Therapeutic Effects of an Anti-Gravity Treadmill (AlterG) Training on Neuromuscular Abnormalities Associated with Spasticity in Children with Cerebral Palsy*

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***Abstract*— We aimed to characterize the therapeutic effects of Anti-Gravity Treadmill (AlterG) Training on neuromuscular abnormalities associated with spasticity in children with cerebral palsy (CP). Eighteen subjects were divided into two groups; AlterG and control. All subjects received up to 40 minutes of training 3 times a week for 8 weeks. The control group received conventional occupational therapy. The advanced parallel-cascade system identification technique was used to characterize the neuromuscular abnormalities associated with spasticity and separated its intrinsic and reflex components. Reflex stiffness gain (GR) and intrinsic stiffness gain (K) were used to track the therapeutic effects of training on neural and muscular abnormalities. Both K and GR were strongly positioned dependent; they varied linearly with the ankle angle at dorsiflexion. Their position dependence was quantified by fitting a linear model to K and GR over dorsiflexion positions. The evaluations were performed at four-time points; i.e. the baseline (before starting the training), 1 and 2 months after starting the training, and 1 month after the completion of the training to assess the persistent effects. We determined the changes in K and GR intercept and slope parameters over these 3 months to evaluate the therapeutic effects of training on neuromuscular abnormalities. The results revealed that all K and GR parameters decreased substantially following using AlterG training and these changes were greater than those observed in the control. The results also showed that these therapeutic effects were persistent to a high extent, particularly in the AlterG group. Our findings suggested that AlterG training could be considered as a robust therapeutic intervention to reduce neuromuscular abnormalities and manage spasticity.**

***Keywords:* Cerebral palsy, Contracture, Stiffness, system identification, spasticity, rehabilitation, reflex, locomotion**

I. INTRODUCTION

Cerebral Palsy (CP) is deemed to be the most prevalent neurological disorder with a prevalence of up to 3.5 per 1000 children in some countries. This disorder mainly results from motor cortex injury that occurs before, during or shortly after birth. Although this brain injury is non-developing, it can deteriorate during children's life span, thereby leading to several physical and cognitive impairments. CP children and their families also encounter social, emotional and beneficial problems [1,2].

Most CP children suffer from spasticity that can cause neuromuscular abnormalities and lead to movement and posture disabilities. Therefore, reducing spasticity has always been in the center of researchers' attention [2]. Enormous efforts have been made and a wide range of rehabilitation means has been utilized. For instance, manual therapy, Robotic-assisted locomotor training and Body Weight Support Treadmill Training (BWSTT), which are the recent therapeutic methods used for SCI and stroke patients [3,4]. These approaches are successful in reducing spasticity and improving neuromuscular abnormalities. However, their therapeutic effects are neither significant nor persistent at least because of two reasons: (1) Manual therapy is mostly performed passively, so it cannot lead to neuroplasticity. (2) The harness of BWSTT can make training sessions uncomfortable for patients [4]. Thus, developing an adequate, effective and persistent therapeutic method remains controversial. One of the most recent therapeutic means used to address this controversy is an Anti-Gravity Treadmill (AlterG). The results have shown the effectiveness of AlterG training in enhancing gait parameters, balance ability, lower extremity strength and reducing the clinical sequel following with Cerebral Palsy [5]. AletrG was firstly used by NASA to simulate weightless conditions for astronauts. Then it has been developed for the therapeutic version comprising a treadmill, an inflatable chamber with two transparent parts.

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Anti-Gravity Treadmill allows therapists to reduce the patient's body weight to the required amount by applying positive pressure. Moreover, the air pressure is uniformly distributed over the lower limbs, which itself provides comfortable training sessions for patients as opposed to BWSTT [5,6]. The therapeutic effects of AlterG on neuromuscular abnormalities associated with spasticity are not well evaluated mainly due to a lack of an accurate technique separately estimating the impacts of this treatment on neural and muscular properties of a spastic joint. To address this issue, a parallel-cascade system identification technique has been developed [7,8,9,10]. According to this technique, neuromuscular abnormalities corresponding to spasticity can be accurately characterized in terms of overall dynamic joint stiffness, which is separated into two components [8,11]: intrinsic and reflex stiffness. In this study, we aimed to characterize the therapeutic effects of an intensive AlterG training on reflex and intrinsic stiffness in spastic CP children using this system identification technique.

II. METHODOLOGY

A. Participants

Eighteen hemiplegic CP children between the ages of 4-14 years and with moderate to severe levels of spasticity (Ashworth score ≥ 2) participated. Subjects were ambulatory (took at least one step without assistance) had no history of seizure, and no or limited cognitive impairments. They were divided into two groups. Two subjects did not complete the training protocol due to their family's personal issues. The AlterG group received anti-gravity treadmill locomotor training, whereas the control group received a conventional occupational therapy. This research had ethical approval from the Tehran University Medical Science Institutional Review Board. All of the participants' guardians signed the written informed consent form.

B. Therapeutic Protocols

The AlterG system consists of six main parts, including a treadmill, a transparent and inflatable chamber, which enables therapists to monitor patient's movement, a force plate to measure patient's weight, two compressors that provide the amount of required pressure inside the chamber, a controller that regulates the amount of produced pressure based on the patient's weight, and a pair of neoprene shorts, which was fastened to the zipper on top of the chamber to prevent patients from falling. The AlterG participants underwent the anti-gravity treadmill training for up to 40 min, 3 times a week for 8 weeks. The control subjects received conventional occupation therapy based on a similar protocol.

C. Experimental Apparatus and Procedure

All subjects were seated and secured on an experimental seat, which can be adjusted in both vertical and horizontal directions. The subjects' affected ankle side was then attached to the footrest and the center of the 6-axis force sensor was aligned with the ankle joint center of rotation. The neutral position was set at the ankle angle of 90°. Dorsiflexion (DF) direction was considered positive by convention [4].

Pseudorandom Binary Sequence (PRBS) perturbations with the amplitude of 2 degrees and a switching rate of 150 ms were applied to the subjects' more affected ankle at different ankle positions over a range of motion (ROM) from PF to DF at 5° position increments. The evaluations were performed under passive condition, when the subject was relaxed, and repeat at four-time points; i.e. at the baseline (pre), after 12 sessions (mid), after 24 sessions (post), and one month after completing the training sessions in both AlterG and control groups (follow-up). Prior to each evaluation session, the passive ROM of the ankle was measured by the examiner.

D. Neuromuscular properties Evaluation

We characterized neuromuscular abnormalities of the spastic ankle in terms of overall dynamic joint stiffness using a parallel-cascade system identification technique. This model has two pathways; intrinsic and reflex stiffness pathways, as shown in Fig.1. The top pathway was used to estimate intrinsic stiffness dynamics in terms of a linear impulse response function (PTQ_{IRF}), between position (input) and torque (output). The bottom pathway, including a delay, a differentiator to convert position to velocity, a half-wave rectifier to pass positive velocities, and a dynamic system, was used to estimate reflex stiffness dynamics in terms of a linear impulse response function (VTQ_{IRF}), between the output of a half-wave rectifier and the residual torque, which was computed by subtracting the predicted intrinsic torque from the recorder torque. Intrinsic stiffness was well described by a second-order model having inertia, viscosity, and stiffness K, while reflex stiffness was described by a third-order model having reflex gain (GR), natural frequency, damping parameter, and real pole. K and GR were the focus of this study since they were shown to be the major factors in our earlier studies [4,8,9].

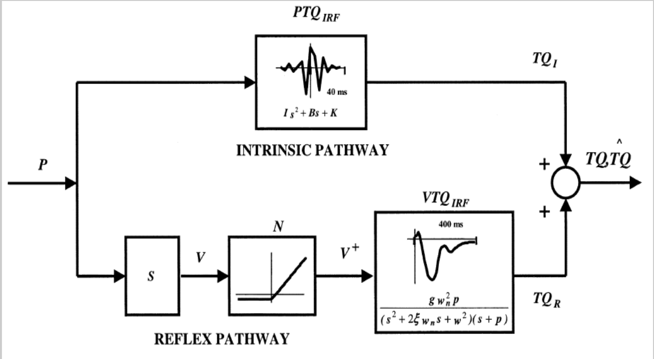

Figure 1: The parallel-cascade system identification model used to characterize ankle joint stiffness and separate its intrinsic and reflex stiffness.

Fig.2 shows the modulation of K and GR as a function of ankle position at the four-time points. In order to describe the changes in intrinsic and reflex stiffness, we fitted a regression line to the K and GR curves from the neutral position (NP) to maximum dorsiflexion (DF) at each time point for each subject. The intercepts and slopes of these lines were used to evaluate the therapeutic effects of training time periods on neural and muscular abnormalities.

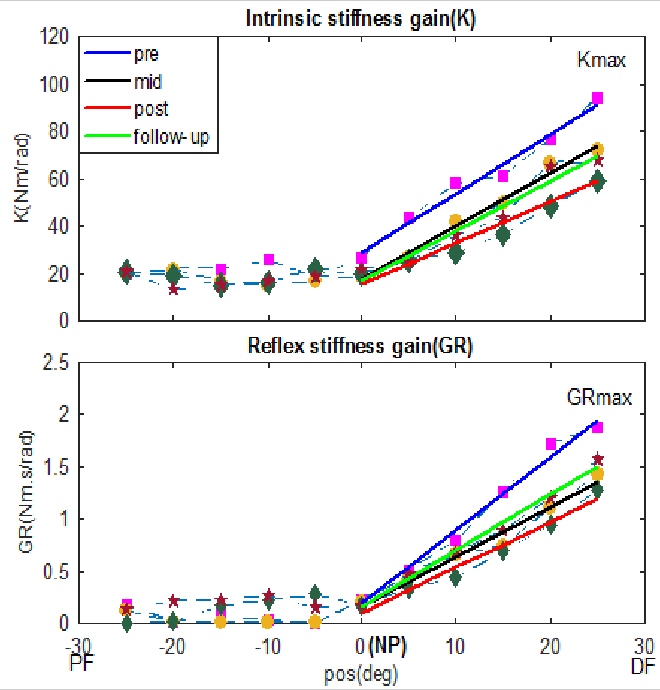

Figure 2: Illustration of the fitted line to intrinsic and reflex gains versus ankle angle

The percentages of improvement of slope and intercept parameters were calculated between pre-mid, pre-post, and pre-follow-up evaluations according to equation 1.

$$p = \left(\frac{post-pre}{pre}\right) * 100 \qquad (1)$$

III. RESULTS

This is an ongoing study and the neuromuscular data of subjects that have been analyzed so far were presented here as pilot findings. Fig.3 and 4 show the pre-, mid-, and post-treatment, and follow-up results of the slope and the intercept of K and GR as well as their percentages of improvement, respectively, for a typical subject in the AlterG group. As shown in Fig.3, the K-slope decreased continuously over the training period, and then reached two-thirds of their initial values one month after the completion of training (follow-up). However, the K-intercept improved by 40% at mid-training and remained invariant during the rest of training and follow-up.

GR also improved substantially by training (Fig.4), similar to K. However, in contrast to K-slope, GR-slope improvement reached to around its maximum at mid-training and remained invariant during the rest of training, then decreased slightly at follow-up. The changes in GR-intercept were similar to that of the K-slope; it increased continuously and substantially during training, but decreased considerably at the follow-up.

Fig.5 shows the group-average of improvement percentages for both K and GR slopes and intercepts for AlterG and control groups. Three major findings emerged:

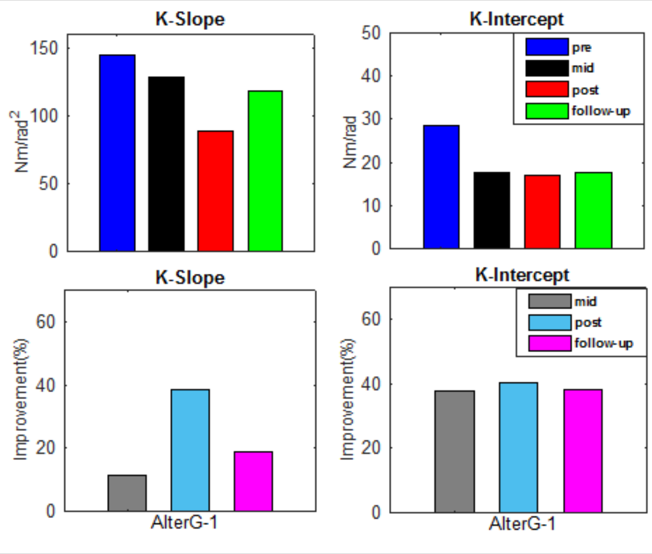

Figure 3: The top rows show that the K-slope and K-intercept absolute values correspond to the fitted lines shown in figure 2 for pre-, mid-, and post-training and follow-up for a typical AlterG subject. The bottom rows indicate the improvement percentages for both slope and intercept parameters between pre-mid (mid), pre-post (post) and pre-follow-up (follow-up) assessments.

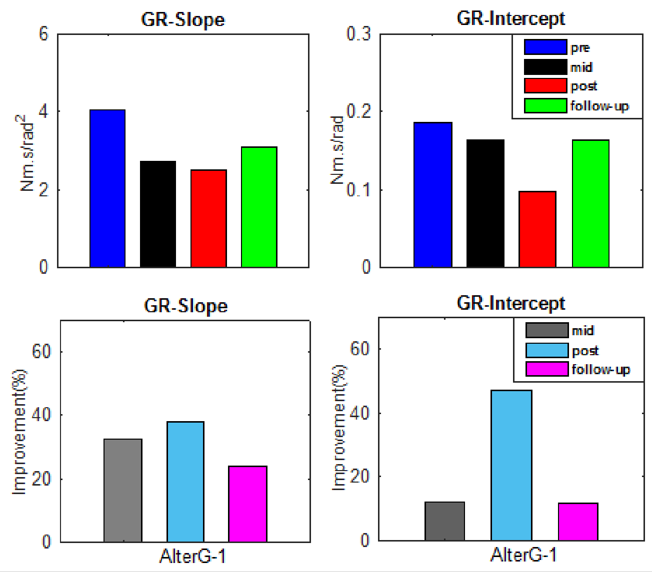

Figure 4: The top rows show that the GR-slope and GR-intercept absolute values correspond to the fitted lines shown in figure 2 for pre-, mid-, and post-training and follow-up for a typical AlterG subject. The bottom rows indicate the improvement percentages for both slope and intercept parameters between pre-mid (mid), pre-post (post) and pre-follow-up (follow-up) assessments.

1. The percentages of improvements for both K and GR slopes and intercepts were larger in the AlterG group than the control group during training and at follow-up
2. The intersubject variability for both slope and intercept parameters was low as indicated by small standard deviations, indicating that all subjects responded similarly to AlterG training.
3. For all parameters, except GR-intercept, the improvement decreased by less than 10% (<25% of max improvements at the end of AlterG training) at follow-up indicating the persistent effects of AlterG training. In contrast, this decrease varied between 50-75% in all stiffness parameters, except K-intercept, at follow-up, indicating weaker persistence effects as compared to the AlterG.

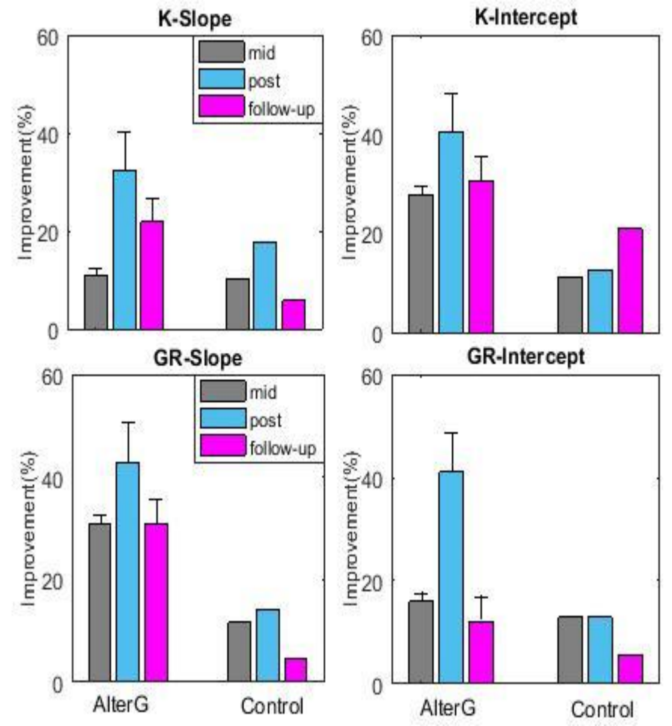

Figure 5: The group-average results of the improvement percentages for the slopes and intercepts of the K and GR for the AlterG group and the control.

IV. CONCLUSION

For the first time, we characterized the therapeutic effects of Anti-Gravity Treadmill Training on neural and muscular abnormalities associated with the spastic ankle in CP children, using advanced system identification techniques Our findings indicate that both K and GR, which abnormally increase in CP children, substantially decreased during the AlterG training. Interestingly, the percentages of improvements of K and GR, which reached their maximum amount at the end of the AlterG training, dropped only by 10% in 1-month during which the subjects used no interventions. This implies to the persistent therapeutic effects of the AlterG training. Our findings demonstrate that AlterG training has the potential to be used as a robust and effective therapeutic intervention to reduce both neural and muscular abnormalities associated with spasticity in CP children.

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