INTRODUCTION

Vertical impact force during downhill running should be analyzed in terms of risk of injuries caused in hill training of distance runners. In spite that the impact force in running was influenced by some kinematic parameters at the foot contact (Gerritsen et al. 1995), few studies analyzed interactions between ground reaction forces (GRFs) and kinematics during downhill running in detail. The purpose of this study was to investigate the relationships between GRFs and kinematics at the foot contact during downhill running in distance runners.

METHODS

Six distance runners (mass: 57.2±4.7 kg, height: 1.69±0.02 m, best 5000 m race time: 16:06±0:37) were asked to run on slopes of 0 % (LV), -3.2 % (D3), -6.4 % (D6), and -9.1% (D9) grades at running speeds of 5.0 m/s (FS), 4.3m/s (MS), and 3.5 m/s (SS). Subjects were videotaped at 250 frames/s using a high-speed video camera. The segment endpoints of the subjects were digitized at 62.5 Hz throughout one running cycle from VTR images. Two dimensional coordinates of body segment endpoints were obtained by a panning DLT method. The displacement and velocity of the center of gravity and joint angular velocities of the lower extremity were calculated.

GRFs were measured at 500 Hz with two Kistler force platforms mounted in a specially made runway, 12m in length, on the slope. Loading rate of vertical GRF were calculated by differentiating the vertical GRF. GRF data normalized by the support time were averaged with all subjects.

A two-way analysis of variance (ANOVA) with repeated measures on two factors (grade of slope x running speed) was used to evaluate whether there were any significant differences in the parameters among the conditions. Statistical significance was determined at p<0.05.

![Figure 1: Horizontal and vertical ground reaction forces during the support phase.](image-url)
RESULTS AND DISCUSSION

Figure 1 shows the horizontal and vertical ground reaction forces during the support phase, and Figure 2 the vertical impact peak force and the maximum loading rate of the reaction force. There was no significant difference in the braking peak force among four conditions. Although the vertical impact peak force was significantly larger for D3, D6, and D9 than for LV, there was no significant difference among three downhill conditions. The maximum loading rate was significantly larger for D6 than for LV, while there was no significant difference between LV and the other downhill conditions. Unexpectedly, these results suggest that the impact shock during downhill running did not increase linearly as the grade of slope increased.

Figure 3 shows the vertical velocity of the center of gravity (CGV) and the vertical velocity of the heel relative to the center of gravity (HRV) at the foot contact. The magnitude of the CGV at the foot contact significantly increased as the grade of slope increased in each running speed (p<0.05). Because the magnitude of the impact force depends on the kinetic energy of the system at the foot contact (Nigg et al. 1995), the downhill conditions are likely vulnerable to the impact. This study, however, showed that the impact shock during downhill running was not so large compared with LV. Not shown in the figure, the heel downward velocity at the foot contact was significantly greater for D6 and D9 than for LV in each speed (p<0.05). The difference in the heel downward velocity among the conditions was, however, smaller than that of the CGV. HRV (upward is positive) at the foot contact was

**Figure 2**: Vertical impact force (top) and maximum loading rate (bottom).

**Figure 3**: Vertical velocity of the center of gravity (CGV; top) and vertical velocity of the heel relative to the center of gravity (RHV; bottom) at foot contact.
significantly greater for D9 of all three running speeds, D6 of MS, and D3 of SS than for LV in each speed (p<0.05, Figure 3). Gerritsen et al. (1995) found that the impact peak force was greatly influenced by the vertical touchdown velocity of the heel in normal running, using a direct dynamics simulation technique. Therefore, the results of this study suggest that in steep downhill, lifting the heel relative to the center of the gravity was one of the factors in keeping impact force low. On the other hand, there was no significant difference in the HRV of FS and SS between LV and D6, which may relate to large loading rate for D6.

Figure 4 shows the thigh angular velocity at the foot contact and the maximum knee flexion velocity in the support phase. At the foot contact, the thigh swung backward slower for D6 and D9 than for LV in each speed (p<0.05). There were positive correlations between the HRV and the thigh angular velocity at the foot contact (r=0.540, p<0.01) in all trials (n=72). These results suggest that in the steep downhill, runners drew up the heel to the center of the gravity by swinging less the thigh before and after the foot contact. Maximum knee flexion velocity just after the foot contact was significantly greater for D9 than for LV, D3, and D6 in each speed (p<0.05, Figure 4). Large knee flexion velocity just after the foot contact in D9 probably led to better compliance of the lower extremity and played an important role in a shock absorption.

The support time (Table 1) was longer for D9 than for D3 and D6 in each speed, especially in MS (p<0.05). The smaller the support time was, the greater force would be needed to obtain same magnitude of the impulse in shorter time. Therefore, short support time may be one of the reasons why the impact was greater for D6.

It was concluded that in order not to experience a larger impact shock in the steep downhill, distance runners usually draw up the heel to the center of gravity by swinging less the thigh before and after the foot contact, increase knee flexion velocity after the foot contact, and keep an appropriate support time.

REFERENCES


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**Table 1 Support time.**

<table>
<thead>
<tr>
<th></th>
<th>LV</th>
<th>D3</th>
<th>D6</th>
<th>D9</th>
<th>Significant difference (p&lt;0.05)</th>
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</thead>
<tbody>
<tr>
<td>FS</td>
<td>0.185 ±0.010</td>
<td>0.183 ±0.013</td>
<td>0.186 ±0.008</td>
<td>0.191 ±0.014</td>
<td>D3,D6&lt;D9</td>
</tr>
<tr>
<td>MS</td>
<td>0.206 ±0.012</td>
<td>0.198 ±0.009</td>
<td>0.196 ±0.010</td>
<td>0.212 ±0.015</td>
<td>D3,D6&lt;D9</td>
</tr>
<tr>
<td>SS</td>
<td>0.232 ±0.016</td>
<td>0.227 ±0.016</td>
<td>0.233 ±0.016</td>
<td>0.237 ±0.017</td>
<td>D3,D6&lt;D9</td>
</tr>
</tbody>
</table>

F: Significant difference in the fast speed at p<0.05.
M: Significant difference in the medium speed at p<0.05.
S: Significant difference in the slow speed at p<0.05.

**Figure 4:** Thigh angular velocity at foot contact (top) and maximum knee flexion velocity in the support phase (bottom).