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Kinetic patterns of treadmill walking in preadolescents with and without Down syndrome

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ABSTRACT

This study investigated the effect of both walking speed and external ankle load on the kinetic patterns of treadmill walking in preadolescents with and without Down syndrome (DS). Ten preadolescents with DS and ten age- and gender-matched children with typical development (TD) participated in this study. We manipulated two treadmill speeds and two external ankle loads. Treadmill speeds were equal to 75% and 100% of the preferred overground walking speed. Two load conditions were with and without external ankle load which was equal to 2% of body weight on each side. We used an instrumented treadmill to collect vertical ground reaction force (GRF). Both timing and magnitude of peak GRFs, the loading and unloading rates, and various impulses were calculated from the GRF data. The results show that the DS group produced a shorter duration of propulsion, a lower F_{Z2} (second peak GRF) and vertical propulsive impulse, a higher loading rate and a lower unloading rate than the TD group. At a faster treadmill speed the DS group increased the duration of propulsion, the unloading rate and the vertical propulsive impulse, but reduced the magnitude of F_{Z2}. External ankle load helped the DS group increase F_{Z2} and vertical propulsive impulse and might facilitate the push off and the initiation of leg swing during treadmill walking. External ankle load may therefore be included in the future physical intervention and exercise programs for the DS group to strengthen leg muscles and develop more efficient push off during locomotion.

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1. Introduction

Down syndrome is the most common genetic disease that affects about 1 out of 800 newborn infants in the United States. Due to their physical deficits such as hypotonia and joint laxity, walking patterns in persons with DS are usually characterized as clumsy and less efficient [1]. Kinematic studies have demonstrated that children with DS show a wider step width and higher angular impulse [2], a greater and more variable medial-lateral motion [3], and lower ranges of motion at the hip, knee and ankle joints [4] than healthy controls during walking. Kinetic studies have demonstrated that children with DS produce a lower vertical ground reaction force (GRF) [5], and a lower ankle plantar-flexion moment and power [4–7] than healthy controls during overground walking. However, the detailed kinetic characteristics of GRF and impulse over the stance have not been reported in the literature for children with DS. This information is essential and clinically relevant as it may reveal the timing and magnitude of peak impact force transmission to the lower extremity bones and soft tissues during walking.

Force plates are usually used to collect GRF data and calculate impulse during overground walking. The common kinetic variables include the timing and magnitude of peak GRF, loading rate, and braking and propulsive impulses [8–11]. Children with typical development (TD) demonstrate the capability of increasing peak vertical GRF while walking at faster speeds [12,13]. However, no study has been conducted to examine the effect of different walking speeds on the kinetic patterns of walking in children with DS. In addition, it is difficult to use force plates to collect kinetic data at the same velocity across several trials. Both kinematic and kinetic patterns of walking on an instrumented treadmill have been found qualitatively and quantitatively similar to that of overground gait [14]. An instrumented treadmill appears to be a reliable equipment for collecting the GRF data of successive steps at the same velocity within a short period [15,16]. Such equipment was used in this study to investigate the kinetic patterns of treadmill walking in children with and without DS.

External ankle load is usually used to increase the moment of inertia of the lower extremities and facilitate its pendulum swing during locomotion [17,18]. It is generally recognized that external ankle load can stimulate the activities of ankle plantar flexors and enhance load sensory feedback during push off [19,20]. A quick unloading has been found to trigger the stance-to-swing transition and initiate leg swing in both animals and humans [21–23].

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However, no study has been conducted to address the effect of external ankle load on walking patterns of children with DS.

The purpose of this study was to investigate the effect of both walking speed and external ankle load on the kinetic patterns of treadmill walking in preadolescents with and without DS. We hypothesized that preadolescents with DS may show a lower peak GRF and impulse during push off than their healthy peers, but may increase these variables like their healthy peers when adapting to a fast walking speed and external ankle load. The knowledge gained from this study may have a clinical implication in designing an effective physical intervention program to improve the biomechanics and efficiency of walking patterns in children with DS.

2. Methods

2.1. Participants

Twenty preadolescents between 7 and 10 years of age participated in this study. There were 10 preadolescents with DS (8 males and 2 females) and 10 preadolescents with TD (8 males and 2 females). The DS group was recruited through the Down Syndrome Association of Atlanta and the local parent support groups. The age- and sex-matched TD group was recruited from the local community through advertisement and personal contact. The majority of the DS group was Caucasian except one Hispanic and one African American. All the participants in the TD group were Caucasian. This study was approved by the university's institutional review board. A written informed consent was obtained from all the participants and their parents or guardians before the data collection. Physical characteristics of these participants are presented in Table 1.

2.2. Data collection

The present study was part of a project which investigated both kinematic and kinetic patterns of walking overground and on a treadmill in preadolescents with and without DS on two separate days. Overground walking was investigated on Day 1 and treadmill walking was studied on Day 2. A seven-camera Vicon motion-capture system and a Zebris FDMT-S instrumented treadmill were used to collect kinematic and kinetic data, respectively, during treadmill walking. The present study presents only the kinetic data for treadmill walking.

Two factors were manipulated during data collection: treadmill speed and external ankle load. Each participant's preferred overground walking speed was recorded over a 10-m walkway. Then, 75% and 100% of this preferred walking speed were used as slow speed (SS) and fast speed (FS), respectively, during treadmill walking [2]. Two levels of external ankle load were manipulated: no load (NL) and ankle load (AL). The AL condition was equal to 2% of the participant's body weight (BW) on each side, which was equivalent to a 39% increase of the moment of inertia of each leg about the hip joint [24]. Another AL condition was proposed in the experimental design and was equal to 4% of BW on each side. However, the majority of the DS group had difficulty adapting to this load. Therefore, this load condition was not included in the present study.

A total of four testing conditions (2 treadmill speed by 2 ankle load) were analyzed in this study. Two 60-s trials were collected at a sampling rate of 100 Hz for each condition. Adequate rest was provided between the trials and between the conditions to minimize fatigue, particularly in the DS group. The order of condition presentation was mostly randomized across the two groups. Because some participants in the DS group initially had difficulty walking in the FS condition, the SS condition was presented first to allow acclimation in these participants [2]. All the participants walked on the treadmill without holding the handrails. Some participants in the DS group occasionally placed their hands on the handrails during walking. Verbally encouragement was given to have these participants remove their hands from the handrails.

2.3. Data analysis

Vertical GRF data were processed in the Zebris FDM-T software and exported as text files. Fig. 1 represents a typical vertical GRF curve over the stance phase of a gait cycle. A custom-written Matlab program was used to process the data and determine gait events such as heel strike and toe off. Heel strike was determined as the first data point above 0 N and toe off was determined as the last data point above 0 N. This Matlab program also determined the magnitude (in BW) and timing (in % stance) of the first peak force (F_{Z1}), minimal force (F_{MIN}), and second peak force (F_{Z2}) for each gait cycle [10]. To assess the rate of loading after heel strike and the rate

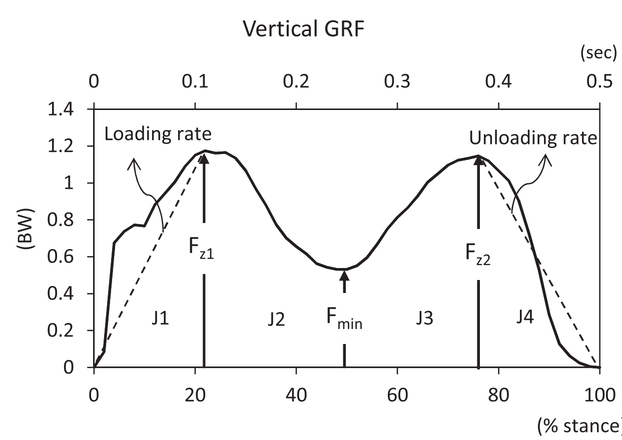

Fig. 1. A representative vertical ground reaction force (GRF) versus time over the stance phase of a gait cycle. There are two x-axes in this figure. The top x-axis represents the real time of the stance phase (unit: s), and the bottom x-axis represents the percentage of this stance phase (unit: % stance). The beginning and end of this stance phase represent heel strike and toe off, respectively. GRF is presented in the times of body weight (BW) along the y-axis. F_{Z1}: first peak during weight acceptance; F_{MIN}: minimal force during mid-stance; F_{Z2}: second peak during push-off. Loading rate: magnitude of F_{Z1} divided by the time between heel strike and F_{Z1} (unit: BW/s); unloading rate: magnitude of F_{Z2} divided by the time between F_{Z2} and toe off (unit: BW/s). Impulse was calculated under the force curve (unit: BW s). J1: impulse over the duration between heel strike and F_{Z1}; J2: impulse over the duration between F_{Z1} and F_{MIN}; J3: impulse over the duration between F_{MIN} and F_{Z2}; J4: impulse over the duration between F_{Z2} and toe off. Vertical braking impulse is the sum of J1 and J2, and vertical propulsive impulse is the sum of J3 and J4. Total F_Z impulse is the sum of vertical braking impulse and vertical propulsive impulse, i.e., the sum of J1–4.

Table 1
Mean (SD) of the physical characteristics of the subjects and the testing conditions.

	DS	TD
Physical characteristics		
Age (years)	9.12 (1.42)	9.31 (1.47)
Height (m)	1.25 (0.09)*	1.34 (0.08)
Weight (kg)	31.67 (5.98)	30.05 (5.67)
BMI (kg/m^2)	20.06 (2.98)*	16.71 (1.67)
Testing conditions		
Treadmill speed (m/s)		
SS	0.76 (0.26)*	1.03 (0.07)
FS	1.04 (0.35)*	1.37 (0.08)
External ankle load (N)		
NL	–	–
AL	5.95 (0.90)	5.86 (1.17)

* Denotes that the DS group was significantly different from the TD group at $p < 0.05$. Body mass index (BMI) was calculated as the ratio between weight in kg and height in square meters. DS, Down syndrome; TD, typical development; SS, slow speed; FS, fast speed; NL, no load; AL, ankle load.