Home-based tele-assisted robotic rehabilitation of joint impairments in children with cerebral palsy

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Abstract— **A portable rehabilitation robot incorporating intelligent stretching, robot-guided voluntary movement training with motivating games and tele-rehabilitation was developed to provide convenient and cost-effective rehabilitation to children with cerebral palsy (CP) and extend rehabilitation care beyond hospital. Clinicians interact with the patients remotely for periodic evaluations and updated guidance. The tele-assisted stretching and active movement training was done over 6-week 18 sessions on the impaired ankle of 23 children with CP in their home setting. Treatment effectiveness was evaluated using biomechanical measures and clinical outcome measures. After the tele-assisted home robotic rehabilitation intervention, there were significant increases in the ankle passive and active range of motion, muscle strength, a decrease in spasticity, and increases in balance and selective control assessment of lower-extremity.**

I. INTRODUCTION

Cerebral palsy is a non-progressive disorder with impaired motor function secondary to injury of the immature brain [1]. It occurs 2-3 per 1000 live births [2], making cerebral palsy the most prevalent physical disability originating in childhood. The lack of selective muscle and motor control, spasticity and muscle weakness [3], among other manifestations of CP result in impaired balance and gait, and reduced quality of life.

A common impairment in children with CP is muscle spasticity, with the ankle dorsiflexor and plantarflexor muscles being weaker by about 30%–35% compared to children without disability [4], [5]. Although no cure exists at this time for CP, many treatments are used to improve mobility and gait functions. These include tendon lengthening [6], tendon transfers, releases, selective dorsal rhizotomy [7], Botulinum toxin injections [8], Baclofen, stretching, serial casting, orthotics, and robotic rehabilitation [9]–[11]. Recent results indicate that increases in ankle or knee strength, range of motion and selective motor control after training can improve gait and function in children with CP [12], [13].

Physical therapy is important in preventing contracture and reducing muscle spasticity, especially during the growing years of children. However, partly due to economic constraint and lack of physical therapists, therapy is more restricted and often not conveniently available or not enough to children with CP. Lack/absence of such treatment over an extended period of time usually results in functional limitations and disability. Therefore, for both patients and therapists, there is a need for robotic devices that automate at least certain aspects of labor-intensive movement therapy and manipulate/mobilize the joints under precise control of the robotic devices. Furthermore, there is a need to combine stretching with voluntary movement therapy [14], and follow up with outcome evaluations. Existing devices like the continuous passive motion (CPM) machine moves a single joint at a constant speed between two preset joint positions. When it is set within the flexible part of the range of motion (ROM), the passive movement may not stretch into the extreme positions where contracture/spasticity is significant. On the other hand, setting a CPM machine too aggressively may risk injuring the joint because the machine controls the joint position without incorporating the resisting torque generated by the soft tissues. There is a need for a device that can safely stretch a spastic joint to the extreme positions with precise control of the resistance torque and stretching velocity.

Moreover, it will be especially helpful if patients can use the device conveniently and frequently at home with periodic interactions with clinicians. In this paper we address such a need and test the hypotheses that combined intelligent stretching and voluntary movement training can be done at patient's home to reduce ankle impairment in children with CP in terms of biomechanical and functional outcome measures.

II. METHODS

A. Participants

Twenty-three participants, age range 5-17 (mean age 9.0 ± 2.64) years, 18 boys and 5 girls, were recruited and completed 6 weeks home-based tele-assisted robotic therapy. Twelve of the participants had hemiplegia and the remaining eleven had diplegia. All subjects continued their regular physical therapy during the experiments except 3 subjects, who did not have regular therapy at the time. The inclusion criteria include (a) at or below Gross Motor Function Classification System (GMFCS) level III (the ability to walk with or without any assistive device. (b) no surgery or serial casting in the prior six months, and (c) subjects be able to follow the instruction during our study. Exclusion criteria were: (a) Subjects who have other unrelated neurological impairments or musculoskeletal injuries. (b) Patients who

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have had orthopedic surgery within 6 months prior to participation in study. (c) Patients who have severe pain in the paralyzed limb. The level of the lower limb impairment for children with CP at admission was assessed using the GMFCS to evaluate the disabilities level for lower extremity. Fourteen children with CP had GMFCS score of I, eight children GMFCS score of II, and one child GMFCS score of III. During this study, subjects continue receive their regular physical therapy. The study was approved by the Institutional Review Board of Northwestern University. All parents/parents gave informed consent at the beginning of the study.

B. Experimental Setup

The tele-rehabilitation system was designed to provide haptic feedback to the clinician and audiovisual interaction between the clinician and the patient. The clinician and patient could see and talk each other through web-cameras and microphones for technical support and communication. The development of a tele-assessment function was an important part of home-based therapy.

As shown in Figures 1 and 2, the children and their parents were trained until they could proficiently operate and set up the robot independently, the parameters and calibration were done individually before patients took the device home, the home setup include Wi-Fi connection, wearing shoe and setup the parameters such as ROM and baseline, which took about 5 minutes, the experimental setup consists of a home-based intelligent stretching robot, which could be connected to a central rehabilitation hospital via the Internet. The home-based device can upload the training results and patients could download updated training parameters provided by the clinician. For the accuracy and consistence, devices were taken back for checking at the 9th sessions.

The training of intelligent stretching is followed by active robot-assisted movement training, which involves computer games playing and biofeedback. The data collected during training is then uploaded from the home based robot via Internet to the central rehabilitation center and an updated training plan can be downloaded to the home robot based on the therapist's evaluation of the individual patient's training progress and condition. On the other hand, the treatment record and quantitatively feedback (such as passive and active ankle ROM, spasticity, muscle strength and movement control) were monitored and saved. Clinicians can check the patient treatment records at the hospital server in an off-line/mode.

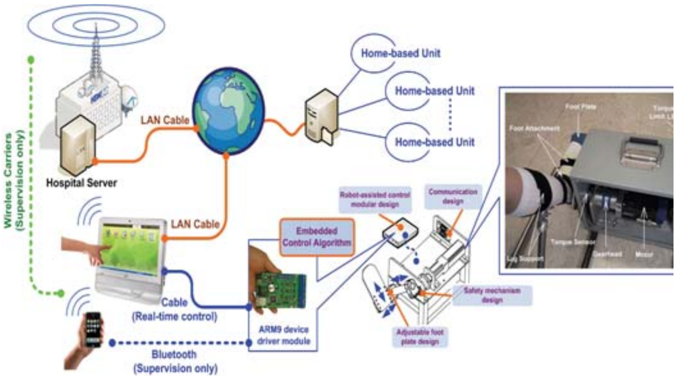

Figure 1. Network Model for Home-based Units

Figure 2. (a) Experimental setup using the portable rehabilitation robot. The affected limb is at full extension and the ankle center of rotation is lined up with the rotation axis of the motor. (b) Screenshots of biofeedback active movement training games.

C. Statistical analysis

To evaluate statistical significance of the difference before and after the treatment on clinical and biomechanical outcomes measures, an one way repeated measures ANOVA was computed. A one-way ANOVA was used for the statistical analysis differences of pre-, post- and follow up during each of these three evaluation sessions of the treatment. Pairwise multiple comparison procedures was then conducted using Tukey Test P<0.05 with Bonferroni adjustment.

III. RESULTS

The robot-assisted therapy was well accepted and tolerated by all children with CP. No patients dropped out of the study. All twenty-three participants completed the 18 sessions of training in addition to the pre-, post- and follow up evaluations. The robotic training outcome measures were compared before and after the training based on laboratory-based outcome evaluations (biomechanical measures such as passive ROM (PROM), active ROM (AROM), joint stiffness and strength), as shown in Figure 3-4. Results from clinical and biomechanical outcome measures showed a decrease in motor impairments in the lower extremity after the robot-assisted treatment. After the 6-week training period, participants showed considerable improvements in the ankle with additional improvements in the adjacent joints as well. AROM of ankle dorsiflexion were increased significantly after the 6-week training. Both DF strength and PF strength increased significantly.

A. Clinical Outcome

Over the 6-week training, spasticity was reduced. Spasticity indicated by MAS decreased slightly after training and became better in the follow-up evaluation.

As the indication of motor function improvement, the selective control assessment of the lower extremity (SCALE) improved from a pre- to post- training and the improvement remained at the follow up, 6 weeks after the end of the treatment sessions. The improvement in selective motor control of the other joints like the hip and foot were also observed.

As the rehabilitation progress of balance, pediatric balance scale (PBS) score improved significantly for subjects in the robotic rehabilitation group, the difference between pre- to post-evaluation was significant (*p*=0.01). The improvement was also retained well at the follow up.

The participants showed walking improvements in terms of walking distance and speed. With the 6 minutes walk test (6MWT), the participants walked significantly longer distance than before the 6-week intervention (394.7±92.3m before training compared with 436.0±103.3m after training, *p*=0.003). Time-Up-and-Go (TUG) scores also improved after 6-week training (*p*=0.047), and dropped a little bit at the follow-up as shown in Table I (NS means no significance).

TABLE I. PRE-, POST- AND FOLLOW UP CLINICAL EVLAUTOINS

	Clinical Evaluation Results				
	A. Pre- (mean±sd)	**B. Post- (mean±sd)**	**C. FU (mean±sd)**	**P_1**	**P_2**
MAS	1.46±0.66	1.28±0.72	1.03±0.75	NS	.006
SCALE	5.75±2.70	7.25±2.07	7.25±2.23	.001	.001
PBS	48.79±6.78	51.52±6.18	51.49±6.70	.012	NS
6MWT (m)	394.7±92.3	436.0±103.3	416.8±100.1	.003	NS
TUG (s)	8.31±2.52	7.30±2.54	7.65±2.27	.047	NS

1. P_1 presented statistical significance between Pre- and Post-. 2. P_2 was between Pre- and FU.

B. *Biomechanical Outcome*

Active ankle dorsiflexion (AROM) increased significantly as a result of the 6-week training program (see Table II). DF AROM was -0.75±12.43° to 6.97±11.43° before training (a negative value means the ankle was still in plantar flexion) and after training, respectively (*p*=0.001). Improvements in DF AROM remained significant at the follow-up (*p*=0.002). The passive dorsiflexion (PROM) was 15.96±5.79° prior to training and 18.42±5.94° after training (*p*=0.18), and the DF PROM was 18.24±7.18° (*p*=0.15) at the follow-up evaluation (see Figure 3).

Both ankle dorsiflexion strength (STDF) and plantarflexor strength (STPF) DF increased significantly as a result of 6-week training program. STDF increased from 1.50±2.76 Nm to 3.68±3.22 Nm (*p*=0.001). Improvements in DF strength were still present at the 6-week follow-up evaluation with DF strength of 3.67±3.46 Nm (*p*=0.001). Significant change in plantarflexor strength was also found and the change was significant (see Table II).

TABLE II. PRE-, POST- AND FOLLOW UP BIOMECHANICAL EVLAUTOINS

	Biomechanical Evaluation Results				
	D. Pre- (mean±sd)	**E. Post- (mean±sd)**	**F. FU (mean±sd)**	**P_1**	**P_2**
STDF (Nm)	1.50±2.79	3.68±3.10	3.67±3.46	.001	.001
STPF (Nm)	16.82±10.63	20.17±9.60	20.79±9.26	.02	.006
AROM (deg.)	-0.75±11.93	6.97±11.15	6.21±12.07	.001	.002
PROM (deg.)	15.96±6.77	18.42±7.30	18.24±7.18	.18	.15

1. P_1 represented statistical significance between Pre- and Post-. 2. P_2 was between Pre- and FU.

The tele-assessment outcomes showed that robot-guided therapy contribute to improvement of motor functions and ankle biomechanical properties in children with CP. Improvement and decay at the different time points in the therapy process have considerable importance. The therapy-induced improvement time course (rate of improvement, saturation, etc.) was investigated preliminarily across a number of therapy sessions involved. Frequent assessments in the therapy process could be done conveniently through tele-assessment at patient home to closely track the improvement and decay processes associated with the therapy.

Table I showed improvements in the selective motor control, balance and walking performance. Table II showed the improvements in DF strength, PF strength and AROM in DF (Figure 3-4). And evaluated the improvement in the four major time courses (1st, 9th, 18th session and follow up), improvement and decay at the first half of the training are considerably different than second half.

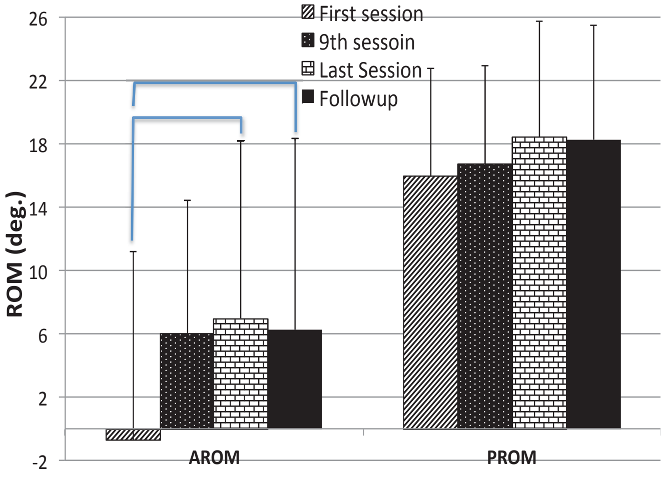

Figure 3. Both AROM and PROM in the first, 9th and 18th sessions of robotic training (connected line indicate p<0.05)

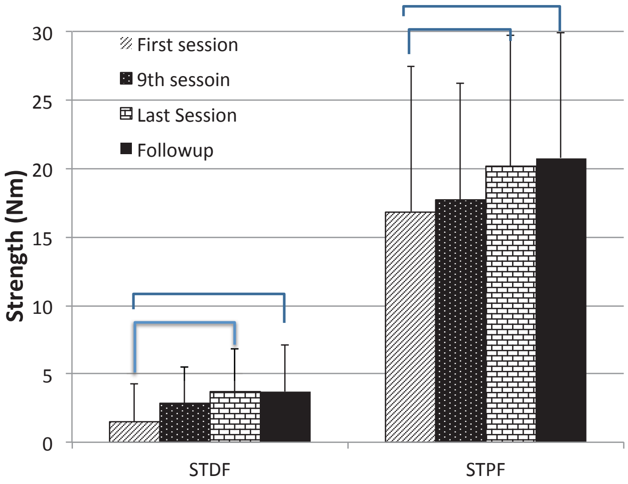

Figure 4. Strength of DF and PF in the first, 9th and 18th sessions of robotic training (connected line indicate $p<0.05$)

IV. DISCUSSION

The home-based rehabilitation approach was low cost and likely to be effective due to a number of reasons: it gave the patients great flexibility to access therapy at all time without traveling and scheduling for in-hospital clinical services. The robot device also allows the caregivers to help conduct multiple trainings simultaneously in a convenient time and location. The home-based therapy reduces the need for individual adjustment in the device setup process, and the home-based therapy made the treatment conveniently available to many patients. Investigation of translation of the gains to daily functional movements and participation in daily life should be conducted further.

V. CONCLUSION

Home-based tele-assisted robotic rehabilitation is convenient and effective in rehabilitation therapies of children with CP. The clinical and biomechanical assessments showed significant improvements in muscle strength and AROM in DF, selective motor control, balance, walking function in children with CP.

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