



## Spatial-temporal and Kinematic characteristics of Gait Carrying Loaded Backpack with Elastic Straps

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**Abstract.** Objective: Applying 3D Motion Capture technology to analyze the kinematic and spatial-temporal characteristics of gait when carrying loaded backpacks with elastic straps, the study investigates the effect of backpacks with elastic-strap on fatigue during walking. Methods: Ten healthy male undergraduates did not do strenuous or fatigue exercise two days before the trials and served as subjects (aged  $19 \pm 1.8$  years). All subjects provided a written and oral explanation of the trial procedures. In two trials departed by two days apart, the subjects randomly carried one of the two kinds of backpacks (with non-elastic straps or with elastic straps backpacks loaded the same weight books (about 10% of their bodyweight). After pasted with markers as the guide of the Vicon 3D motion capture system, the subjects walked on the treadmill at 4.5 km/h for 20 min in each trial. Before and after each walking trial, the gait parameters of the subjects were measured by a 6 meters-long plantar pressure test plate (Zebras FDM System). Results: The change of the COP and the change of the gait parameters in the subjects with elastic straps backpacks after 20 min walking were relatively less than those with no elastic-strap backpacks, showing better stability and delaying fatigue. From this statement, it can be reasoned that being able to reduce the effect of the load on the person by returning the gait pattern closer to an unloaded walking pattern may reduce problems associated with loaded carriage. The elastic straps decreased the elevation of the mean vertical position of the backpack and create a gap between the shoulders and the shoulder pads. Conclusion: The decompression backpack with elastic straps shows the effect of protecting the user's spine and in delaying the cervical back muscle fatigue, during walking at appropriate pace maybe reduce the risk of musculoskeletal injuries and muscle fatigue associated with carrying heavy backpack loads while reducing the metabolic cost of loaded walking.

### 1. Introduction

Backpacks play a very important role in people's daily life both for teenagers and adults which can free our upper limbs by increasing load carriage capacity [1], especially when we are working, hiking, and marching. The utilization rate of backpacks among children and teenagers is more than 90% [2]. And the same condition appears in adults when they are traveling, working, hiking, marching and so on. Although the experts propose that the weight of backpacks in school should below 15% of the individual's body mass

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[3], the load carriage of most students can be overweight. Excess backpack loads carriage acting on the human body may lead to muscle discomfort, numbness, fatigue, and contribute to the high risks for the neck, shoulder and back pain, stress fracture, joint problems, abnormal body posture and gait characteristics[3, 4]. To prevent the aforementioned problems, the backpack design, weight, and strap patterns have been taken into account by many studies. There are so many studies of the existing papers paid attention to the effect of backpack load carriage on the adolescents and young adults by parameters of gait, kinematics and plantar pressures. The effect of strap patterns(single or double shoulders or trolley) have received little attention. However, the functional backpack designs just like shape, size or strap.etc, have not been taken into account.

Aiming to adjust body posture, relieve muscle fatigue and reduce injury risks, a functional backpack based on the Anti-Gravity System(AGS) was designed. This system contains elastic strap and back support aiming to produce the bounce interacting human body and disperse loads when backpackers are walking. Meanwhile, more thick air-cushion attached on both sides of the spine can keep the spine straight and improve scoliosis caused by abnormal posture. Therefore, the purpose of this study was to investigate the function of this backpack compared with ordinary backpacks on gait parameters analysis and provide references to the design of functional backpack.

## 2. Methods

### 2.1. Participants

Ten healthy, male undergraduates participated in the experiment (age  $19.9 \pm 0.74$  years, stature  $167.3 \pm 3.27$  m, leg length  $0.88 \pm 0.037$  m, and weight  $61.8 \pm 0.96$  kg). The experimental protocol was approved by the Guangzhou Sport University Institutional Review Board and informed consent was obtained from all participants before the experiment. All subjects were right foot dominant and free of any physical disorders or impairments or fatigue that might impede their ability to walk. Subjects completed the full protocol during a single visit. The subjects carried 10% of their body weight (BW). This load was chosen to fall within the weight range normally tested in load carriage studies. A motion capture camera system was used to track these markers (Vicon Motion Systems®, Oxford, UK), sampled at 100 Hz. The labeling skeleton template and marker files use the Plug In Gait Lower Body Ai Functional.vst in the Vicon Nexus Reference Guide. The 3D motion capture system contains eight high-speed cameras which can identify CAST model markers at a rate of 100Hz, two force platforms(KISTLER Company, Swiss) integrated with the Vicon Motion Capture System at the rate of 1000Hz. Sixteen reflective markers were attached by double-coating tapes to the skin of hip, knee, ankle joint and the thighbone, tibia, and foot. All subjects wore the same type of shoes in order to normalize the results and compare the differences in two conditions.

### 2.2. Protocol

Each participant took part in the study in two day interval of 3-5 days for recovered same physical fitness. On each day, the subjects in a randomly assigned order carried the backpack with no elastic straps loaded with 10% body weight (control pack) or the backpack with elastic straps loaded with the same weight(elastic pack). At the beginning, subjects walked on along a 6-meters pathway, 3 times back and forth for 6 times trails without carrying backbag, then walked another 3 times back and forth carrying back loaded with 10% of their body weight. The self-selected walking speed ( $0.86 \pm 0.31$  m/s) was used which was determined before the beginning of the experiment and was consistent across all sessions. Then, the subjects walked on a treadmill at for 20 minutes while carrying a backpack(1).

Backpack motion was captured with the markers placed on top of the rigid frame of the backpack. After 20 minutes walking, the subjects also were captured gait motion carrying the backpack and without carrying the backpack respectively, like those at the beginning, walking on along a 6-meters pathway, 3 times back and forth for 6 times trails. Figure 1 shows a subject walked along the 6-meters pathway and walk on the treadmill.

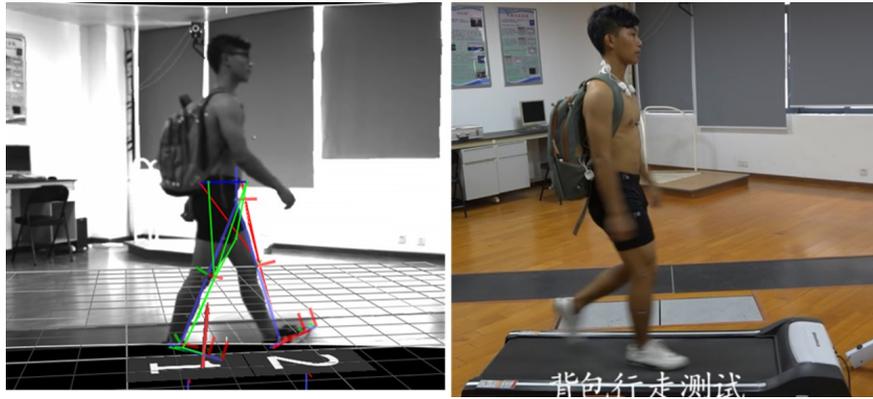


Figure 1: A subject walked on the 6-meters pathway (left) and walk on the treadmill(right).

### 2.3. Data processing

The Vicon Nexus 2.8.0 and Polygon 4.4.0 were applied to do the data processing and output the results, based on the Plug In Gait Lower Body model. Then each parameter was normalized in time to 100% of the gait cycle (GC) based on gait events. Heel strike (HS) and toe off (TO) were detected for each leg through the force plate, and a gait cycle was defined from a right heel strike (RHS) to the subsequent right heel strike. Sagittal plane and frontal plane gait kinematics, ankle, knee, pelvis, and backpack vertical motions, were analyzed. Based on gait events and self-selected walking speed, spatiotemporal variables were analyzed, which were the double support period (DS), single support period (SS), stance to swing ratio, step length (mm), toe clearance (mm) and cadence (steps/min). Spatial parameters with the dimension length (step length and toe clearance) were normalized to subject's leg length to eliminate differences among participants' data attributable to differences in body height. The t test infers the probability of difference occurrence by t distribution theory. It can be used to compare the difference between two averages. The t test is used for small sample size and the T test is used for large sample size. The article adopts the t test of double sample. At the beginning and after 20minutes walking, the same person's walking speed, cadence and stride time were measured many times in data processing, the same person's observations were merged. We calculated the mean value of walking speed with experimental and control bags as two different variables. The unpaired t test of stata13.0 was used to compare the differences of mean value between the two groups.

## 3. Results

### 3.1. Spatio-temporal parameters

The null hypothesis  $H_0: \mu = \mu_0$ , the alternative hypothesis  $H_1: \mu \neq \mu_0$ . The t test showed that  $H_1$  was significant under the significance level of 0.05.  $H_1$  could not be rejected. There was a significant difference in walking speed between the elastic and no-elastic packages. The t test reflected that cadence and stride time were only significantly under in significance level of 0.1. But the walking speed of the elastic and no-elastic backpacks were obviously different (Table 1).

After 20 minutes walking, cadence, walking speed and stride time variables were the mean values of the same subject carrying the elastic and no-elastic backpacks, respectively. The unpaired of t test were used to compare whether there were differences between the two groups of variables. The t test reflected that cadence and stride time were only significantly under in significance level of 0.1. But table ?? shows that the walking speeds of the elastic and no-elastic backpacks were obviously different.

Table 1: the difference of walking speed when carrying two kinds backpacks at the beginning

	mean	std.err	95% conf.interval	Pr( T  >  t )	Mean Diff
elastic backpacks	1.162	0.036	1.078	1.247	2[2]*0.032
no-elastic backpacks	1.205	0.042	1.106	1.305	2[2]*-0.043*

Note: + p < 0.1, \* p < 0.05, \*\* p < 0.01, \*\*\* p < 0.001.

Table 2: the difference of gait parameters between carrying two kinds backpacks after 20 mins walking

	backpacks	mean	std.err	95% conf.interval	Pr( T  >  t )	MeanDiff
cadence	elastic	107.142	1.951	102.367	111.916	0.075
	no-elastic	109.51	2.192	104.147	114.872	
walking speed	elastic	1.167	0.042	1.064	1.27	0.01
	no-elastic	1.233	0.045	1.123	1.343	
stride time	elastic	1.123	0.021	1.072	1.173	0.078
	no-elastic	1.099	0.022	1.045	1.153	

Note: + p < 0.1, \* p < 0.05, \*\* p < 0.01, \*\*\* p < 0.001.

The other parameters of gait, such as single support time and double support time during a gait when carrying two kinds backpacks, showed that there were no significant difference in the gait parameters during the trials.

### 3.2. Kinematics of lower limb joints during walking

Picture 2 and 3 showed the angle change of lower limb joints during a normalized gait process in some planes carrying two kinds of backpacks before 20 mins walking and after 20 mins walking. In all, it showed that there was no significant difference between the two conditions, but showed some little better gait stability in the condition of carrying elastic backpacks compared with no-elastic backpacks.

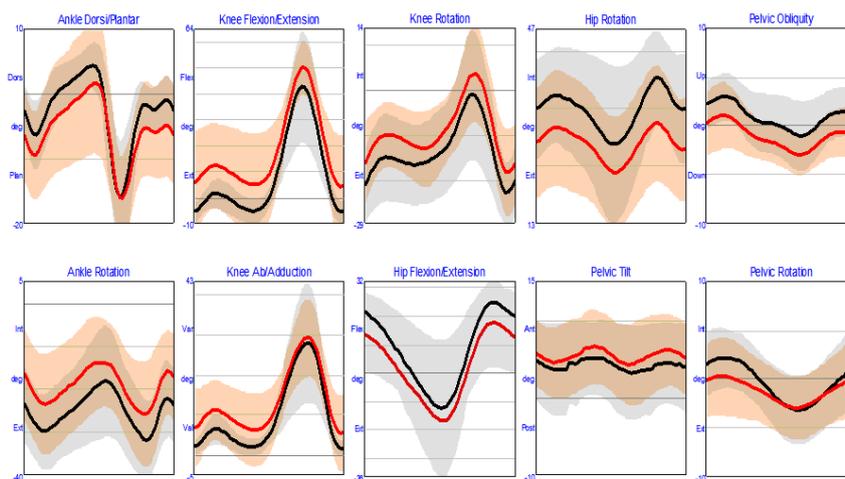


Figure 2: Lower limb joints ankle change of .gait carrying two kinds backpacks before 20 mins walking (Blackline: carrying no- elastic backpacks, while redline: carrying elastic backpacks).

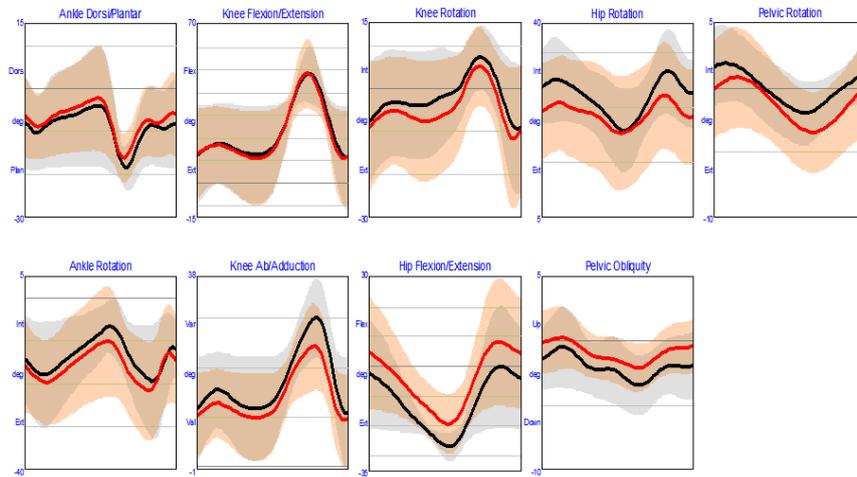


Figure 3: Lower limb joints angle change of gait carrying two kinds backpacks after 20 mins walking( Blackline: carrying no- elastic backpacks, while redline: carrying elastic backpacks).

### 3.3. Vertical ground reaction forces and predicted force of lower limb joints

Picture 4 and 5 showed the vertical ground reaction forces during a normalized gait process in some planes carrying two kinds of backpacks before 20 mins walking and after 20 mins walking.

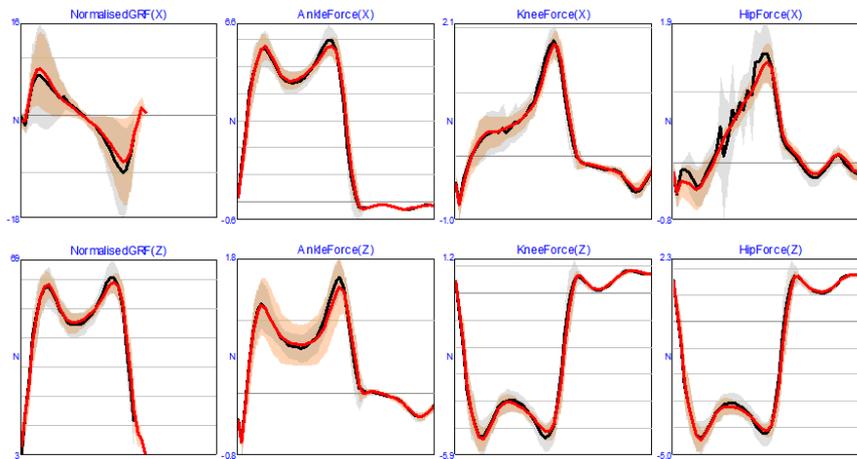


Figure 4: Lower limb joints force during gait carrying two kinds backpacks before 20 mins walking( Blackline: carrying no- elastic backpacks, while red line: carrying elastic backpacks).

## 4. Discussion

The purpose of the study was to explore the gait motion characteristics when carrying normal loaded backpack with elastic straps, and its influence on gait parameters or kinematic characteristics. However, the results of the study showed that the backpack doesn't work obviously. No significant difference in gait parameters was found in two conditions. The reason for the design of this functional backpack is to relieve fatigue and keep people's strength with elastic straps which are aiming to coordinate the vibration of backpacks. Although this study may not provide more supports about the AGS backpack, it can serve a

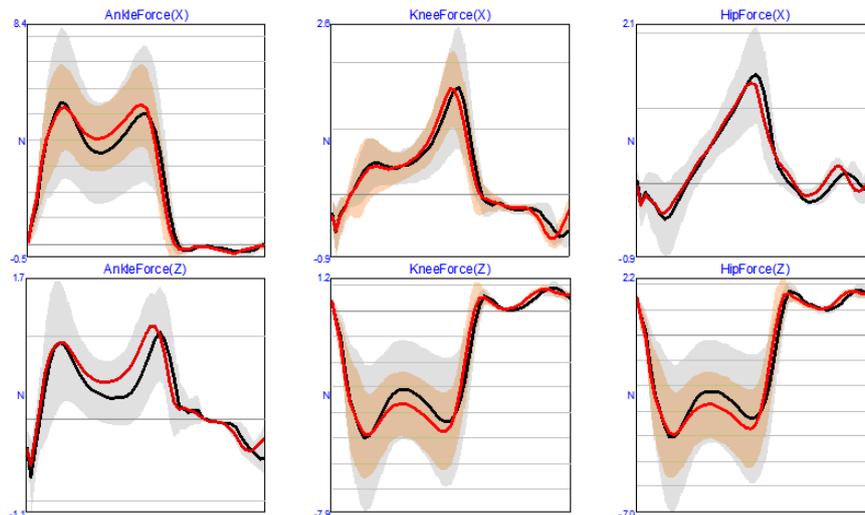


Figure 5: Lower limb joints force during gait carrying two kinds backpacks after 20 mins walking( Blackline: carrying no- elastic backpacks, while redline: carrying elastic backpacks ).

direction for the design of backpacks.

There was no significant difference in the gait parameters when the participants walking unloaded as well as walking with a backpack under two test conditions. These results are consistent with a previous study [2] that they didn't find out any differences on spatiotemporal gait parameters when the schoolchildren walking unloaded and carried a backpack of 5.2 kg. Moreover, the study of Cho DH et al who tested normal adolescent girls reported the stride length and stride time unchanged between walking unloaded and with a backpack [5]. Common with Cho DH, Connolly et al [6]. proved that stride length and velocity didn't differ between unloading and backpack load. However, Kinoshita found that compared to normal walking without any load carriage, the double support under backpack carriage(i.e.20% and 40% body weight) condition increased significantly while single support period decreased, the step length, step width maintained constant [7]. The other study by Cottalorda et al. also confirmed the conclusion that double support period increased [8]. We found no difference in gait parameters before and after 30-minute walking with the same backpack. Hong and Cheung [9]got this result as well,they asked 9-10-year-old school boys walking normally with backpack of 0%,10%, and 15% body weight, and found walking distance and load carriage cannot change the gait parameters(i.e.walking speed, cadence, stride length, single and double support period).In contrast, Hong and Bruggemann [10] assessed the gait parameters of 10-year-old boys with backpacks of 10%,15%,20% body weight after over 20-minutes walking, the results showed a significant difference in double support and stance duration of 20% load when compared to the unloaded condition. Nevertheless, they found there was no difference between unloading and 10% load condition likewise. Why the afore-mentioned studies are not agreed with our study? The factors of subjects and backpack load may not be ignored. In the present study, we chose ten young males as subjects while the other study selected children or adolescents, and backpacks in 10% body weight were used in our test which may be lighter than other studies. The gait parameters in all test condition among two types of backpack didn't differ significantly in our study. Combined with what fore-mentioned, the two kinds of backpacks have no effect on gait during a 30-minute walking period. There was a lack of studies about backpack design at the present time. However, similar researches about backpack carriage pattern have been existed. Many researchers had discussed gait parameters when carrying bag with 1 or 2 straps. Abaraogu et al.suggested that no significant changes on gait between 1 shoulder load and 2 shoulders load [11, 12]. Not exactly, the other researchers reported that walking speed decreased with a single backpack strap. The trolley as a new transportation method has been popular in schoolchildren which can free their shoulder and back, reduce

the risk of pain. For this method, some researchers [13] did the study and found out that gait parameters when pulling a trolley were similar to an unloaded condition. Furthermore, the stride length and swing phase with a backpack decreased compared to the unloaded condition. It means walking carried a trolley may be more comfortable than carrying a backpack.

## 5. Limitation

According to the previous relative studies, our experiment procedure may be not perfect. Choose of subjects, backpack load and walking speed cannot achieve our expected goals. Many studies suggested that backpack load up to 20% BW can change the gait pattern. And most of the studies chose children as subjects who may be affected easier. Besides, only gait parameters were tested in our study while the other studies assessed kinematic analysis, postural changes planter pressure, perceived exertion and so on.

## 6. Conclusion

Based on our study, we got a conclusion that the gait pattern of young adults could not be affected whether carrying a backpack or not, particularly for short distance walking. And there was also no significant difference in gait parameters between carried a normal backpack and the backpack with elastic straps. It means that the backpack of elastic straps cannot take effect obviously on gait. However, whether the elastic straps can influence the kinematic, electromuscular sensibility and perceived exertion of carriers should be explored in future studies. Furthermore, the backpack design needs to be more rigorous.

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