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Anticipatory changes in control of swing foot and lower limb joints when walking onto a moving surface traveling at constant speed

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ABSTRACT

Adapting to a predictable moving surface such as an escalator is a crucial part of daily locomotor tasks in modern cities. However, the associated biomechanics have remained unexplored. In a gait laboratory, fifteen young adults walked from the ground onto a moving or a static surface while their kinematic and kinetic data were obtained for calculating foot and pelvis motions, as well as the angles and moments of the lower limb joints. Between-surface-condition comparisons were performed using a paired *t*-test ($\alpha = 0.05$). The results showed that anticipatory locomotor adjustments occurred at least a stride before successfully walking onto the moving surface, including increasing step length and speed in the trailing step ($p < 0.05$), but the opposite in the leading step ($p < 0.05$). These modifications reduced the plantarflexor moment of the trailing ankle needed for stabilizing the body, while placing increased demand on the knee extensors of the trailing stance limb. For a smooth landing and to reduce the risk of instability, the subjects adopted a flat foot contact pattern with reduced leading toe-clearance ($p < 0.05$) at an instantaneous speed matching that of the moving surface ($p > 0.05$), mainly through reduced extension of the trailing hip but increased pelvic anterior tilt and leading swing ankle plantarflexion ($p < 0.05$). The current results provide baseline data for future studies on other populations, which will contribute to the design and development of strategies to address falls while transferring onto moving surfaces such as escalators.

1. Introduction

Adapting to the surrounding environment is a crucial part of daily locomotor tasks [1,2]; unsuccessful adaptation being one of the most frequent causes of falls, among other factors [3]. A common environmental challenge to daily locomotion in modern cities is moving surfaces such as escalators and moving walkways in Metro transport, shopping malls or at the airport. Failure to transfer between the ground and a moving surface, leading to a loss of balance [4,5], often results in falls with injuries to the extremities, as well as to the head, leading to serious consequences [4]. It has been reported that there are approximately 10,000 escalator-related injuries requiring emergency treatment each year in the United States [6] and approximately 2000 children each year receive medical treatment for an escalator-related injury [7]. It was reported that escalator-related injuries occur across a range of ages, from children to older people [8]. Despite this high prevalence, previous studies have focused mainly on analysis of injury types and patterns [8–10]. Few studies have examined the biomechanical adaptations needed for a successful transfer between the ground and moving surfaces, knowledge of which will be helpful for developing strategies to reduce the risk of related falls.

Biomechanical adaptations have been studied in activities on challenging surface conditions, aimed at preventing falls [11–13]. Such studies include standing balance on a perturbed force platform [13] and walking on slippery surfaces [11]. During walking on a slippery surface various biomechanical variables, such as foot-floor angle, toe clearance, heel horizontal velocity, and joint angles and moments, have been used to identify the control of the end-point and joints of the lower limbs

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[11,14–17]. These variables will be useful for assessing the locomotor adaptations during the transfer between the ground and a moving surface.

In order to negotiate any hazards, maintain locomotion and achieve the desired movement goals, the neuromusculoskeletal control system proactively monitors the environment and predicts the appropriate adjustments required to prevent stumbles, slips or trips [18–20]. These adaptations, termed "anticipatory locomotor adjustments" (ALA) [18,19], are the additional voluntary actions during a locomotor task that are planned in advance in response to environmental changes, such as avoiding obstacles [19] or stepping up to a new level during walking [21]. Inappropriate adjustments may compromise the necessary adaptation to the environment, thus affecting the stability of locomotion, especially in populations at a higher risk of falling [22]. Therefore, identifying the ALAs when walking onto a moving surface will be helpful for a better understanding of the control of the locomotor system and its end-point for a successful transfer.

The purpose of the study was to identify the ALAs in the control of the end-point segment (i.e., foot) and lower limb joints of healthy young adults when walking from the ground onto a moving surface traveling at constant speed.

2. Materials and methods

Fifteen healthy adults (age: 22.33 ± 1.18 years, height: 167.40 ± 4.55 cm, LL: 77.20 ± 3.36 cm, mass: 58.53 ± 10.03 kg) participated in the current study with informed written consents as approved by the Institutional Research Board. They all had normal or corrected-to-normal vision and were free of neuromusculoskeletal pathology that might affect gait.

Each subject wore twenty-eight retroreflective markers for tracking the motion of the body segments of the pelvis-leg apparatus [23]. They walked along an 8-m walkway and stepped onto a treadmill embedded flush with the floor at the end of the walkway (Fig. 1a) under two test conditions, namely from ground

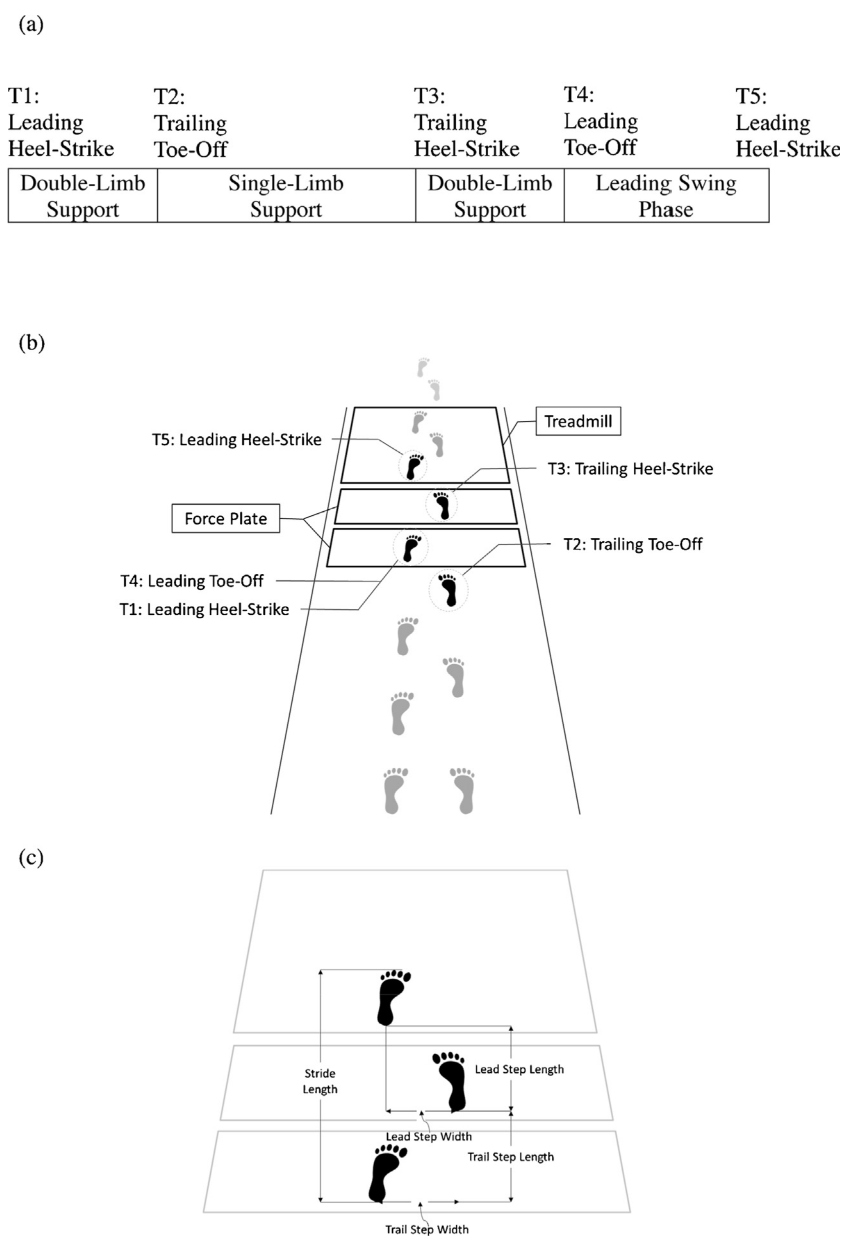

Fig. 1. (a) Definitions of the transferring stride and key events when walking from the ground onto a static/moving surface, (b) spatial arrangement of the forceplates and the treadmill, and (c) the definitions of the lengths and widths of the transferring stride, leading step and trailing step.