The Effects of Lower Body Positive Pressure Treadmill Training on Dynamic Balance of Children with Cerebral Palsy*

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***Abstract*— We aimed to characterize the therapeutic effects of Anti-gravity (AlterG) body weight supported treadmill training on the impaired balance of children with cerebral palsy (CP). Four spastic CP children participated; two received AlterG training 3 times a week for 8 weeks and the other two received typical occupational therapy accordingly. Their dynamic balance was evaluated before the start of the treatment and 2 months after it. Features related to the center of pressure (COP) and the center of mass (COM) were considered as dynamic balance parameters. Our results showed that the maximum velocity and acceleration of the COP and COM, the average variability (RMS[1]) and peak to peak of the COM-COP separation, and RMS of velocity and acceleration of the COM and COP were all improved for both AlterG training patients (15-90%), though there was a limited improvement of 0.2-24% in some features of the control patients. Our results demonstrate that intensive sessions of the AlterG training program could have the potential to be used as a therapeutic tool that can produce dynamic balance improvements in CP children compared to that of typical occupational therapy.**

***Keywords*— cerebral palsy, gait, impairment, spasticity, rehabilitation, therapy, center of pressure, center of mass**

I. INTRODUCTION

Cerebral palsy (CP) is a non-progressive neurological disorder that results from brain injury prior to brain development completion [1]. This injury occurs during the prenatal, perinatal, or postnatal periods. This disorder causes many permanent disabilities and impairments, which can be exacerbated during children's life span [2]. About 80 percent of patients with CP are spastic that suffer from poor balance and gait impairment [1]. There are reports claiming that its prevalence is 3.5 per 1000 live births, making it the most common cause of physical disability in children [2]. Therefore, one of the major goals of every society is helping them have a less dependent life.

Many treatments have been used to improve movement abilities, body control, and self-independence [3]. Robotic-assisted gait training is one of the treatments used to improve walking ability and balance in children and adolescents with cerebral palsy; but the improvements were limited to clinical and spatiotemporal gait characteristics [4, 5]. One of the main problems of this approach is its passive function, which may not result in neuroplasticity [6, 7]. Subsequently, an active traditional method, which supported the subjects' partial body weight during treadmill gait training, showed improvements in the walking performances of CP children; though, it caused discomfort in the patients during unloaded walking, which prevented them from adjusting to the therapeutic protocol or decreased the therapy session time [8]. A recently introduced therapy that aids in lower extremity unloading is the lower body positive pressure system (LBPP); it has been used for children with CP and showed effective changes in gait and balance recovery [9-11]. LBPP creates a force that unloads the patient and reduces effective body weight. It has a total decrease in ground reaction force and maintains gait patterns during treadmill walking [9].

Children with CP have deficits in balance and postural control due to brain damage and its secondary neuromuscular effects [12]. Dynamic stability in gait provides a more complete understanding of the impairments of postural control in CP children. Analysis of the center of pressure (COP) and the center of mass (COM) is common in studies on human postural control and gait. Changes in motor control will be reflected in changes in the COP and COM displacements. Alterations in them will show experimental condition on movement, hence its quantification indicates abnormal patterns. The total COP and COM displacements are useful measurements that provide valuable insight into balance and postural control in healthy humans or people with impaired gaits. Also

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[1] Root Mean Square

simultaneous investigation of the COM and COP can allow for a more complete assessment rather than examining the COP and COM separately [13]. Also, the literature represents that velocity and acceleration of the COM and COP are measures of dynamic balance during walking and can show balance dysfunctions [14]. Among different methods that have been used to improve balance and postural control in children with CP, intensive and repetitive sessions of the LBPP can correct abnormal gait pattern and promote neuroplasticity, therefore being beneficial in improving dynamic balance.

Our aim is to characterize the changes in the dynamic stability of children with CP following an intensive and repetitive LBPP support treadmill training. This was done by assessing the COP and COM and their acceleration and velocity during walking.

II. Methodology

A. *Participants*

Four children aged between 4 to 14 years with Hemiplegic cerebral palsy (CP) participated in this study, two of which were in our experimental group that received AlterG training. The two others received typical occupational therapy. All of them provided written informed consent, and the study had ethical approval from the Tehran University of Medical Science Institutional Review Board. They all had moderate spasticity, and Gross Motor Function Classification System (GMFCS) which was at level II.

B. *Experimental Protocol*

The lower body weight support system is a treadmill, which is enclosed in a pressurized chamber and contains compressors that are placed to control the amount of pressure inside the chamber. The patient was positioned in the treadmill, attached to a pair of shorts in the chamber. The calibration processes were performed to calibrate the weight of the participant with the amount of power, which the compressor produced. At first, the body weight support was set at 50 percent of the participant's weight, and the speed was about 1 meter per second. As time passed, the speed increased and the body weight support gradually decreased. Every session took one hour including about 15 min preparation and 45 min training. The training was provided 3 times a day for 8 weeks. The occupational therapy with the focus on lower limb training was provided 45 min per session, 3 times a week for 8 weeks. The occupational therapist was different from the professionalist who trained the AlterG group.

C. *Dynamic balance evaluation*

The kinematic data was recorded with a six VICON MX motion capture system (VICON, Oxford, UK), sampled at a 120 Hz frequency using a VICON NEXUS software. All data was acquired in the Djavad Mowafaghian Research Center of Intelligent NeuroRehabilitation Technologies. The markers were placed on each participant's body landmarks using the Helen Hayes model marker set [15]. The position data of the markers were filtered using a digital 3rd-order low-pass zero lag Butterworth filter with a cutoff frequency of 6 Hz in order to remove the high frequency noise and movement artifacts. The COM was evaluated using a 12-segment model (2 feet, 2 shanks, 2 thighs, pelvis, trunk and head, 2 upper arms, 2 forearms and hands) according to the equation below [16].

$$COM_x = \frac{\sum_{i=1}^{12} m_i COM_{i,x}}{\sum_{i=1}^{12} m_i} \qquad \text{Equation (1)}$$

Where m_i and COM_i is the mass and center of mass of each of the 12 body segments, which were calculated from the anthropometric data. COM_x is the total COM of the body in the Anterio-Posterior (AP) direction; the same equations were used for the total body COM in the Medio-Lateral(ML) and vertical directions.

The kistler force plates with a sampling rate of 1200 Hz were used to collect ground reaction forces. Also, the force plates' data was acquired in the same center. The COP displacement was calculated with the equations described in Lafond's study [17]. At first, we normalized the COP and COM data to 100 points for comparison, and then normalized them in accordance with each person's leg length to eliminate the influence of the individual's stature [13]. At least three data trials were averaged for further analysis. The velocity and acceleration of the COP and COM were calculated by getting the first and second derivatives of the signals. One sample of the COM and COP signals for a CP subject and their velocity and acceleration, for the same subject were shown in figures 1-3, respectively. In order to compare the COP and COM trajectories between cases, we used peak to peak of COP and COM signals in both AP and ML directions. Also, the RMS of acceleration and velocity of COP as well as the RMS of acceleration and velocity of the COM were used as a measure of variability of signals. Finally, the RMS of the COM-COP distance was used as a measure of dynamic stability [13, 14]. All of the calculations and analyses were processed with a custom Matlab (2017-a) program.

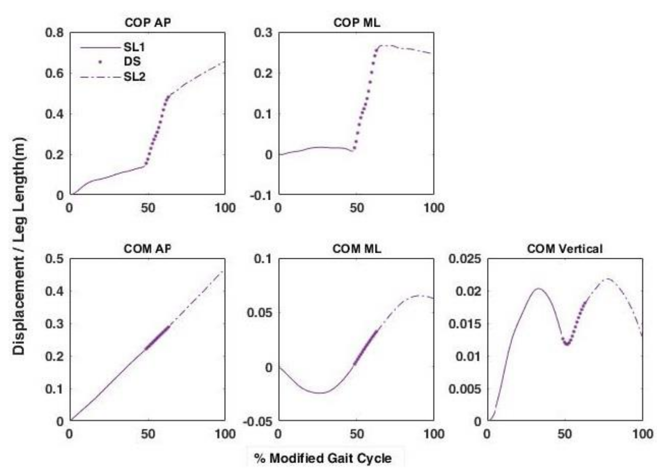

Fig. 1: COM and COP signals for a CP patient. The solid line (SL1) shows the percentage of the single limb stance of the first foot, dot line (DS) shows the percentage of the double support and dash-dot (SL2) line shows the percentage of the single limb stance of the other foot in one gait cycle.

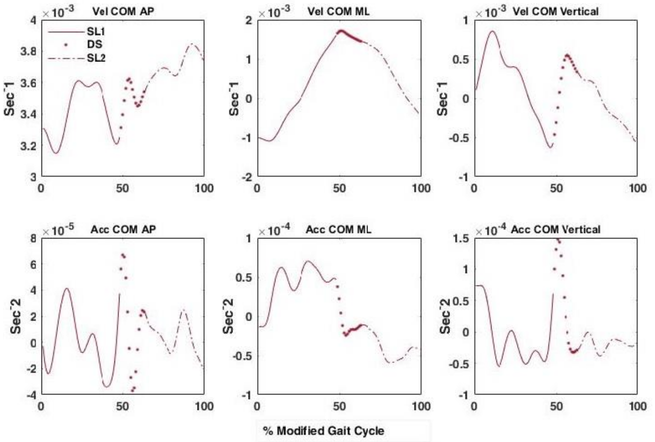

Fig. 2: Velocity and acceleration of COM in AP, ML and vertical directions for the same CP patient in Fig. 1. The solid line (SL1) shows the percentage of the single limb stance of the first foot, dot line (DS) shows the percentage of the double support and dash-dot (SL2) line shows the percentage of the single limb stance of the other foot in one gait cycle.

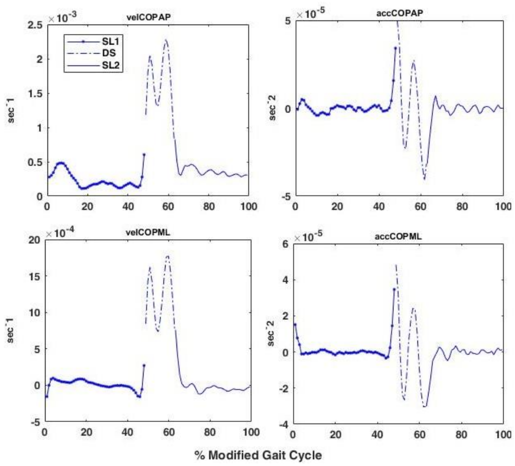

Fig. 3: Velocity and acceleration of COP in AP and ML and directions for the same CP patient in Fig 1. The solid line (SL1) shows the percentage of the single limb stance of the first foot, dot line (DS) shows the percentage of the double support and dash-dot (SL2) line shows the percentage of the single limb stance of the other foot in one gait cycle.

III. RESULTS

Pre-treatment and post-treatment results for the subjects in both groups were evaluated. Pre-post changes were shown in a coordinate system, which had an x-dimension showing pre-treatment values and y-dimension showing post-treatment values. This figure indicates the changes in the features' scores after training. The recovery is evident from the decrease in all the features; the shapes under the line of equation y=x show decrease in those features. In this study, we observed that all AlterG group features decreased after the treatment, but the decrease in some control patients' features were less rather than the experimental group ones. Figure 5 shows the pre-post feature changes. The variability of the velocity and acceleration of the COP and COM signals (the RMS value) were decreased in both of the experimental group patients. In control group, RMS of velocity and acceleration of the COP_ML, maximum of velocity and acceleration of COP_ML, maximum of velocity and acceleration of COP_ML all decreased for both of them (Figure 4). Peak to peak of COM-COP in ML direction (Figure 5), RMS of velocity of COM in vertical direction, RMS of COM-COP_ML, maximum acceleration of COM, maximum velocity of COM in ML and vertical directions and maximum velocity of COP_AP decreased in one of the patients in this group. The decrease of features mentioned above in the control patients was below 24 percent, while decrease in AlterG group patients were up to 90 percent. The red and pink colors in Figure 4 show the features related to the control patients and the other two colors (black and green) represent the features of cases in the AlterG group. The features which are below the blue line (y=x) show that the post-treatment value is less than the pre-treatment value. Other features like peak to peak COM-COP_AP, maximum velocity of the COM_AP, maximum acceleration of the COP_AP, RMS of the velocity of the COM_ML, RMS of velocity of COP_AP, RMS of the acceleration of COM and COP_AP and peak to peak of the COM-COP separation in AP direction had an impalpable increase in both control patients.

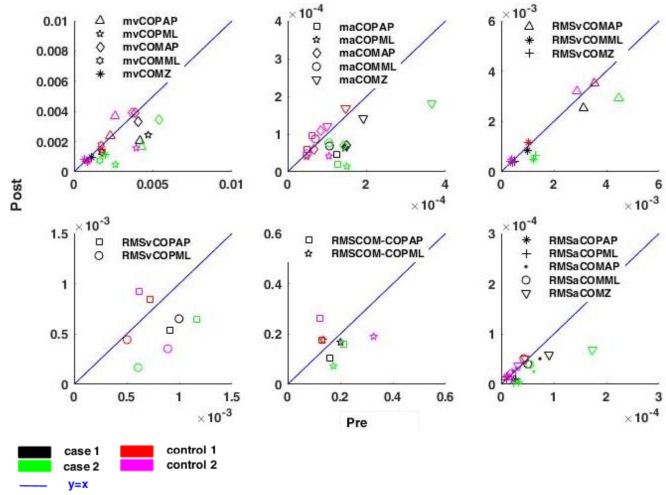

Fig. 4: Pre-Post treatment values of patients in the control and experimental groups. Red and pink colors represent the parameters related to the control patient and the green and black colors are for the two patients in the AlterG group. The shapes represent the parameters. Mv is the maximum velocity, ma is the maximum acceleration, RMSv is the RMS of velocity and RMSa is the RMS of acceleration of parameters.

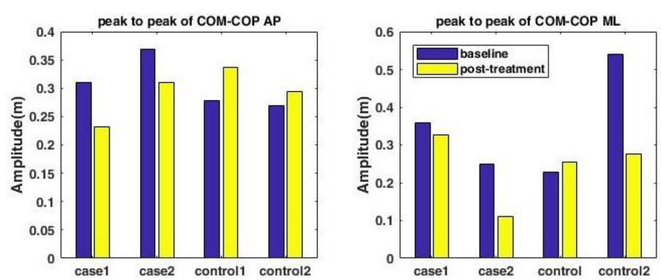

Fig. 5: Peak to peak of the COM-COP in AP and ML directions in the pre and post evaluation. Blue and yellow colors are related to the base line and post treatment values respectively.

IV. Discussion and Conclusion

For the first time, we characterized the therapeutic effects of AlterG training on balance control during walking in children with cerebral palsy. Quantification of dynamic stability during walking requires both the COP and COM movements. Our results showed that maximum velocity and acceleration of the COP and COM in AP, ML and also COM in vertical directions decreased for both patients in the AlterG group. According to previous studies, an increase in COP acceleration is resulted from the ankle plantar flexors of the first stance foot and placement of the swing foot, which is affected by the ability to rebuild a fixed base of support and restabilization [14]. Thus, the decrease in the COP acceleration of the AlterG group can be interpreted as the ability to re-stabilize after receiving anti-gravity treadmill training sessions.

Inappropriate muscle tone distribution, muscle weakness and joint stiffness in CP children prevent them from dampening the COM oscillations, which can result in larger vertical COM velocity and acceleration. A decrease in maximum vertical COM velocity and acceleration in AlterG group may show that this training could lead them to overcome COM oscillations.

The distance between the COM and COP is the moment arm for the ground reaction forces to create momentum generation; thus the larger the distance, the greater the momentum generation [13]. The RMS of COM and COP separation (COM-COP) and the peak to peak in AP and ML directions decreased for the AlterG group. The RMS value of any parameter is an indication of the average variability of it and its peak to peak shows the parameter's maximum variability. Therefore, it could be concluded that the average distance and maximum variability of the COM and COP separation decreased for the experimental group, which results in smaller moment arms for the body weight around the joints of the supporting limb and requires less muscular effort to maintain balance.

The peak to peak of the COM and COP separation shows an external flexion moment about the lower extremity joints. Thus, smaller flexion moments decrease the demand for resistive muscular force generation. In addition, the RMS or average variability of velocity and acceleration of the COM is in three possible directions, and the COP is in the AP and ML directions are used as measures for gait efficiency [14], all of which decreased for the AlterG patients.

The improvement of some features in the control group was in the range of 0.2-24 percent, whereas all the mentioned features were improved for the AlterG group between 15-90%. These findings demonstrate that AlterG training has potential to be used as an effective therapeutic tool to improve dynamic balance in CP children.

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