LOWER EXTREMITY KINEMATICS, LEG STIFFNESS, AND VERTICAL GROUND REACTION FORCE DURING DROP LANDING IN 11-YEAR-OLD CHILDREN

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SUMMARY
The purpose of this study was to investigate the correlation between lower extremity kinematics, leg stiffness, and GRF parameters to identify the factors that affect the lower extremity load during drop landing. GRF parameters, lower extremity kinematics, and leg stiffness data during the landing phase were obtained from 21 subjects (11.8 ± 0.7 yrs) performing a landing task as they would naturally from drop height of 40 cm, using high-speed camera, force palates, Kwon3D system, and KwonGRF system. The Pearson correlation coefficients between the lower extremity kinematics, leg stiffness, and GRF parameters were determined. The lower extremity kinematics were significantly correlated with the peak vertical GRF and the vertical loading rate (P<0.05). The leg stiffness were significantly correlated with the peak vertical GRF, the vertical loading rate, and the time to peak GRF (P<0.05). In summary, decreasing hip and knee flexion at initial foot-ground contact, decreasing hip and knee flexion angular displacement, and increasing leg stiffness increased the peak vertical GRF, enhanced the vertical loading rate, and reduced the time to peak vertical GRF during landing in a drop landing task in children, which would increase the risk of lower extremity injury.

INTRODUCTION
The risk of lower extremity injuries may be associated with the magnitude of the ground reaction force (GRF) and the loading rate, which are affected by the motions of the lower extremity during landing [1-2]. Furthermore, recent biomechanical studies have often utilised stiffness to analyse lower extremity movement modulation and injury [4,5]. One study investigated the effects of developmental stage on lower extremity kinematics and GRF during landing and found that, compared to adults, children use different kinematics, particularly during landing with increased GRF, and that they have a reduced time to peak vertical force [6]. Quatman et al. [7] also demonstrated that the loading rate decreases with maturation in children. The majority of injuries in children are associated with activities that involve landing [8]. To our knowledge, few researchers have examined the factors that affect lower extremity load during drop landing in children. It is important to identify the factors affecting GRF characteristics during landing to prevent lower extremity injury in children. The purpose of this study was to investigate the correlation between lower extremity kinematics, leg stiffness, and GRF parameters to identify the factors that affect the lower extremity load during drop landing. The study population included 11-yr-old children who were fifth-grade students, whose physical education curriculum for includes many landing actions.

METHODS
The participants consisted of 21 child volunteers (11 girls, 10 boys, height: 1.49 ± 0.07 m; mass: 40.28 ± 8.05 kg; age: 11.8 ± 0.7 yrs) healthy and without lower extremity injuries during the six months prior to the experiment. All participants and the children’s guardians signed informed consent forms before participating in this study.

Kinematic data and GRF parameters were collected by a MegaSpeed high-speed camera system (120 Hz) and an AMTI force plate (1200 Hz). Each subject performed a landing task from drop height of 40 cm. The participants were instructed to keep their hands on their waist and asked to perform the landing task as they would naturally. Prior to the experiment, the participants had a sufficient warm-up (20 minutes) and practiced the drop landing task before data collection. Five markers were placed on the acromial end, greater trochanter, femoral condyles, lateral malleolus, and head metatarsal II. The kinematics and GRF data were analysed using the Kwon3D and KwonGRF systems. Segment data were calculated based on Jensen [9] segment parameters. The leg stiffness calculation equation was based on the mass-spring model concept: leg stiffness=F_{max} (Y_1-Y_2), where F_{max} is the peak vertical GRF, Y_1 is the vertical height of the CG at initial foot contact with the ground, and Y_2 is the vertical height of the CG at the moment of peak vertical GRF [10]. The loading rate was defined as the F_{max}/Δt, where the Δt is the interval between the initial time of landing and the peak vertical GRF. Statistical analysis was performed with SPSS 14.0 for Windows. The Pearson correlation coefficients between the lower extremity kinematics, leg stiffness, and GRF parameters were determined. The significance level was set at α = 0.05.

RESULTS AND DISCUSSION
The results of this study are shown in Table 1. Similar to previous work in adults by Yu et al. [3] and Decker et al. [11],
we found that in children, decreasing hip and knee flexion at initial foot contact with the ground increased the peak vertical GRF and the loading rate during landing in a drop landing task (P<0.05). Moreover, the joint angular displacement during landing may primarily affect the peak vertical GRF and the loading rate in children. Landing with greater hip and knee flexion angular displacement may decrease the peak vertical GRF (P<0.05), and landing with greater knee flexion angular displacement may decrease the vertical loading rate (P<0.05). These findings were also partly similar to those of a previous study in adults, which found that hip and knee extensions were the major contributors to energy absorption during landing; hence, increased hip and knee joint angular displacement during landing would reduce the peak value of the GRF and delay the time at which the peak GRF appeared [12,13]. However, the results of our study show that the hip and knee flexion angular displacement did not affect the time to peak vertical GRF in children (P>0.05). Based on the results of our study, we inferred that decreasing hip and knee flexion at initial foot-ground contact and decreasing hip and knee flexion angular displacement increased the vertical loading rate by increasing the peak vertical GRF during landing in a drop landing task in children. These findings may be important, as previous studies have indicated that a greater peak GRF and loading rate during landing increases the risk of lower extremity injury [1,2]. Prapavessis et al. [8] indicated that verbal instructions related to the control of joint kinematics can effectively reduce the vertical peak GRF during landing from a jump in children. It has been suggested that older students given verbal instructions on the best action to take in a landing task could focus on increasing hip and knee flexion at initial foot contact with the ground and on increasing knee flexion angular displacement.

The loading rate is calculated based on the peak vertical GRF and the time to peak vertical GRF. A short time to reach the peak GRF corresponds with a high loading rate during landing. Landing with greater leg stiffness may reduce the time to reach the peak GRF in children (P<0.05). Moreover, this study showed that leg stiffness during landing significantly affects the peak vertical GRF and the loading rate in children (P<0.05). Previous studies have also indicated that greater stiffness increases the lower extremity load rate in adults [5]. However, it is important to understand that either excessive or insufficient stiffness will likely result in increased risk of lower extremity injury [14].

CONCLUSIONS
Decreasing hip and knee flexion at initial foot-ground contact, decreasing hip and knee flexion angular displacement, and increasing leg stiffness increased the peak vertical GRF, enhanced the loading rate, and reduced the time to reach peak GRF during landing in a drop landing task in children, which would increase the risk of lower extremity injury.

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REFERENCES

Table 1: The descriptive data for the parameters (M ± SD) and the correlation coefficients (P-value) of the lower extremity kinematics and leg stiffness with the lower extremity load parameters during landing. (N=21)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normalized Peak Vertical GRF (BW) (2.97 ± 0.91)</th>
<th>Time to Peak Vertical GRF (ms) (54.57 ± 9.25)</th>
<th>Normalized Vertical Loading Rate (BW/sec) (58.60 ± 29.29)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip Flexion Angle at Initial Foot Contact with Ground (deg) (18.54 ± 7.21)</td>
<td>-0.59 (0.005) *</td>
<td>0.21 (0.353)</td>
<td>-0.52 (0.016) *</td>
</tr>
<tr>
<td>Knee Flexion Angle at Initial Foot Contact with Ground (deg) (23.54 ± 6.78)</td>
<td>-0.44 (0.046) *</td>
<td>0.29 (0.198)</td>
<td>-0.45 (0.041) *</td>
</tr>
<tr>
<td>Hip Angular Displacement During Landing Phase (deg) (22.20 ± 11.37)</td>
<td>-0.58 (0.005) *</td>
<td>0.18 (0.424)</td>
<td>-0.39 (0.082)</td>
</tr>
<tr>
<td>Knee Angular Displacement During Landing Phase (deg) (42.67 ± 9.11)</td>
<td>-0.60 (0.004) *</td>
<td>0.17 (0.456)</td>
<td>-0.44 (0.048) *</td>
</tr>
<tr>
<td>Normalized Leg Stiffness (BW/BH) (33.02 ± 18.16)</td>
<td>0.84 (&lt;0.001) *</td>
<td>-0.69 (0.001) *</td>
<td>0.82 (&lt;0.001) *</td>
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</table>

* Significant correlation between the two parameters (P<0.05).