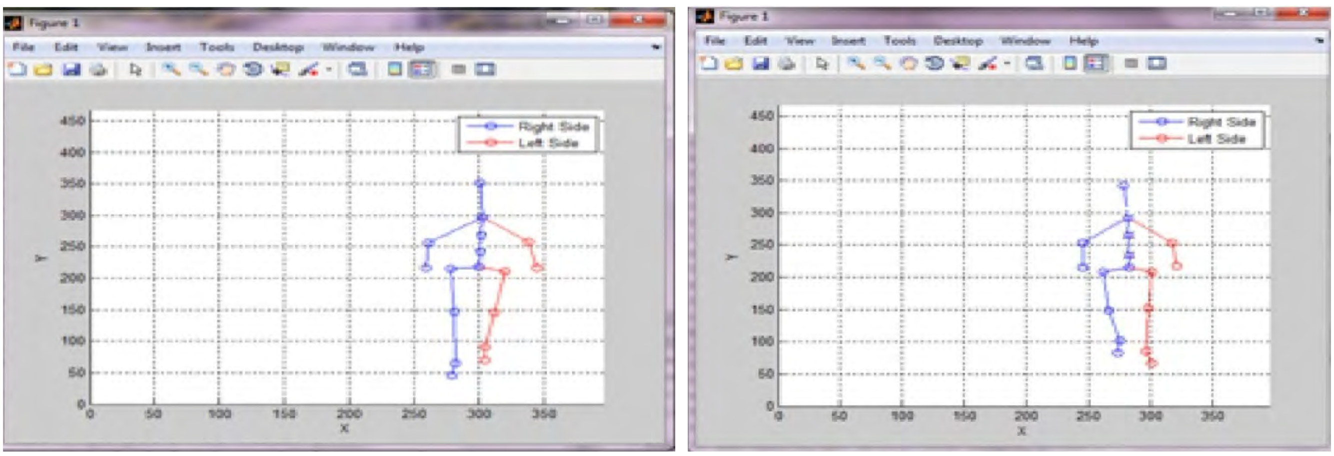

Figure 4 Biomechanical Model

The results for all six subjects were averaged to give the average values of lateral displacement, stride length and step length.

3. Observations and Results

3.1 Frequency of Steps

The frequency of the steps were measured from the side facing video and converted into steps per minute. It was observed that in the cases with assymetrical loading (ie right hand load or left hand loading) there was an increase in the frequency of the steps. However it was surprising to note that there was not much variation in the case when people walked with the weight distributed on both arms.

This is probably because the stability of walking is more important than the mere presence of weight. The asymmetrical distribution of weight makes for a skewed center of gravity which required the subject to reduce the step length and hence increase the frequency of the steps taken. So the subject takes more frequent steps while walking with an asymmetrical load. This deviation in our experiments came out to be a maximum of 4.8% for subject 2 during loading of the right hand.

This is similar to the observations found in J.Knapik *et al (1996)* where the effects of loading on two strap bags are found to be less than that of one strap bags. While the deviation was significant in most cases, it is found that the magnitude of deviation differed from person to person. This is because the subjects were of different heights which led to a difference in absolute values.

Table 1 Steps per minute (both Left and Right)

Sr. no	Normal Walk	Right Loading	Left Loading	Symmetric Loading
1	91.2	91.8	92.4	89.4
2	80	90	88	87
3	96	97	95	91.8
4	85.2	88	87	86
5	81	86.4	84	82
6	89	94	92.5	91
Average	87.06667	91.2	89.81667	87.86667

3.2 ***Step Lengths***

Case	Average Right Step Length	Average Left Step Length
No Load	61	60
Right Load	60.7	67
Left Load	63	58
Symmetric load	59.5	60.5

Table 2 Average Step Lengths

It was observed that while carrying weights, the step length on the opposite side of the load increased (by a maximum of 11%) while the step length on the same side decreased slightly as compared to normal walking.

Step lengths for symmetric loading were almost similar to the normal step length.

3.3 Spinal Lateral Flexion Variation

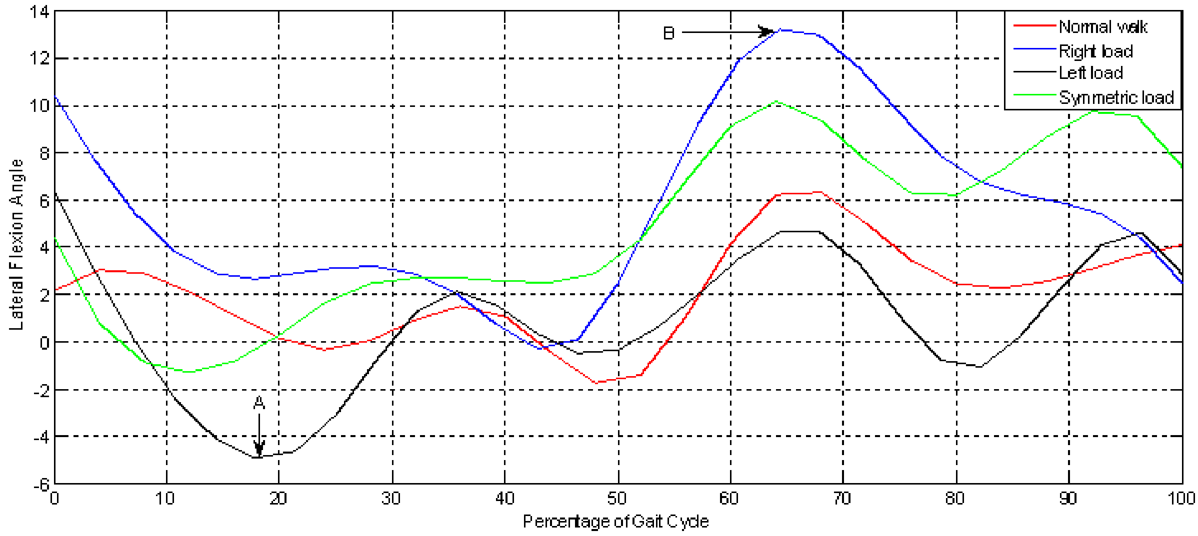

Figure 5 Average spinal lateral flexion versus percentage of gait cycle

The lateral flexion has a direct impact on the posture of the person and is of importance in ergonomic studies. Due to the variation in individual step frequencies and step lengths, lateral flexion angles showed some phase differences. However similar features were obtained in each of the cases albeit at slightly different times.

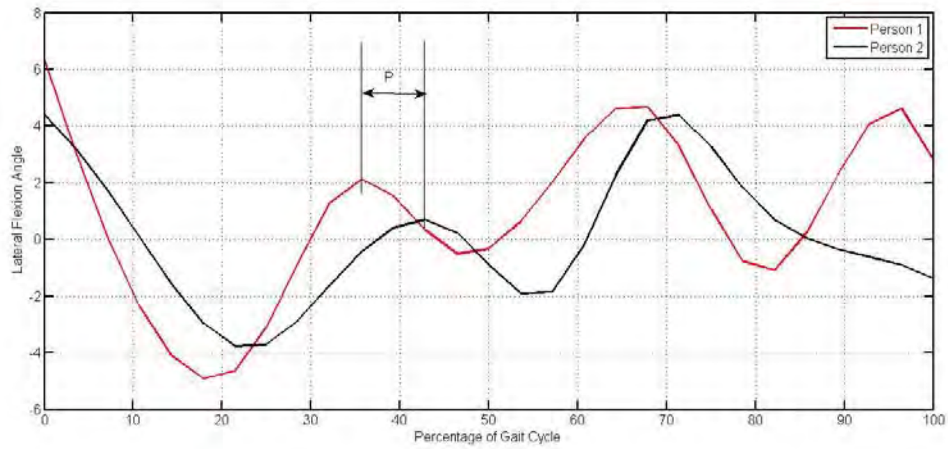

Figure 6 showing phase differences between subject 1 and subject 5

Figure 5 shows the graphs from the analysis of the biometric models between the key points. According to the convention followed, positive flexion angles denoted a lean towards the subject's left side and negative angles denoted a lean towards the subject's right side.

As can be seen from the graph, the maximum and minimum angles were obtained for asymmetrical loading with the angular deflection for no load and normal load conditions falling in between these ranges.

The maximum average positive deflection for all the conditions was obtained at the beginning of the right swing phase which corresponds to the large peak at about 65% of the gait cycle. The maximum positive value of the left lean was highest when there was a weight in the right hand (point B).

Similarly the minimum value of negative deflection (i.e. maximum value of right lean) was noted at the beginning of the left swing phase when the load was on the left hand. (Point A).

This was contrary to our expectations as we assumed that the subject would lean in the direction of the weight. Our observations indicate that the subject leans opposite to the direction of the weight. Further we found that this leaning is maximum at the same point as in normal walking, i.e. at right toe off. The asymmetrical weight increased the magnitude of the lateral deflection opposite to the side of loading.

An interesting corollary is that the weight decreased the angle of lateral flexion during the swing phase of the limb on the weight carrying side.We posit that the increase in deflection is a result of the subjects gait trying to adjust the center of mass to fall within the body center by moving the upper torso to the side opposite to the loading. Further the increase in lean also aided in clearance for toe off of the swing phase of the foot bearing the weight.

It was observed that the case of symmetrical loading was similar to that of normal walking. There was an increase in the magnitude of the angular deflection which could not be explained on the basis of deflections. The increase in this case may be attributed to the increase in moment of inertia of the arms due to the weights. To compensate for the increasing inertia of the arm swing there is a smaller amount of opposite lean.

The values of lateral flexion were found to be greater than those of those cited by D.D Poscoe *et al* 1997 who performed similar experiments using shoulder loading in bags.

4.Conclusion

The effect of carrying weights on gait cycle parameters was documented using a code developed in MATLAB. The experiments were conducted keeping in mind the various sources of error and steps were taken to remedy these to the maximum extent possible. Even so, some errors were introduced in the results due to motion of the markers which were attached to the subjects' clothes and due to the slight variations in the front camera distance from the subject. To minimize these errors many readings were taken and average values were used. The code developed can be used to analyse gait parameters during other activities like stair case climbing or during some sports activity.

Further research could focus on the magnitude of the weights and observe how varying the loading in each of these cases affects the parameters listed above.In addition the same study may be widened to include a larger number of people and include both sexes to verify our findings conclusively.

5.References

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