INTRODUCTION
Cerebral palsy (CP) is the most prevalent physical disability originating in childhood with an incidence of 2.7 per 1000 live births [1]. The development of efficient and independent walking is an important therapeutic goal for many children with CP [2]. Theories of motor learning suggest that task-specific, repetitive practice can improve walking in children with neurological disorders such as CP [3]. As a consequence, there has been a growing interest of using treadmill training, particularly with body weight support, to improve locomotor function in children with CP [2]. However, while significant improvements in walking capacity with treadmill training have been shown, the functional gains are relatively small [2], suggesting a need to improve techniques in order to produce greater functional improvements in children with CP.

Data from hemiparetic subjects practicing upper limb movements with forces that provide passive guidance versus error enhancement indicate that greater improvements in performance are achieved when errors are magnified [4]. These results suggest that causing adaptation by using error-augmentation training might be an effective way to promote functional motor improvement for children with CP. In addition, previous studies have shown that, with repeated exposure to forces that resist hip flexion during swing phase of gait, healthy subjects form anticipatory motor commands in response to the resistance [5]. The development of these anticipatory motor commands is revealed by the presence of aftereffects (i.e., greater stride length and higher stepping) once the disturbance is removed. These aftereffects following a period of training under resistance imply the formation of motor output for a given task. Yet, to date, locomotor adaptation to resistance added during the swing phase of gait has not been investigated in children with CP. We postulate that applying a controlled, resistance load to produce kinematic deviations of the leg during treadmill training will accelerate the motor learning in children with CP.

METHODS
Five children (3 girls and 2 boys, 11.2 ± 2.4 years) with diagnosed CP (spastic diplegia, GMFCS level II) participated in the study after obtaining informed consent. A custom designed, cable-driven robot was utilized to provide controlled, resistance loads to the leg at the ankle (Fig 1) during treadmill walking. A 3D position sensor consisting of a detector rod and three potentiometers was used to measure the ankle position during treadmill walking [6]. The cable-driven robot was highly back-drivable and therefore, had minimal constraints to subject voluntary movements.

A controlled, resistance load approximately equivalent to 15-18% of the maximum voluntary contraction of hip flexion during standing was applied to the right leg of each subject from the late stance to mid-swing phase of gait. The treadmill speed was pre-determined in an earlier overground test using an instrumented walkway (GaitMat II, EQ Inc., Chalfont, PA). The average treadmill speed was set at 0.39 ± 0.20 m/s. A body weight support was provided as necessary to assure stable stepping. Subjects were allowed to hold onto a handrail during walking. Subjects first walked on the treadmill without loads for 2 minutes (baseline), followed by a 10-minute walking with a resistance load applied to the right ankle (adaptation). The load was then removed while subjects continued to walk on the treadmill for another 3 minutes (post-...
adaptation). The ankle position data obtained from the 3D sensors were recorded on a personal computer with a sampling rate of 500 Hz.

Data processing was performed using custom written routines in MATLAB (MathWorks, Natick, MA). Ankle kinematic data were low-pass filtered at 5 Hz cutoff frequency using a zero-lag, fourth-order Butterworth filter. Stride length, defined as the distance that the treadmill belt moved between two consecutive heel contacts of the right foot [7], was calculated for each subject. In addition, gait patterns in terms of the foot trajectory in the sagittal plane immediately before loading and after load removal were determined and compared.

RESULTS AND DISCUSSION

An immediate decrease in stride length was observed in early adaptation period when a resistance load was applied (Fig 2). Then, the stride length gradually returned to a level close to the baseline during the late adaptation period. An aftereffect consisting of an increase in stride length was observed after resistance training, implying the development of anticipatory motor commands during locomotor adaptation in children with CP. While motor adaptation to resistance and associated aftereffects are generally short-lived, the phenomenon may have the potential for clinical significance following repeated exposures. Results from this study may be used in the development of a novel, targeted therapeutic training strategy to improve locomotor function in children with CP through robotic resistance treadmill training.

REFERENCES

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