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Abstract

Determination was made of step length, stride width, time factors and deviation in the center of pressure during up- and downslope walking in 17 healthy men between the ages of 19 and 34 using a force plate. 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 less than 0.01) in both up- and downslope walking. The most conspicuous phenomenon in upslope walking was in cadence. The steeper the slope, the smaller was the cadence. The most conspicuous phenomenon in downslope walking was in step length. The steeper the slope, the shorter was the step length.

KEYWORDS: force plate, gait analysis, slope walking, time factors, center of pressure

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Gait Analysis of Slope Walking: A Study on Step Length, Stride Width, Time Factors and Deviation in the Center of Pressure

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Determination was made of step length, stride width, time factors and deviation in the center of pressure during up- and downslope walking in 17 healthy men between the ages of 19 and 34 using a force plate. 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 < 0.01) in both up- and downslope walking. The most conspicuous phenomenon in upslope walking was in cadence. The steeper the slope, the smaller was the cadence. The most conspicuous phenomenon in downslope walking was in step length. The steeper the slope, the shorter was the step length.

Key words: force plate, gait analysis, slope walking, time factors, center of pressure

Gait analysis of level walking has been extensively conducted (1–5). However, little such data are available on slope walking (6, 7). In daily life, a human being walks various slopes in addition to those that are level. This study was conducted to determine step length, stride width, time factors and deviation in the center of pressure during slope walking.

Materials and Methods

Seventeen healthy men from 19 to 34 years of age (25.3 ± SD 4.3) were studied. Height ranged from 161 to 181 cm (172.9 ± SD 4.8), and body weight from 54 to 72 kg (63.1 ± SD 6.0).

To measure step length, stride width, time factors and deviation in the center of pressure (COP), a force plate consisting of a matrix system (Anima Co., Ltd., Tokyo, Japan) was used (Figs. 1 and 2). Strain gauges were attached to each matrix so that three-dimensional force acting on the platform of the force plate could be measured. The cross talk among three dimensional forces was less than 2 percent. Each plate was 250 by 40 cm and four force plates were connected to make a large platform 500 by 80 cm. Measurements were processed by a micro-computer with a 16-bit central processing unit (CPU).

With this device, gait data for each step were obtained independently and consistently. Mean and standard deviation were also calculated for each of the following parameters: 1. Step length, 2. Stride width, 3. Time factors; cadence, speed and duration of each walking cycle and component phase, 4. Deviation in COP.

For the above determinations, slopes (3, 6, 9 and 12 degrees) made with a rigid steel frame were set up on the force plate. The subjects could walk on the platform fixed on the rigid steel frame. Each platform was covered by felt to avoid slipping (Fig. 3).

Steps at the beginning would be attended by accelera-
tion, and at the end there would be some deceleration. Consequently, as pre- and post-slope walking the subjects were made to walk 2 m or more of level walking. In front of the slope, there was a level walking platform 2 m in length so that the subjects could smoothly approach the slope. At the top of the slope, there was a level walking platform 2 m in length so that the subjects could pass over the slope. The subjects were allowed to walk freely.

Fig. 1  Step length, stride width and movement of the center of pressure (COP); Lp is total distance of the movement of COP and Ls, total distance of the straight line.

Fig. 2  Duration of walking cycle and component phases.

Fig. 3  Measuring system.
Kawamura et al.: Gait analysis of slope walking: a study on step length, stride

Gait Analysis of Slope Walking

Fig. 4 Schematic diagram of measuring system. Fa is the real vertical force on the slope and Fb, measured vertical force by the force plate. Data were obtained using the force plate which was always set level. Correction should thus be made to obtain accurate values. A computer should thus process data obtained using the force plate set level to obtain accurate values for each slope.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Components of gait for free-speed upslope walking (mean values for 17 normal men)</th>
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<tbody>
<tr>
<td></td>
<td>Level</td>
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<tr>
<td>Stride width (cm)</td>
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</tr>
<tr>
<td>Cadence (step/min)</td>
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<tr>
<td>Cycle duration (sec)</td>
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<tr>
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Mean ± SD

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<th>Components of gait for free-speed downslope walking (mean values for 17 normal men)</th>
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Mean ± SD

on the slope in bare feet.

Each parameter was always obtained with the force plate set level. The computer would make compensation so that each value corresponded to the correct value on the slope (Fig. 4). A subject could walk more than five steps at a time on the force plate 5m in length. The steeper the slope, the greater was the walking area. On each slope, at least 5 steps could thus be measured. For each slope, the computer processed the three dimensional force of middle five steps. The natural frequency of the measuring system including the slopes was from 30 to 50 Hz.
**Fig. 5** Results of t-test for walking speed.
3: 3 degrees. 6: 6 degrees. 9: 9 degrees. 12: 12 degrees.
NS: p > 0.05. *: p < 0.05. **: p < 0.01.

**Fig. 6** Results of t-test for step length.
3: 3 degrees. 6: 6 degrees. 9: 9 degrees. 12: 12 degrees.
NS: p > 0.05. *: p < 0.05. **: p < 0.01.

**Fig. 7** Results of t-test for cadence.
3: 3 degrees. 6: 6 degrees. 9: 9 degrees. 12: 12 degrees.
NS: p > 0.05. *: p < 0.05. **: p < 0.01.

Mean and standard deviations were obtained for all 17 subjects at slope (Tables 1 and 2). The Student’s t-test was used for assessment of statistical significance (Figs. 5, 6 and 7).

**Results**

*Step length.* Mean step length in level walking was 68 cm. In upslope walking, step length increased significantly for 6 (p < 0.05) and 9 degree slopes (p < 0.01). In downslope walking, step length decreased significantly at 9 and 12 degree slopes (p < 0.01).

*Stride width.* Mean stride width in level walking was 14 cm. No significant differences could be found between inclinations for up- or downslope walking (p < 0.01).

*Cadence and cycle duration.* Mean cadence in level walking was 113 steps/min. In upslope walking, cadence at each inclination decreased. Although no significant difference was observed...
between inclinations, cadence at 12 degrees was less than that of 3 degrees (p < 0.01). In downslope walking, significant increase in cadence was noted between level walking and 6 degrees (p < 0.05), and between level walking and 9 degrees (p < 0.01).

The duration of a walking cycle reciprocated cadence.

Walking speed. Mean level walking speed was 77 m/min. In up- and downslope walking, this speed decreased significantly (p < 0.01) only at an inclination of 12 degrees. The decrease was greater in downslope than in upslope walking.

Component phases of a walking cycle. In level walking, the mean duration of the stance phase was 0.64 sec., i.e., 59.8 percent of the total walking cycle. The mean duration of the swing phase was 0.43 sec., or, 40.2 percent of a cycle. In upslope walking at 12 degrees, the stance phase (percentage of a cycle) increased significantly (p < 0.01).

Deviation in COP. Lp and Ls were measured at each level. Lp was the total distance of COP movement along the curve in a trial. To obtain Ls, the maximum point of the curve of the COP movement was connected to a straight line. Ls was the total distance of the straight line in a trial. Lp/Ls gives the degree of deviation in COP. This ratio increased with steeper inclination and was greater in downslope than in upslope walking.

Discussion

Many studies have been carried out on level walking since the 19th century (1–5). However, few data are available on slope walking (6, 7). The earliest report was conducted by Mann and Inman (6) who measured EMG of intrinsic muscles of the foot during slope walking. In 1985, Tokuhiro et al. examined EMG of the lower leg during slope walking (7). Neither of the reports, however, mentioned step length, stride width, time factors or deviation in COP.

In this study, the most characteristic phenomenon in slope walking was observed in walking speed. At 12 degrees, speed decreased significantly (p < 0.01) in both up- and downslope walking. A critical inclination at which walking speed changed was found between 9 and 12 degrees. Walking speed is the product of step length and cadence. In upslope walking, decreased walking speed at an inclination of 12 degrees was due to decrease in cadence and downslope walking owing to decrease in step length.

Generally speaking, the most conspicuous phenomenon in upslope walking was observed in cadence. The steeper the slope, the smaller was the cadence. In upslope walking of between 0 and 9 degrees, the steeper the slope, the longer was step length, the reason being that the subject tried to maintain constant walking speed. Cadence should possibly be smaller to effectively augment body weight.

The most conspicuous phenomenon in downslope walking was in step length. The steeper the slope, the shorter was step length. In downslope walking between 0 and 9 degrees, the steeper the slope, the larger was the cadence in that the subject tried to maintain constant walking speed. The characteristics of downslope walking are considered to be first, braking action of the foot and secondly, balancing the center of gravity. Mann and Inman mentioned that a rigid lever arm of the foot is required early in the cycle to counteract moment created by acceleration (6). Here "counteract" means braking the descension of body weight.

Tokuhiro et al. noted the phasic activity of the lower extremity muscles to change at an inclination exceeding 6 degrees in upslope walking and 3 degrees in downslope walking (7). It thus follows that muscles stabilize the knee and ankle joints much more in slope walking than in level walking. To assist stabilization of the knee and ankle joints, step length becomes shorter.

Deviation in COP indicates how unstable slope walking is. A comparison of the deviation
in COP of upslope walking with that in downslope walking indicated the latter to be larger. Down-slope walking is thus shown to be more unstable than upslope walking.

A special characteristic of human walking is rhythmic movement (8, 9). It is quite interesting that the ratio of stance phase to swing phase showed the similar values of about 6:4 at most inclinations. However, an exception was observed at 12 degrees in upslope walking. Many authors report that the stance phase ratio increases in accordance with decrease in cadence (3, 5, 10). This exception, the decrease in cadence, perhaps can be explained on this basis.

In summary, differences between level walking and slope walking were observed in walking speed, deviation in COP and the ratio of stance phase to swing phase. A critical inclination that changes these parameters is considered to be between 9 and 12 degrees.

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References


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