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Biomechanical and perceived differences between overground and treadmill walking in children with cerebral palsy

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ABSTRACT

The treadmill is widely used as an instrument for gait training and analysis. The primary purpose of this study was to compare biomechanical variables between overground and treadmill walking in children with cerebral palsy (CP). Perceived differences between the two walking modes were also investigated by comparing self-selected walking speeds. Twenty children with CP performed both overground and treadmill walking at a matched speed for biomechanical comparison using a 3-D motion analysis system. In addition, they were asked to select comfortable and fastest walking speeds under each walking condition to compare perceived differences. Significant differences in spatiotemporal variables were found including higher cadence and shorter stride length during treadmill walking at a matched speed (for all, $P < .003$). The comparison of joint kinematics demonstrated significant differences between overground and treadmill walking, which showed increases in peak angles of ankle dorsi-flexion, knee flexion/extension, and hip flexion (for all, $P < .001$), increases in ankle and hip excursions and a decrease in pelvic rotation excursion while walking on treadmill (for all, $P < .002$). Comparison of perceived difference revealed that children with CP chose significantly slower speeds when asked to select their comfortable and fastest walking speeds on the treadmill as compared to overground (for both, $P < .001$). Our results suggest that these biomechanical and perceived differences should be considered when using a treadmill for gait intervention or assessment.

1. Introduction

Approximately 41% of children with Cerebral Palsy (CP) display limited walking ability [1]. A typical form of gait training has been performed overground with assistive devices or parallel bars. The treadmill has recently gained more attention as an instrument for gait training and assessment with several advantages over conventional methods. The treadmill can help clinicians overcome space constraints, reduce physical demands, and establish a convenient set-up for gait evaluation. The benefits are enhanced when a partial weight-bearing (PWB) or an anti-gravity system is accompanied. Treadmill-based gait training with PWB showed improvements in gait patterns of children with CP [2,3]. In addition, the use of a treadmill for gait analysis can allow researchers to control walking speed, which can help acquire improved inter-trial and inter-session reliability [4].

Several studies have investigated differences in gait parameters of healthy adults between overground and treadmill walking. Most of them agreed upon spatiotemporal differences, including increased cadence and decreased stride length during treadmill walking [5,6,9–16]. Treadmill walking decreased knee excursion [9,10,12,19] and decreased ankle dorsi-flexion angles [5,19,20] compared to overground. Reduced pelvic rotation was also reported as well as slower comfortable walking speeds during treadmill walking [22]. However, results from kinematic comparison studies have been inconsistent. A few studies have reported an increase in hip flexion [5,6,17] while others found no change or even the opposite result [12]. It is interesting to note that some authors have suggested that kinematic differences might be clinically irrelevant despite the statistical significance [12,17,19].

The number of studies comparing gait variables between the two walking modes in people with gait pathology has been limited. People post-stroke demonstrated increased cadence [7] and decreased stride length [7,8] during treadmill walking. Slower

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speeds were selected for comfortable walking on the treadmill by people post-stroke [7]. These results of spatiotemporal variables and self-selected walking speed are consistent with those from healthy population.

Two comparative studies involving children with CP showed shorter stride lengths and slower comfortable walking speeds [18] as well as longer durations of double stance [21] during treadmill walking. Van der Krogt et al. documented that children with CP increased pelvic excursion and knee flexion and decreased ankle dorsi-flexion on the treadmill [18]. On the contrary, Celestino et al. reported different kinematic changes including increases in ankle dorsi-flexion, knee extension, hip flexion/extension, and pelvic tilt during treadmill walking [21]. These inconsistent findings appear to be associated with the methodological differences between two studies. One used a split-belt treadmill with a virtual reality while the other used an instrumented treadmill with a customized PWB system. However, these types of treadmill are cost-prohibitive and not commonly found in a typical rehabilitation setting.

The primary purpose of this study was to compare biomechanical variables between overground and treadmill walking in children with CP. It was hypothesized that treadmill walking would alter spatiotemporal and kinematic gait variables in children with CP. In addition, perceived differences between the two walking modes were examined. Based on clinical observations and users' comments, we hypothesized that slower speeds would be chosen for self-selected walking speed on a treadmill.

2. Methods

2.1. Participants

A total of 20 children with bilateral spastic diplegic CP (mean age 10.8 ± 3.3 years) were recruited, and their functional scales ranged from classes I to III based on the Gross Motor Function Classification Scale (GMFCS) [23]. Children were excluded if they had: hemiplegia, prior surgery within the past six months, medications for spasticity, uncontrolled seizures, intellectual or other developmental disability, and inability to communicate verbally. Eight out of 20 children with CP used an assistive device for everyday walking (six walker and two crutches users). Orthotics and shoe inserts were used by 14 out of 20 children (11 ankle–foot orthotics and three shoe inserts). Detailed information about each participant is presented in Table 1. Informed consent forms were acquired prior to participation. The study protocol was approved by an institutional review board.

2.2. Study design and test protocol

A cross-sectional comparative study was used for this investigation. All tests were performed in a gait analysis laboratory at a children's rehabilitation center. Participants were asked to change into tight fitting shorts and shirts. The participants wore their own footwear for both overground and treadmill walking. Barefoot walking was not feasible due to the use of orthotics or shoe inserts.

Basic anthropometric data were measured and 15 reflective markers (10 mm in diameter) were attached to the bony landmarks using the Vicon Plug-in-Gait Lower Body Sacrum Model [24]. Reflective markers were attached to the sacrum, and bilaterally on the anterior superior iliac spine, the midpoint of the lateral femur, the lateral femoral epicondyle, the midpoint of the lateral tibia, the lateral malleolus, the calcaneus and the second metatarsal head (Fig. 1). The markers were not replaced between the test conditions. After a 30-s static standing trial, three practice trials on a 10-m carpeted walkway were provided, followed by three overground walking trials at a self-selected comfortable speed. The average of the three comfortable walking speeds was calculated and later applied to treadmill walking trials in order to match the walking speed for both test conditions.

A single-belt treadmill (Biodex Gait Trainer, Biodex, Shirley, NY) was used, and the treadmill's front panel and handrails were removed to achieve an unobstructed view from motion cameras. A safety suspension harness was used over the treadmill, which did not provide any weight support (Fig. 2). A height-adjustable walker was installed on the treadmill's platform for walker or crutches users. The frame of this walker was covered with non-reflective tape in order to eliminate any interruptive metallic reflection. No participant had previous experience using a treadmill for gait training. A 2-min treadmill walking practice was provided for all participants. Three 2-min treadmill walking trials at a matched speed were captured for data collection. The durations of practice and test walking trials were determined to minimize any fatigue effect while still providing them with familiarization time.

In order to collect data for perceived differences, all participants were asked to return to our laboratory on a separate day within a

Table 1
Participants' information.

Participants #	Gender	Age	GMFCS	GMFM	Orthotics	Assistive devices
1	F	8	II	94	Bilateral SMO's	
2	F	8	II	91	Bilateral hinged AFO's	
3	F	9	II	94	Right PLS	
4	F	10	III	68	Bilateral solid AFO's	WALKER
5	F	10	I	95	Bilateral solid AFO's	
6	F	12	III	55	Bilateral solid AFO's	WALKER
7	F	13	II	96	None	
8	F	14	I	99	None	
9	F	15	III	70	Bilateral solid AFO's	WALKER
10	F	16	III	74	Bilateral shoe inserts	CRUTCHES
11	M	6	II	89	Left PLS, right shoe insert	
12	M	7	II	93	None	
13	M	7	III	75	Bilateral hinged AFO's	CRUTCHES
14	M	8	II	85	Bilateral solid AFO's	
15	M	8	II	93	None	
16	M	10	III	73	None	WALKER
17	M	10	I	100	Bilateral hinged AFO's	
18	M	13	III	73	None	WALKER
19	M	14	II	91	Bilateral shoe inserts	
20	M	17	III	53	Bilateral FRAFO's	WALKER

Abbreviations: M: male, F: female, GMFCS: Gross Motor Function Classification System, GMFM: Gross Motor Function Measure, PLS: posterior leaf spring (a type of AFO), SMO: supramalleor orthotic, AFO: ankle–foot orthoses, FRAFO: floor reaction AFO (an AFO with solid ankle).