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Gait adaptations to different paths of stair descent

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ABSTRACT

Gait characteristics during stair descent have been characterized for a straight descent path; however, pedestrians are likely to encounter a variety of staircase designs that allow one to descend at an angle (i.e. an oblique or monumental staircase). The purpose of this study was to determine the temporospatial lower limb joint kinematics differences between descending a staircase on straight versus oblique descent paths. Sixteen subjects (8 males, 8 females) descended a staircase under three different conditions: straight descent and at a 25° and 45° angle compare to the straight path. Cycle time, cadence, speed, step width, and step length were significantly affected by descent angle, while the proportion of the cycle dedicated to the stance and swing phases remained constant over the descent paths. Peak knee flexion angle increased by approximately 2.5° in the 45° condition compared to the 0° condition ($p = 0.0044$); however, the remainder of the time series was unchanged. A decreased step width and increased step length occurred to allow the foot to sufficiently clear the steps. Changes in the temporospatial variables, hip joint angle and a constant stance/swing proportion demonstrates that these adaptations may be made to maintain characteristics of the gait cycle and prevent subjects from adopting an unfamiliar gait pattern.

1. Introduction

Over the past 30 years, gait characteristics of staircase descent have been quantified for temporospatial variables, and lower limb kinematics and kinetics, as well as for adaptations to changes in staircase geometry, such as riser height [1–3] and tread depth [1]. These studies have primarily focused on straight descent of a staircase, with subjects walking perpendicular to the step edge; however, pedestrians encounter a variety of staircase designs beyond this straight decent route, and the different geometry of a staircase can allow for a variety of walking patterns. One design of particular interest is the oblique (or monumental) staircase (Fig. 1), which allows pedestrians to descend the stairs on angled paths. Given the lack of research on different descent paths, this study aimed to quantify the temporospatial and lower limb kinematic adaptations made when descending a staircase along different paths.

Many studies have investigated the impact of altered tread depth and riser height of a step during descent [1–3]; however, none of these studies assessed changes in tread depth without a physical change in the staircase geometry. An interesting aspect of angled descent is that it increases the effective tread depth available for the foot to be placed without physically altering the staircase geometry. For example, for a 30 cm tread depth the effective tread depth available for foot placement when descending at a 45° angle is approximately 43 cm. Although this tread depth is acceptable according to provincial building codes, the effective tread depth is greater than the requirement of a maximum tread depth of 35.5 cm set by the Ontario Building Code [4]. Complications during staircase descent have been shown to arise when stair treads deviate from 28 cm [5,6] and accidents have been shown to increase when tread depths are deeper than 36 cm [5,6]. This increase in effective tread depth on angled descent may force pedestrians to adapt their gait and impact the risk for accidents. These adaptations may be preventative measures to ensure the safe navigation of stairs; however, since one's gait is constrained when walking down stairs [7], it is possible that pedestrians might be forced to adapt unnatural and unsafe gait patterns [5,6]. For example, the increased effective tread seen with an angled descent might cause a person use longer strides that can potentially affect a person's balance or may be difficult to perform if the pedestrian, such as an older adult, cannot meet the lower limb range of motion demands to allow for an increase in step length. Pedestrians may also change their gait if they are more cautious, such as increasing their step width in order to further increase their base of support [8]. As a result, assessing the temporospatial and lower limb adaptations in young healthy

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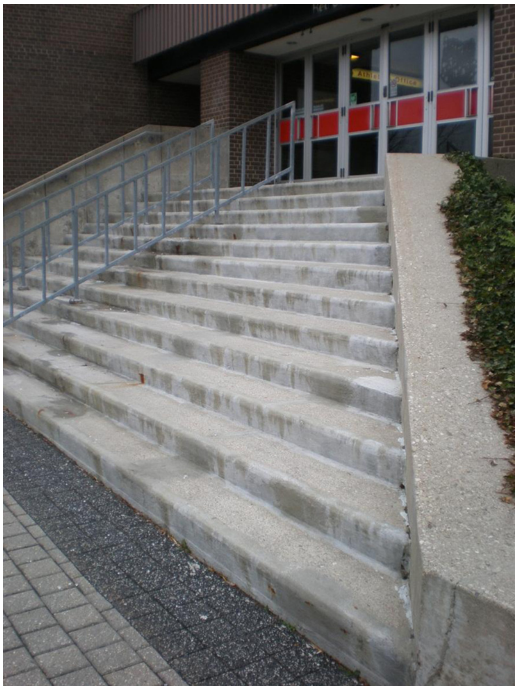

Fig. 1. Example of an oblique or flared staircase.

individuals to descending a staircase at an angle is important first step for an assessment of potential issues for public safety and whether or not all individuals in a population will have the ability to meet the demands to potential adaptations to their gait when descending these staircases.

The purpose of this exploratory study was to determine the temporospatial and lower limb kinematic adaptations that may occur with changes in descent path on an oblique cut staircase. This study compared walking at an angle with an effective tread depth that is still within the OBC (2006) requirements for maximum tread depth (35.5 cm), and at an angle that has an effective tread depth outside of that defined by OBC (2006). Due to the proposed changes in stair geometry described above, it was hypothesized that when compared to walking perpendicularly to the stair tread, both temporospatial (speed, cadence, cycle time, step length, step width, and percent stance, swing, and double support), as well as sagittal lower limb and frontal plane hip angles, would be altered when descending the staircase at an angle. It was hypothesized that the geometry of the staircase would require an increased step length when descending at an angle so the participant could clear the steps and utilize the increased effective tread depth, but step width would remain the same as a way of increasing their base of support, as well as a decrease in cadence and speed because participants would be more cautious. Finally, it was hypothesized that an increased hip extension and knee extension would be required to achieve the increased step length.

2. Methods

2.1. Subjects

Sixteen individuals (Male: $n = 8$, 23.3 (2.6) years, 1.82 (0.09) m, 84.0 (13.1) kg; Female: $n = 8$, 21.6 (1.2) years, 1.64 (0.10) m, 62.3 (8.0) kg) were recruited from the University of Waterloo student population. Participants were excluded if they had a history of balance or gait conditions or lower back or leg pain within the last 12 months. The study protocol received approval from the University Office of Research and subjects gave informed consent before testing began.

2.2. Experimental protocol

A custom built set of stairs that were widened obliquely on one side at a 45° angle were used in this study (Fig. 2). The staircase consisted of a platform and three steps (rise 20 cm, run 30 cm). Subjects were instructed to descend the stairs along three paths – 0 (0D), 25(25D) and 45(45D) degrees (Fig. 2). The 0D condition represented a typical, straight path of descent down the stair case, while 45D represented the path of descent that was in line with the oblique cut of the staircase. The 25D condition represented an intermediate path between 0D and 45D. Each angle was measured with respect to the straight edge of the staircase. Subjects began on the platform of the staircase approximately 40 cm from the first step. Subjects initiated the descent trial by taking their first step on the platform and then descending the stairs and continued to walk on the floor once the end of the staircase was reached. Subjects were instructed to maintain their path of descent by visually focusing on a pole that was placed 180 cm horizontally from the rise of the last stair at one of three locations, depending on the desired path. All conditions were randomized and each subject performed five trials on each path. No instruction of foot initiation preference was given.

Kinematics of the pelvis and bilateral thigh, shank, and foot were tracked with an Optotrak Certus motion capture system (Northern Digital Inc., Waterloo, ON) using infrared emitting diodes fixed to rigid plates during collection. Anatomical landmarks were tracked with respect to these rigid plates and their location was captured during a 10 s static calibration trial. Motion data were sampled at a frequency of 30 Hz. Location of the staircase was digitized in order to capture its location within the global system. Location of the anatomical landmarks and staircase geometry were brought into Visual3D (C-motion, Kingston, ON) for subsequent analysis.

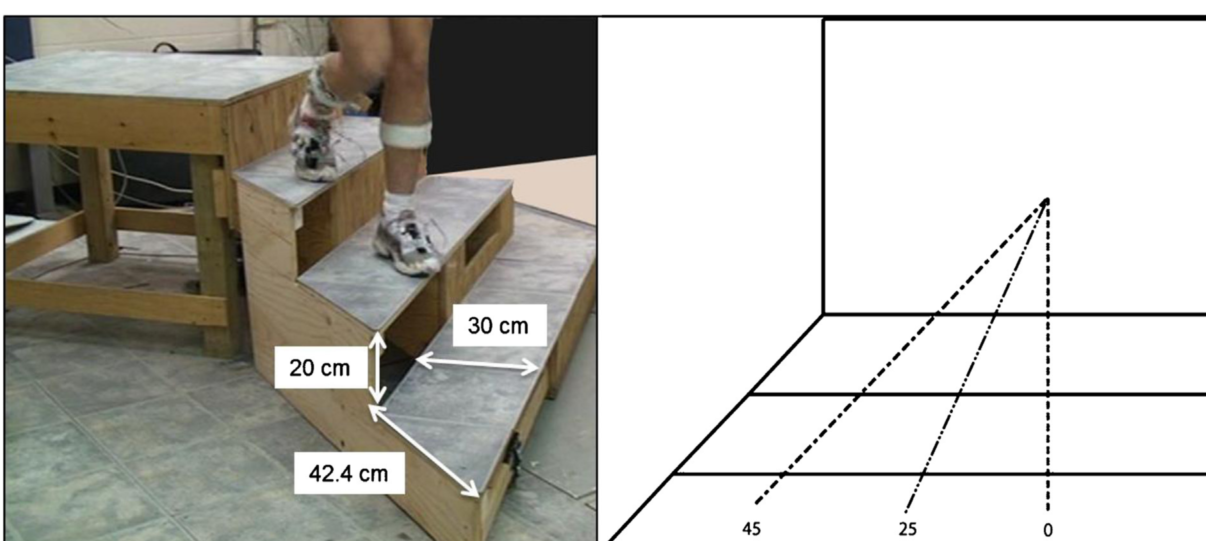

Fig. 2. Example of the staircase setup with the person descending at a 45° angle (left) and the three descent paths tested in this study (right).