Anticipatory Locomotor Adjustments of the Lower Extremities in Young Adults when Walking onto a Moving Surface

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SUMMARY
Causes of falls are complex and involve both human and environmental factors. Adapting our gait to cope with a predictably moving surface is a common facet of life in modern cities. Loss of balance or riders who were stuck by other passengers especially when stepping onto a moving walkway or escalators can lead to serious injuries. Awareness of the risks and the circumstances leading to those injuries allow for better guidance of development of intervention strategies for injury prevention. Fifteen young subjects walked along a walkway and stepped onto a static surface (SS) or moving surface (MS) while kinematic and kinetic data were measured with a Vicon system and two forceplates. End point variables, joint angles, moments and powers of the lower limbs were calculated. Compared to the baseline data in the SS condition, anticipatory locomotor adjustments (ALA) started as early as the trailing heel-strike and mainly occurred during swing phase of the leading limb when walked onto a moving surface. With increased leading step speed and length but decreased trailing step speed and length during the pre-tride, decreased leading toe clearance and foot angle were found during the late leading swing phase which was longer. Compared to those in the SS condition, smaller ankle plantar flexor and hip abductor moments during the late stance suggested that not the muscular strength but proper temporal-spatial controls of locomotor system were essential to achieve a safe and smooth striking for the young subjects. Greater horizontal velocities of the swing heel, greater trailing ankle power and angular velocities were also observed during late anticipatory phase. Knowledge of the ALA to walking onto moving surface in young subjects was established and that could be served as a baseline data for the management of other populations with balance deficits in the future.

INTRODUCTION
Adapting our gait to cope with a predictable moving surface is a common facet of life in modern cities, such as on escalators and moving walkways in underground transportation, shopping malls, or at the airports. The United States Consumer Product Safety Commission (USCPSC) estimates that there are approximately 9200 escalator-related injuries in the United States each year, which are often associated with falls and entrapment [1]. The majority of those escalator injuries were caused by loss of balance or riders who were stuck by other passengers especially when stepping on or off from moving walkway or escalators [1-3]. Escalator-related injury patterns have been studied at Taipei Metro Rapid Transit stations (TRTC) to evaluate the effect of proposed safety rules and passenger education [1]. Loss of balance, not holding the handrail, and riders struck by other passengers were reported as the leading causes of injuries.

Locomotion is adapted regularly to the environment and the desired movement goals. To negotiate any hazards and maintain locomotion, the balance system proactively monitors the environment and predicts the appropriate adjustments required to prevent stumbles, slips or trips [4]. These adaptations are termed “anticipatory locomotor adjustments (ALA)” [5]. Awareness of the risks and the circumstances leading to escalators injuries allow for better direction of development of intervention strategies for injury prevention. Since investigating the task of transferring from ground to a moving surface may help identify the risk factors of falls, stepping on and off a moving surface is the paradigm used to explore these issues. The walking patterns when walking onto a moving surface remained unexplored. The current study thus aimed to investigate the anticipatory strategies adopted by normal young adults when walking onto a moving surface from ground in terms of the temporal-spatial variables and kinematics of the leading and trailing limbs, including foot clearance, 3D pelvis and joint angles.

METHODS
Fifteen young adults (age: 22.33 ± 1.18 years, height: 167.40 ± 4.55 cm, LL: 77.20 ± 3.36 cm, weight: 58.53 ± 10.03 kg, BMI: 22.66 ± 3.47 kg/m2) participated in the current study with written informed consents. Kinematic data were measured using a 7-camera motion analysis system (Vicon 512, Oxford Metrics Group, U.K.). Two forceplates (AMTI, Advanced Mechanical Technology, U.S.A.) were placed in series next to the end while kinematic and kinetic data were measured with a Vicon system and two forceplates. End-point variables, joint angles, moments and power of the lower limbs were calculated. The differences between surface conditions were analyzed using paired t-test (α=0.05).

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RESULTS AND DISCUSSION
With respect to the control condition, namely SS condition, significant differences were found in temporal-spatial parameters with increased trailing speed but reduced leading speed in the MS condition (Table 1). Increased trailing step lengths but reduced leading step lengths were also found in the MS condition (Table 1). Significant differences were found in time variables with increased duration of leading swing phase and trailing stance phase (Table 1).

Table 1: Mean temporal-spatial parameters of gait speed, step length, and step width during the anticipatory phase when walking onto a static surface (SS) and moving surface (MS). An asterisk indicates a significant between SS and MS conditions (P<0.05).

<table>
<thead>
<tr>
<th>Temporal-spatial Variables</th>
<th>Surface Conditions</th>
<th>P-values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SS</td>
<td>MS</td>
</tr>
<tr>
<td>Stride Speed</td>
<td>0.98</td>
<td>0.97</td>
</tr>
<tr>
<td>Trailing Step Speed</td>
<td>0.96</td>
<td>1.00</td>
</tr>
<tr>
<td>Leading Step Speed</td>
<td>1.01</td>
<td>0.96</td>
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<tr>
<td>Stride Length</td>
<td>1136.87</td>
<td>1136.93</td>
</tr>
<tr>
<td>Trailing Step Length</td>
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<td>553.05</td>
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<tr>
<td>Leading Step Length</td>
<td>595.60</td>
<td>581.21</td>
</tr>
<tr>
<td>Trailing Step Width</td>
<td>117.66</td>
<td>120.67</td>
</tr>
<tr>
<td>Leading Step Width</td>
<td>99.05</td>
<td>107.94</td>
</tr>
</tbody>
</table>

For the end-point variables compared to control (SS), significantly reduced toe-clearance and foot angle of leading limb were found around the later half of leading swing phase, indicating that the leading foot was moving almost horizontally without rotation before walking onto a moving surface. The early appearance of foot-flat occurred around 89 % of stride cycle, being 48.94 ms on average in the MS condition while foot-flat occurred 135 ms after leading heel-strike in SS condition. Values for the horizontal velocity of the leading heel were significantly higher at T5 in the MS condition than in the SS condition (Fig. 1), which also occurred earlier in the MS condition than in the SS condition.

Figure 1: Curves of the horizontal velocity of the leading heel when walking onto a static surface (SS, dash lines) and on a moving surface (MS, solid lines). The vertical lines indicate the key events: leading heel-strike, trailing toe-off, trailing heel-strike, leading toe-off, and leading heel-strike on the moving surface (at 100% of leading stride).

ALA adjustments in terms of joint angles were observed at the hip in both leading and trailing limbs. Before T5, no significant differences of the joint angles of both limbs between SS and MS conditions were found except for smaller hip extension angles of leading limb and greater hip flexion angles of the trailing limb were found. Right after leading toe-off, joint kinematics of both limbs also contributed to the temporal-spatial variables and control of the end-point which was required to walking onto a moving surface. The reduced maximal leading toe-clearance and foot angle found during the late leading swing phase may be contributed from the greater knee flexion angles of the leading limb and smaller hip extension angles of the trailing limb. Right before T5, increased leading hip and knee flexion together with more anteriorly-flexed pelvic and plantar-flexed ankle resulted in the obvious decreased leading toe-clearance and foot angle. The reduced foot angle and maximal toe-clearance of leading limb were essential as ALAs which occurred shortly before the leading foot stroke on the moving surface to achieve a safe and smooth landing. Compared to those in the SS condition, smaller ankle plantar flexor and hip abductor moments during the late stance suggested that the young subjects walk onto moving surface with less demand in the trailing limb.

CONCLUSIONS
Even when asked to walk as naturally as possible, ALAs were identified in terms of altered temporal-spatial variables and control of end-points when walking onto moving surfaces in young subjects. With altered speed, length, and time of leading and trailing steps, the subjects adopted specific gait patterns as indicated by the changes in the end-point variables and joint angles and moments of the lower extremities. The ALA’s started as early as the trailing heel-strike and mainly occurred during the swing phase of the leading limb. Although the degrees of freedom in the human locomotor system are redundant in nature, the CNS in young subjects appeared to be able to plan and organize necessary adjustments, the reduced leading toe-clearance and foot angle in this case, without changing too many joint components.

REFERENCES