PedBotHome: robotically-assisted ankle rehabilitation system for children with cerebral palsy

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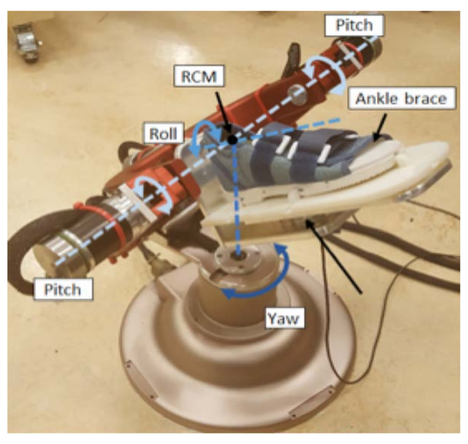
Abstract

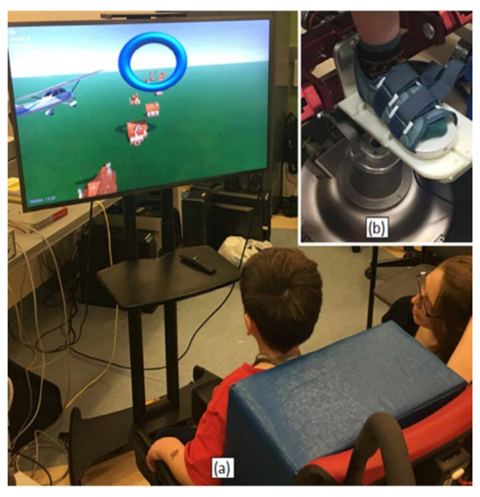
Our research team has developed two versions of an ankle robot for children with cerebral palsy. Both devices provide three degrees of freedom and are connected to an airplane video game. The child uses his/her foot as the controller for the plane and attempts to fly through a series of hoops arranged to manipulate the foot across the ankle joint. The first device is for lab-based therapy and four children have completed 20 sessions each with the device. The second device is for home-based therapy and two children have completed a 28-day trial using the device at home. Both studies were done under Institutional Review Board approval and all participants improved ankle range of motion. Further studies are ongoing to gather more data and validate the results.

Introduction

Cerebral palsy (CP) is the result of a static perinatal brain injury which causes deficits in motor skills. CP is the most common life-long physical disability occurring in childhood, affecting 2.3 to 3.6 per 1,000 school-age children. At least 8,000 new cases are reported each year in the United States. In the United States alone, 500,000 children under age 18 are affected by CP; in Europe, the affected population is even higher. The population of children with CP may be increasing due to increased number of surviving premature infants, higher incidence in normal-weight term infants, and longer survival overall.

Current treatment options for children with CP are often not sufficient to develop adequate strength and flexibility in the legs, resulting in impaired quality of gait. Targeting key muscles in the ankle is critical, but often requires extensive bracing or complex constraint mechanisms. As a result, this critical therapy needed to improve gait requires time-intensive in-office treatment as well as an intensive home exercise program. Compliance is therefore difficult to maintain and children often do not receive the level of care needed. A mechanical platform that can target specific muscles involved in gait disturbance in children with CP and that can be used in-home could lead to improved compliance rates and therapeutic outcomes.





Left: Pedbot with 3 DOFs: pitch (dorsiflexion and planterflexion), roll (eversion and inversion), and yaw (abduction and adduction). Center: Child with cerebral palsy (a) playing airplane video game using PedBot as an input device (b). Photograph used with consent of the parents and child. Right: PedBotHome System showing blue chair, control box under chair, and device in front with smart phone under foot plate (not seen).

System Description: PedBotLab and PedBotHome

We developed a three degree of freedom (DOF) robot (PedBot) for ankle rehabilitation at our pediatric hospital. The 3 degree of freedom robot provides a Remote Center of Motion (RCM) point close to the ankle joint. The robot consists of three intersecting axes and includes a 6 DOF force/torque sensor. The system includes 4 flat brushless servo motors with planetary gearheads and integrated encoders, all made by Maxon Motor Inc. (Sachseln, Switzerland). A 3-axis controller (Galil Inc., CA, USA) with an internal amplifier is used as the control hardware.

The lower cost robotic home device, similar to the lab version, has 3 degrees of freedom and can be used in both active or assist/resist mode rehabilitation. The angular motion of the device is tracked by an Android cell phone attached underneath the foot plate. This cell phone communicates with the desktop computer via Wifi network and sends the angular positions of the robot. A custom Xamarin phone application was written for this purpose. In practice we found this method both accurate and fast enough for our use.

Results: PedBotLab

Four children have completed 20 sessions each in the trial of PedBot Lab. Each session consisted of approximately 30 minutes of exercises via game play in the robotic device. The subjects followed a protocol guided by the physical therapist, which aimed to challenge each subject's strength, range of motion, and multi-planar movements. Prior to the beginning exercise sessions with PedBot Lab and following the last session participants completed an evaluation with a physical therapist who assessed passive and active range of motion, ankle strength, gait speed, and isolated joint control of the lower limb.

Some results are shown in the tables below for the four subjects denoted L1 to L4. Strength, measured by hand held dynamometry, improved in all subjects in eversion, inversion, plantarflexion, and dorsiflexion, The greatest increase in strength was by 6.6kgf (L2 DF) and smallest increase was by 1.3 kgf (L3 Inv). The baseline strength was variable for all subjects in the study. Each subject demonstrated different trends on the amplitude of change in strength; however, all except subject L1 had the greatest change in dorsiflexion strength, with average post-dorsiflexion strength of 8.13kg/f and average pre-dorsiflexion strength of 3.15kgf.

Subject #	Age	Sex	GMFCS level
L1	12	M	1
L2	13	F	1
L3	15	F	2
L4	15	M	2

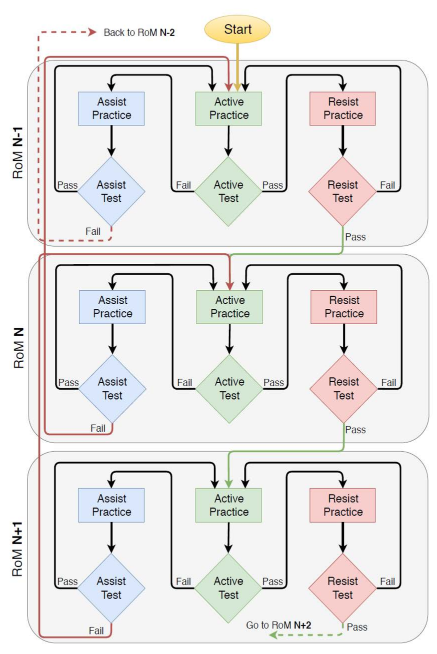
Subject #	Strength (kgf)							
	DF		PF		Inv		Ev	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
L1	4.8	7	5.7	7.7	3.4	6.0	3.3	5.8
L2	1.9	8.5	1.6	4.8	2.1	6	1.4	4.9
L3	2.6	7.8	3.9	6.8	2.8	4.1	0.9	4.9
L4	3.3	9.2	5.2	8.6	3.9	6	2.8	5.4

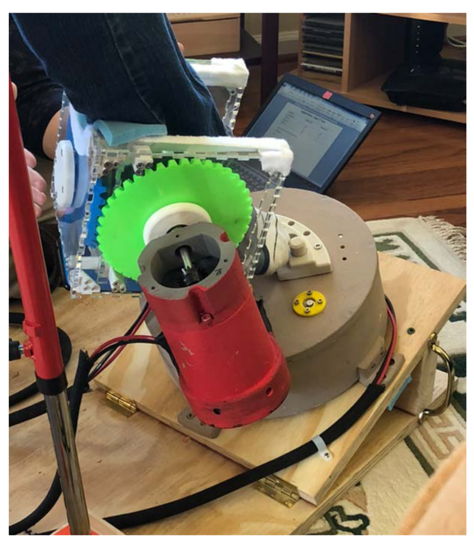
Results: PedBotHome

Subjects H1 and H2 used the system for 26 and 19 days during the home trial. The results are shown in the next column. The age range was 13 to 14 with GMFCS levels 1 and 2. Subject H2 had completed the lab trial and is the same as subject L2. Both subjects successfully integrated PedBotHome into their daily routines, with planning support, along with reminders, from their caregivers (mothers). Both children were independent with set up and minor troubleshooting. Both children found the airplane maneuvering game that mediated their exercise programs to be sufficiently engaging. noted by caregivers in previous studies of home exercise programs was absent. Both teens and their caregivers reported subjective perception of improved ankle flexibility following their trials of PedBotHome: the first child noted greater facility in rock gym climbing and the second child reported increased flexibility in dance class.

Subject #	Age	Sex	GMFCS level
H1	14	F	2
H2	13	F	1

Subject #	Strength (kgf)							
	DF		PF		Inv		Ev	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
H1	4.6	8.3	5.1	9.8	3.3	3.7	3.4	5.4
H2	5.8	10.8	6.1	6.3	5.8	3.3	3.9	3.4





Left: PedBotHome software flow chart. Center: PedBotHome device with child's right foot inserted. Red cylinder is motor housing and large 3D-printed green gear is also seen. Right: PedBotHome in first child's home. Photograph used with consent of the child and parents.

Discussion / Conclusions

While extremely preliminary, our experience to date has convinced us of the value of an approach to pediatric rehabilitation therapy facilitated by a robotic platform and incorporated gaming system. Such a system has the potential to enhance center-based therapy, but we anticipate the greatest value will be as part of a home exercise program.

Funding Sources: Research supported by U.S. Department of Health and Human Services (DHHS) AWD00002531, Clinical and Translational Science Institute (CTSI) award UL1TR001876 from the NIH National Center for Advancing Translational Sciences, and the American Academy for Cerebral Palsy and Developmental Medicine (AACPDM). All authors except for Manon Schladen and Sarah Helen Evans are with Children's National Medical Center, Washington DC (corresponding author Kevin Cleary, phone 202-476-3809; e-mail: kcleary@childrensnational.org). Manon is with the MedStar Health Research Institute. Sarah is with the Children's Hospital of Philadelphia.