COMPARISONS OF THE INTERJOINT COORDINATION BETWEEN LEADING AND TRAILING LIMBS WHEN CROSSING OBSTACLES OF DIFFERENT HEIGHTS

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INTRODUCTION
The multi-joint coordination and end-point control nature of the locomotion system during obstacle crossing has warranted its inclusion in Frenkel's exercises for training in neurological patients. Previous studies on the mechanics and control of the lower extremities during the task were mainly through kinematic and kinetic analyses of crossing obstacles of different heights. These studies reported the changes of the states of individual joints but the data failed to reveal multi-joint coordination performance for the whole cycle. Interjoint coordination may provide more information on how the central nervous system organizes the various joints to perform functional activity. However, no study has investigated both the patterns and stability of interjoint coordination of the lower limbs when walking over obstacles. Moreover, it remains unclear whether these characteristics would be different between the leading and trailing limbs. Therefore, knowledge of the differences between the leading and trailing limbs in the pattern and stability of interjoint coordination may help in the design of fall prevention methods and in the rehabilitation of patients with unilateral pathology during obstacle crossing.

METHODS
Fifteen normal adults walked and crossed obstacles of different heights (10%, 20% and 30% of leg length) with each limb while kinematic data were measured to obtain joint angles in the sagittal plane. Phase angles of each joint were calculated from the angular velocities (x') and displacement (x) as \( \phi = \tan^{-1}(x'/x) \) (Figure 1) [1]. Relative phase angles (RPA) were then calculated by subtracting phase angles of the distal joint from that of the proximal (\( \phi_{\text{hip-knee}}, \phi_{\text{knee-ankle}} \)) [1]. A parameter called deviation phase (DP) was then calculated by averaging the standard deviations of the ensemble RPA curve points for the stance and swing phase for each obstacle height. The calculated DP variables were tested using a two-factor repeated ANOVA.

RESULTS AND DISCUSSION
The leading and trailing limbs were found to have similar patterns of interjoint coordination but with different level of stability. The leading limb was more stable than the trailing one (p<0.05) except for the knee-ankle coordination during stance (p<0.05) (Table 1). More stable interjoint coordination in both limbs when the leading limb was crossing seemed necessary for maintaining whole body balance with accurate foot clearance when the body center of mass was moving away from the stance limb. Only the stability of the knee-ankle coordination for both limbs decreased with increasing obstacle-height during stance (p<0.05) (Table 1). Decreased stability of the knee-ankle coordination may indicate an increase of difficulty in the control of the ankle joint in modulating the stability of the body.

CONCLUSIONS
It is suggested that clinical obstacle-crossing training programs for patients with unilateral pathology should include the training of the affected limb not only as leading but also as trailing limb. Increase of the stability of the ankle joint may be helpful for the stability of the knee-ankle coordination and thus the general performance of obstacle crossing.

REFERENCES

Table 1: Means and standard deviations of the deviation phase (DP) values of the hip-knee and knee-ankle coordination

<table>
<thead>
<tr>
<th>Obstacle Height (%)</th>
<th>10% Leading</th>
<th>10% Trailing</th>
<th>20% Leading</th>
<th>20% Trailing</th>
<th>30% Leading</th>
<th>30% Trailing</th>
<th>p-value of limb (p_l) and height (p_h) effect</th>
<th>Trend of Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip-Knee</td>
<td>80.98 (24.13)</td>
<td>65.13 (13.94)</td>
<td>77.88 (27.01)</td>
<td>68.65 (14.99)</td>
<td>72.69 (18.75)</td>
<td>81.00 (26.30)</td>
<td>p_l=0.247</td>
<td>p_h=0.435</td>
</tr>
<tr>
<td>Knee-Ankle</td>
<td>81.18 (22.87)</td>
<td>59.80 (13.00)</td>
<td>82.12 (24.54)</td>
<td>62.38 (11.90)</td>
<td>85.42 (20.19)</td>
<td>79.89 (26.54)</td>
<td>p_l=0.009*</td>
<td>p_h=0.020</td>
</tr>
</tbody>
</table>

Figure 1: Definition of the phase angle in the phase plot

stability. The leading limb was more stable than the trailing one (p<0.05) expect for the knee-ankle coordination during stance (p<0.05) (Table 1). More stable interjoint coordination in both limbs when the leading limb was crossing seemed necessary for maintaining whole body balance with accurate foot clearance when the body center of mass was moving away from the stance limb. Only the stability of the knee-ankle coordination for both limbs decreased with increasing obstacle-height during stance (p<0.05) (Table 1). Decreased stability of the knee-ankle coordination may indicate an increase of difficulty in the control of the ankle joint in modulating the stability of the body.