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The effects of altering attentional demands of gait control on the variability of temporal and kinematic parameters

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ABSTRACT

The purpose of this study was to investigate the effects of cognitive and visuomotor tasks on gait control in terms of the magnitude and temporal structure of the variability in stride time and lower-limb kinematics measured using inertial sensors. Fourteen healthy young subjects walked on a treadmill for 15 min at a self-selected gait speed in the three conditions: normal walking without a concurrent task; walking while performing a cognitive task; and walking while performing a visuomotor task. The time series data of stride time and peak shank angular velocity were generated from acceleration and angular velocity data recorded from both shanks. The mean, coefficient of variation, and fractal scaling exponent α of the time series of these variables and the standard deviation of shank angular velocity over the entire stride cycle were calculated. The cognitive task had an effect on long-range correlations in stride time but not on lower-limb kinematics. The temporal structure of variability in stride time became more random in the cognitive task. The visuomotor task had an effect on lower-limb kinematics. Subjects controlled their swing limb with greater variability and had a more complex adaptive lower-limb movement pattern in the visuomotor task. The effects of the dual tasks on gait control were different for stride time and lower-limb kinematics. These findings suggest that the temporal structure of variability and lower-limb kinematics are useful parameters to detect a change in gait pattern and provide further insight into gait control.

1. Introduction

Walking is a frequently performed activity that is both a voluntary and a highly automated process [1] and is controlled by complex dynamic sensorimotor interactions [2]. In daily living, there are situations that distract attention away from walking, as well as situations that require greater attention to walking. The complexity of gait control may increase when an individual is adapting to a momentarily changing environment. Traditionally, the mean, standard deviation (SD), and coefficient of variation (CV) of various parameters have been used to express the features of gait patterns. However, these measurements neglect the temporal structure of the variability. It has recently been shown that the temporal structure of variability in stride time in healthy walking exhibits complex manner, called long-range correlations, that should not be neglected [3]. Degeneration of long-range correlations is more sensitive to changes in the gait pattern of people at high risk of falls than conventional variability parameters [4] and is related to aging and the severity of neurological diseases [5,6]. It has been proposed that long-range correlations may relate to complex self-organized physiological systems and reflect adaptability of systems to varying environmental conditions [2,3,7], and loss of long-range correlations would be related to looser cortical control [2]. Therefore, long-range correlations represent a useful indicator of the complexity of gait control and may provide further insights into the gait control systems.

The addition of concurrent secondary tasks while walking has been used to investigate the influences of altering attentional demand on gait control and the involvement of the cortical level in gait control [8]. Cognitive tasks such as an arithmetic task have

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been used to test the effects of divided attention on gait [9]. Such cognitive tasks may interfere with gait control. However, Bollens et al. [9] and Grubaugh et al. [10] showed that long-range correlations in stride time were not affected by cognitive tasks. Stride time can be regarded as the final output of a locomotor system, and cognitive tasks may influence other parts of that system, such as lower-limb kinematics. The kinematics of the lower-limb are often examined for gait analysis, but the influences of cognitive tasks on the kinematics of the lower-limb remain unclear. In contrast to cognitive tasks, a task of adjusting foot placement to a visual target has been used to test the effects of greater attentional demand devoted to the control of walking [11] and assess gait adaptability, defined as the ability to adjust gait to environmental circumstances [12]. Adjusting the step based on visual information may involve higher cortical control of the lower-limb. Gait adaptability has been evaluated using stepping accuracy and walking speed [12,13]. However, the gait pattern recruited to the task remains unclear. Evaluating the gait pattern when increasing attention on gait by focusing on movement of the lower-limb may facilitate understanding the gait control required when people adapt to environmental circumstances.

The purpose of this study was to investigate the effects of two types of dual tasks (gait with a cognitive task or with a visuomotor task) on the temporal structure of variability of stride time and lower-limb kinematics during walking. We hypothesized that the effects of the dual tasks on the long-range correlations would be different for stride time and lower-limb kinematics. Specifically, we hypothesized that the dual tasks would have an effect on lower-limb kinematics, but not on stride time.

2. Methods

2.1. Subjects

Subjects were 14 healthy young people (eight males, six females; mean ± SD; age: 23.6 ± 2.5 years; body height: 167.1 ± 7.5 cm; body weight: 59.0 ± 8.2 kg) with normal or corrected-to-normal visual acuity and no history of injury or disease that affected their walking. The Ethics Committee of the Division of Physical Therapy and Occupational Therapy Sciences, Graduate School of Biomedical and Health Sciences, Hiroshima University approved this study. Written, informed consent was obtained from all subjects prior to participation.

2.2. Apparatus

Subjects walked on a motorized treadmill (Minato Medical Science, Osaka, Japan). One inertial sensor with a tri-axial accelerometer and gyroscope (MicroStone, Saku, Japan) was attached to each shank at a position of 30% of the length from the distal end. The measurement range of the accelerometer was $\pm 20\ \mathrm{m/s^2}$, with an accuracy of $0.479\ \mathrm{m/s^2}$. The measurement range of the gyroscope was $\pm 500^\circ/\mathrm{s}$, with an accuracy of $1.466^\circ/\mathrm{s}$. The acceleration and angular velocity of the shank in the sagittal plane were measured with a sampling rate of 200 Hz.

2.3. Tasks and procedures

Before data collection, subjects walked for 5 min on the treadmill at a self-selected gait speed to habituate to treadmill walking. The self-selected gait speed was decided according to the subjects' feeling of the speed that was most comfortable. This self-selected speed was then used in the three measurement conditions: (1) normal walking, (2) walking while performing serial subtraction as a cognitive task (subtraction task), and (3) walking while adjusting the swing limb to a visual target (visuomotor task). In the subtraction task, subjects were asked to count aloud, counting backwards by 13 from a 3-figure number that was given by the examiner every 1 min. There was no instruction to prioritize gait or subtraction. In the visuomotor task, subjects were asked to look continuously at a right–left direction line projected on the treadmill using a laser light for every stride, and to swing their right lower-limb to adjust their toe position to the line on each stride (Fig. 1). The line was constantly projected at the same position. Subjects were instructed to swing their left lower-limb naturally without any conscious adjustment. The order of conditions was randomized. Each condition was performed for 15 min 30 s. The first 30 s was for habituation to the speed, and the following 15 min was the measurement period. The rest period between conditions was at least 5 min.

2.4. Data analysis

Data were processed using Matlab 2014a (MathWorks, Natick, MA). The angular velocity signal was filtered using a 4th order Butterworth low-pass filter with a cut off frequency of 10 Hz. Then, angular velocity peaks of the shank during the swing phase (Fig. 2) were extracted for both shanks and used to generate a time series of this parameter. Shank angular velocity was selected to evaluate lower-limb kinematics. Angular velocity data have been used to evaluate variability of lower-limb kinematics in previous studies [14,15]. In particular, peak angular velocity of the shank has been shown to identify abnormal gait patterns during the swing phase [16]. Heel contact points were identified from shank acceleration peaks (Fig. 3) and used to generate a time series of stride time for both lower-limbs. The time series data of the angular velocity peak of the shank and stride time consisted of at least 652 continuous strides across all subjects in each condition. This satisfies the number recommended to estimate the fractal scaling exponent α with reasonable accuracy [17].

The mean, CV, and fractal scaling exponent α [18] were calculated for the time series of each parameter. CV was calculated by dividing the SD by the mean and represents the magnitude of variability. To present the magnitude of variability of angular velocity for the entire stride, angular velocity data were time normalized to 0–100% of stride duration. The SD was calculated across all strides at each normalized time point (SD (j)) and averaged across all normalized time points (Mean SD) [19].

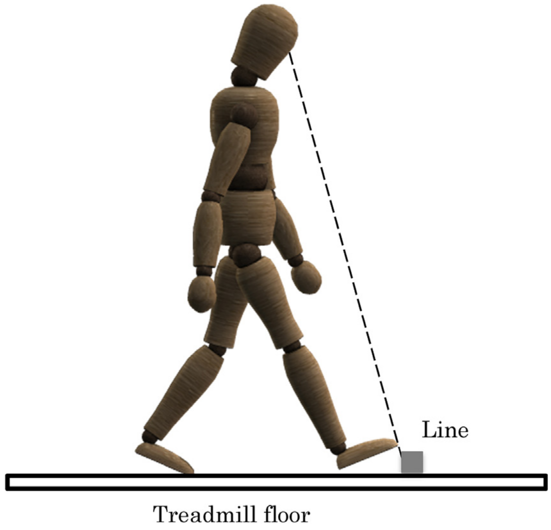

Fig. 1. The visuomotor task. A line is projected on the treadmill using laser light for every stride.