Gait Analysis of Slope Lateral Walking: A Preliminary Study

Chien-Ju Lin[1] Lin-Hwa Wang[1, 2] Fong-Chin Su[1,*]

[1]Institute of Biomedical Engineering, National Cheng Kung University, Tainan, 701, Taiwan ROC
[2]Department of Physical Education, National Cheng Kung University, Tainan, 701, Taiwan ROC

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Abstract

Objective: The purposes of this study were to investigate the differences in gait parameters of lower extremity joints and the center of the pressure between level and slope lateral walking, and hopefully to improve labor safety.

Method: Four normal subjects participated in this study. The entire lateral walking cycle can be divided into the stance phase and the swing phase. Slope inclinations were set at 5 degree. The subjects walked from the bottom of the slope to the top. The data was collected for 5 seconds for each trial.

Results: Similar pattern was found in the first and the second force plate which indicated that the increasing height on the slope didn't change the trajectory of center of pressure.

Conclusions: The pattern of the ankle joint of the left foot was significantly different from that of the right ankle during level and slope lateral walking. The results will help labors to decrease the possibility of being injured, and to promote the performance.

Keywords**:** Slope, Force plate, Gait analysis, Lateral walking, Center of pressure

Introduction

With labors' dedication, the economy continues developing. As the production process becomes more and more complicated nowadays, more operating risks are involved. As a result, the workers' occupational safety turns into one of the primary concerns for all the developing countries.

Tubular steel scaffolding is commonly used in Taiwan as construction false work and finishing structure of high headroom buildings. According to labor law, when it's necessary for labors to work on 2-meter or higher scaffoldings, the width of the scaffoldings should not be narrower than 30 centimeters. And since the center of pressure (COP) is the point where the force is collectively exerted at the surface, the measurement of the COP has been a successful tool for gait analysis [1].

To investigate the phasic activity of the lower extremity muscles during upslope and downslope walking, five muscles of ten healthy men were examined by telemetered electromyography (EMG)[2]. The muscles were the tibialis anterior (TA), gastrocnemius (Gc), rectus femoris (RF), semitendinosus (St), and gluteus maximus (GM). The inclinations of the slope were 3, 6, 9 and 12 degrees. EMG of the muscles and the time factors of a walking cycle were recorded by a 12-channel polygraph simultaneously. In upslope walking, the duration of TA, St and GM activity was longer and that of RF activity was shorter than in level walking. The phasic pattern of Gc in upslope walking was the same as in level walking. In downslope of Gc and RF activity was longer than on the level. St showed biphasic activities. The phasic pattern of TA and GM were nearly the same as the pattern in level walking. The phasic activity of the muscles altered when the upslope inclination was over 6 degrees, or over 3 degrees in downslope. The findings indicate that the muscles stabilize knee and ankle joint much more in slope walking than in level walking, and in slope walking, they also exert themselves to elevate or lower the body weight. The determinations of step length, width, time factors and deviation in the center of pressure during upslope and down slope walking in 17 healthy men between the ages of 19 and 34 were made by a force plate [3]. Slope inclinations were set at 3, 6, 9 and 12 degrees. At 12 degrees, walking speed, the product of step length and cadence, decreased significantly ($P<.01$) in both upslope and down slope walking. The most conspicuous phenomenon during upslope walking was found in cadence. The steeper the slope, the smaller was the cadence. On the other hand, the most conspicuous phenomenon in downslope walking was step length. The steeper the slope, the shorter the step length was.

Kinematic and kinetic parameters are important for investigation of gait patterns. To authors' best knowledge, however, no studies had focused on the kinematic or kinetic changes during slope walking. In our previous studies [4-7], gait models were established to analyze the phenomena occurred in patients and normal subjects. The technique can be

*Corresponding author: Fong-Chin Su
Tel: +886-6-2760665; Fax: +886-6-2343270
E-mail: fcsu@mail.ncku.edu.tw

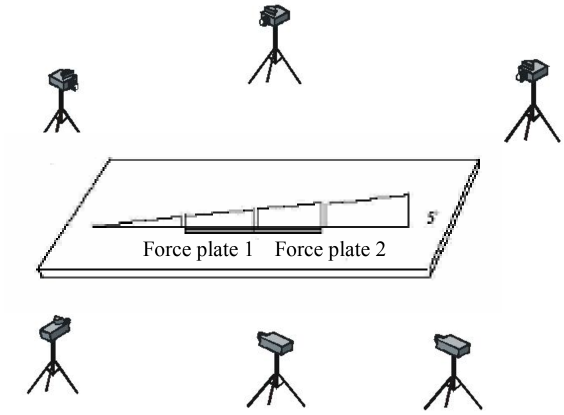


Figure 1. The laboratory setup

Figure 2. The Helen Hayes markers set

Figure 3. The data collection in the motion analysis system

applied to investigate the lateral walking, a simulation of walking on the scaffolding.

The purposes of this study were to investigate the differences in gait parameters of lower extremity joints and the COP in level and slope lateral walking respectively. Hopefully the result will provide useful information on improving labors' working safety.

Methods

Four normal subjects (one male and three females, ages:

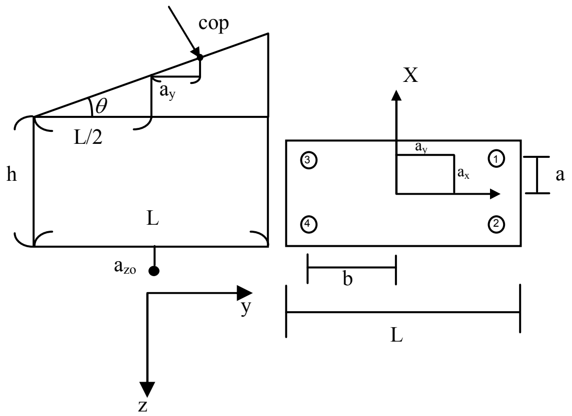


Figure 4. The slope and force plate set

27.8±2.4 years, height: 161.5±5.1 cm and weight: 56±8.3 kg) participated in this study. A six-camera EVa RT system (Motion Analysis Corporation, Santa Rosa, CA, USA) was used to collect the three-dimensional trajectory data of markers placed on each subject at a sampling frequency of 60Hz while the subject performed lateral walking on ground level and a slope respectively (Figure 1). The system was calibrated with a 4-point L-frame calibration square and a calibration wand. Base on the Helen-Hays marker set, nineteen retro-reflective markers were attached to the subject anatomic landmarks in static standing to calculate the knee and ankle joints center while fifteen were used in the movement data collection. These anatomic landmarks are as follows: sacrum (midline of posterior superior iliac spine, PSIS), bilateral anterior superior iliac spine (ASIS), mid-thigh, lateral femoral condyle of thigh, mid-shank, lateral malleolus, heel, location between 2nd and 3rd metatarsophalangeal joint in action and add bilateral medial femoral condyle, medial malleolus in static position (Figure 2). The markers at bilateral medial femoral condyle and medial malleolus were removed during walking.

Slope inclinations were set at 5 degree. The subjects were instructed to walk with right leg leading from the bottom of the slope to the top at self-selected speed (Figure 3). The entire lateral walking cycle can be divided into stance phase and swing phase. The stance phase started with the initial foot contact, and the swing phase begins as the foot cleared off from the floor. The data was collected for 5 seconds for each trial.

The computer software "OrthoTrak 6.13" (Motion Analysis Corporation, Santa Rosa, CA, USA) was used to analyze the kinematic data. Two Kistler force plates (Kistler Instrument Corporation, NY, USA) were used in this experiment to collect the data of the reaction force of the ground for further computation of center of pressure (Figure 4). Each force plate had 4 transducers which consisted of three pieces of quartz chips arranged at three orthogonal directions respectively. In accordance to the piezoelectric effect, the potential changes of the quartz chips, caused by different loads, were collected simultaneously and transferred into x, y and z axes forces and moments respectively on the basis of the independent character of forces.

Table 1. The proportion of stance phase

	Level Lateral Walking	Slope Lateral Walking
Right stance phase (% right gait cycle)	53.41±1.87	55.90±2.54
Left stance phase (% left gait cycle)	65.63±0.85	65.35±1.98

Table 2. Temporal distance parameters of gait cycles

	Step Width (cm)	Stride Length (cm)	Velocity (cm/s)
Level Lateral Walking	1.62±0.96	61.26±3.71	57.19±4.65
Slope Lateral Walking	1.60±1.01	67.93±1.89	62.27±3.86

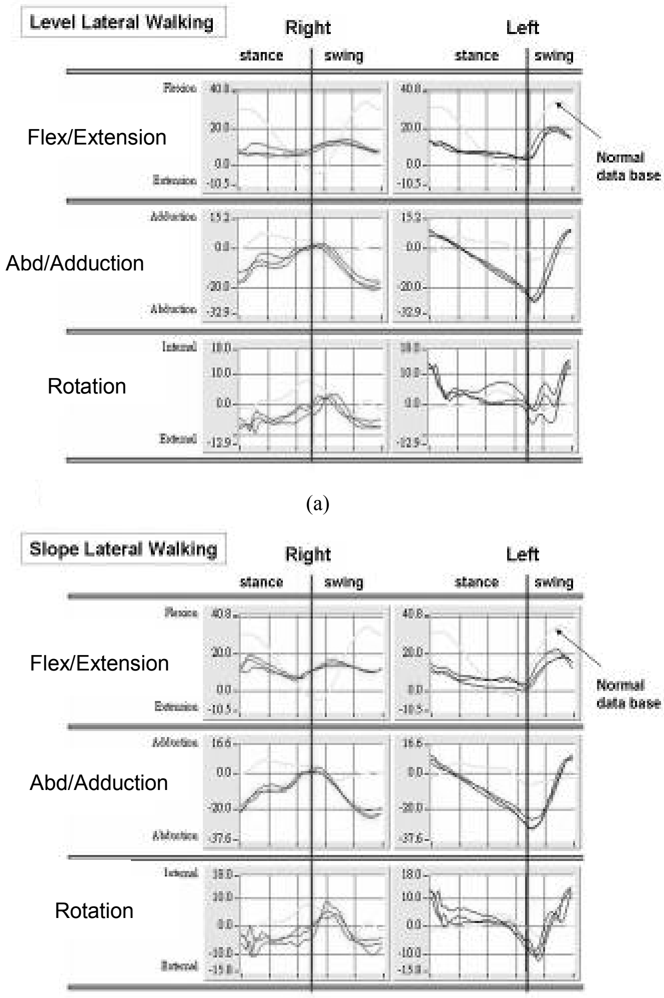


Figure 5. Hip angle during (a)Level lateral walking and (b)Slope lateral walking

Results

Temporal distance parameters

Base on the original data, we found that the proportion of stance phase is longer in the left cycle than that in the right cycle (Table 1). In addition, there are large variations

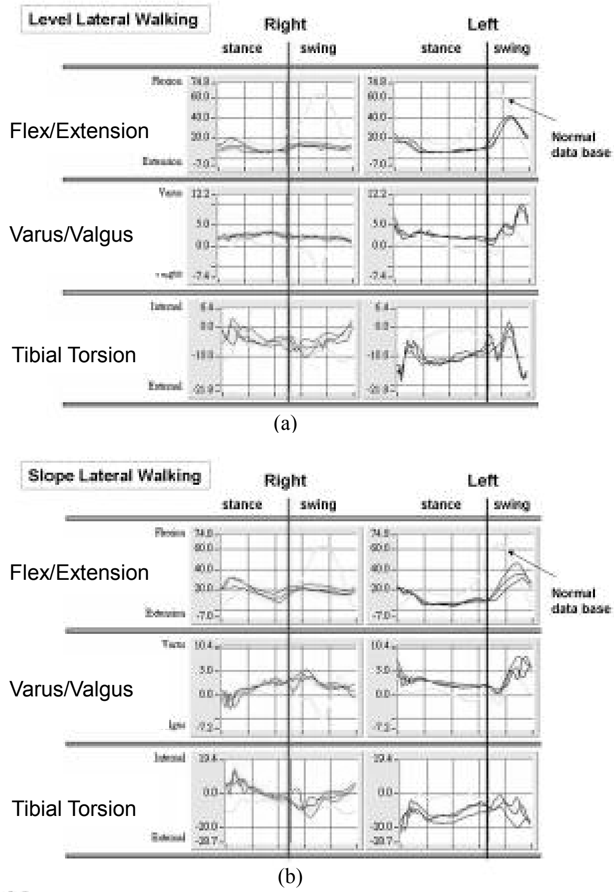


Figure 6. Knee angle during (a)Level lateral walking and (b)Slope lateral walking

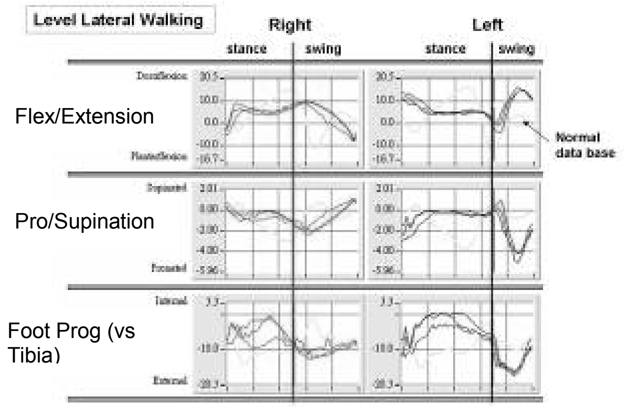
in the average step width, stride length and velocity during slope lateral walking and level lateral walking (Table 2).

Kinematics

For the hip joint (Figure 5), the motion of abduction/adduction was most obvious in both slope and level lateral walking, and the range of motion of abduction/adduction was larger in slope walking then that in level lateral walking. Besides, the range of motion of right (leading) hip flexion during slope lateral walking was larger than that of level lateral walking.

There was no obvious difference in knee joint angle between slope and level lateral walking (Figure 6). The extensions occurred during stance phase and the flexion happened during the swing phase after toe off. Compared with normal walking database, the extension and flexion angles were both smaller for right and left knee joints during level lateral walking while the average flexion angle was larger for knee joints at initial contact.

In ankle joints (Figure 7), comparing with the pattern of right and left ankles, we found left and right ankles had different motion patterns in not only slope walking, but also level lateral walking. The pronations/supinations of both the slope and level lateral walking were rather similar. In addition, during the initial stage of the swing phase in slope lateral walking, the left ankle joint conducted larger supination than



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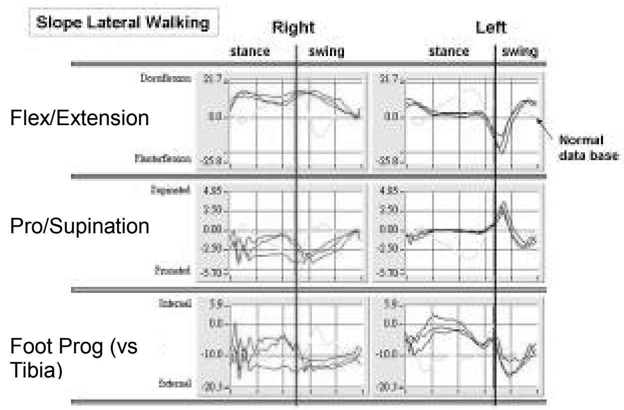
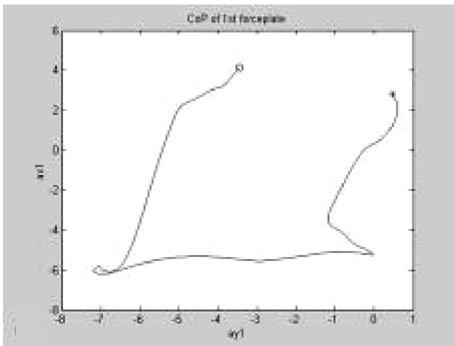


(b)

Figure 7. Ankle angle during (a)Level lateral walking and (b)Slope lateral walking



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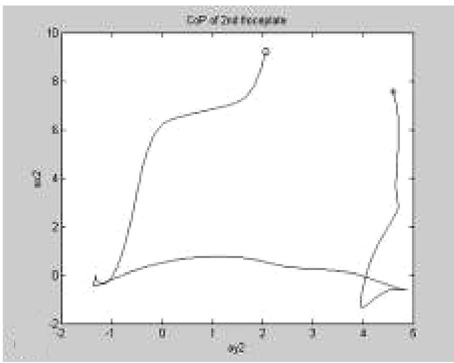
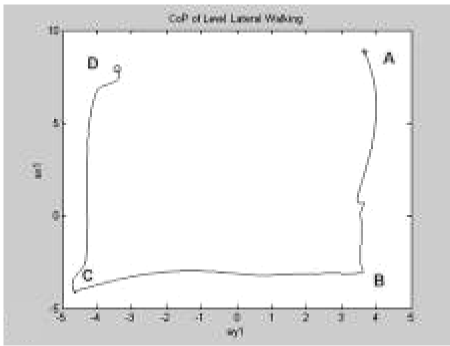


(b)

Figure 8. The trajectory of COP of (a)1st force plate and (b)2nd force plate during slope lateral walking (✦: start; ○: end)



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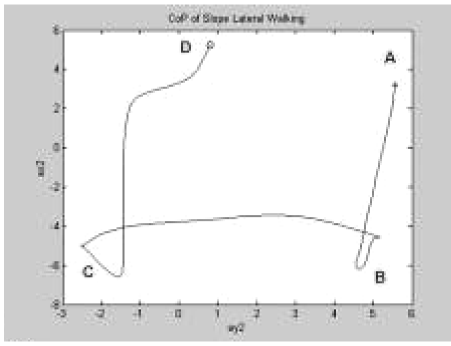

(b)

Figure 9. The trajectory of COP during (a) level walking and (b) slope walking (✦: start; ○: end)

that in level lateral walking. During the initial stage of stance phase in slope walking, the right ankle performed smaller supination than that in level walking because of being on the slope surface.

COP

During slope lateral walking, similar pattern was found in the first force plate and second force plate which indicated that the increasing height of the slope didn't change the trajectory of COP (Figure 8).

The "*" in the figures indicated the start position of COP as right foot contacted the force plate and the "o" indicated the end position of COP when left foot was lifted from the force plate.

All subjects touched the force plate with their right toes following by a heel contact. Thus we found the COP moved from anterior to posterior (from A to B) after the foot contacted the force plate (Figure 9). The adduction of left hip shifted the location of COP rightward (at the corner B) until left foot was drawn close to the right foot. During the swing phase of right leg, subjects shifted their COP leftward (at the corner C) to perform right hip abduction. The forward movement of the COP indicated the toe off of the left foot (from C to D).

Discussion

We found that the proportion of stance phase and swing phase were different between right and left cycle. While the right side had longer swing phase, the left side had longer stance phase. This may be caused by the walking direction.

Subjects were asked to walk from left to right with the right foot as the leading foot. The right foot took charge of the mobility while the left side served as the stabilizer in a gait cycle. Kuan, T. S. et al [4]. found that stroke patients can slightly increase their walking velocity with a cane because the cane provide higher stability for them. Su, F. C. et al [6]. also concluded that children with cerebral palsy had smaller walking velocity due to reduced step length and stride length. In our study, the existing variation between the time and spatial parameters may be due to the unfamiliarity to lateral walking of the subjects.

Hip and knee joints, particularly the right ones, had larger range of motion in flexion during slope lateral walking. The subject needed lift his right leg to a higher surface on the slope and maintained trunk upright, which was achieved by the flexion of right hip and knee joints.

Additionally, different motion patterns were found between right and left ankles. This phenomenon was resulted from the different walking patterns. In other words, almost all subjects performed "toe contact" and "heel off" on the right foot while they exhibited "heel contact" and "toe off" on the left foot. Only one subject performed "toe contact" on the left foot.

Different knee joint positions during gait cycle will affect the moment occurred on the knee joint [5]. Besides, the foot can be further divided into hindfoot and forefoot when analyze the ankle and foot motion [7]. Since slope lateral walking is not a typical motion in our daily lives, and this unnatural motion may cause unexpected load to the ankle and knee joint resulting in the damage of the tissue surround these joints, this issue deserves further investigation in the future.

As to COP, compared with the level lateral walking, the trajectory of COP was less smooth during slope lateral walking. This may reflect the unsteadiness in slope walking. Also, from the different curves between right and left foot, we found that during slope walking left foot is dominant in maintaining stability. As seen in the Figure 6, the displacement of the COP trajectory (from C to D), which indicated toe off of the left foot, was larger. Furthermore, the unsteadiness can be seen in the obvious lateral and backward shift of COP at point B and C during slope lateral walking.

Conclusion

In accordance to the preliminary results of this study, 5-degree-slope and level lateral walking shared similar kinematic data which was rather different from that of normal walking data base. The pattern of left ankle joint was obviously different from that of the right ankle in gait cycle. Examining the smoothness of COP trajectory, we found the unsteadiness during slope lateral walking, the phenomenon which we suppose that the ankle joint may be easily injured as larger pronation and supination range of motion is performed during slope lateral walking. The results will help labors to decrease the possibility of being injured, and to better the performance.

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斜坡側移步的步態分析:初步研究

林倩如[1] 王苓華[1, 2] 蘇芳慶[1,*]

[1]國立成功大學醫學工程研究所
[2]國立成功大學體育室

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摘 要

本篇研究的目的主要是希望能以工地之鷹架爲例，探討在平地以及傾斜面上側走時之下肢運動學及壓力中心的改變，同時希望能藉此探討工人在鷹架上行走可能遭受之傷害。共有 4 位正常的受測者參與此研究。每位受測者依自己覺得最舒適的速度，以右腳爲前導腳在平地上側走以及傾斜五度的斜坡上由下往上側走，同時收取運動學及力板的資料加以分析。結果發現壓力中心的軌跡在斜坡側走時較爲彎曲，而在平地側走時較爲平滑。運動學方面的資料顯示無論在平地或是斜坡側走時，左右腳之腳踝關節的表現有明顯差異。藉由運動學以及壓力中心之軌跡來分析斜坡側走時下肢的生物力學，有助於探討在鷹架上行走之工人可能遭受到之下肢關節的傷害，可以進一步加以預防，減少職業傷害。

關鍵詞：斜坡、力板、步態分析、側走、壓力中心

* 通訊作者：蘇芳慶
電話：+886-6-2760665；傳真：+886-6-2343270
電子郵件信箱：fcsu@mail.ncku.edu.tw