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Power Walker Helps a Child with Cerebral Palsy

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Abstract - Advancements in technology represent hope for children with complex neurologic conditions and their families. Clinical specialists, patients, their families and experts in assistive technology development must work together to advance this technology for unique populations with the greatest need. This paper highlights an excellent example of collaboration, following appropriate research protocol, to study the use of a power walker (the Solowalk) for the first time in a child with cerebral palsy. The result was impressive. A child with cerebral palsy, and associated significant weakness and contractures, who hadn't walked in over two years, was able to walk using this device. This led to feedback from family stating "I have read articles over the years since my grandson was born and dreaming of the day that this might occur. Your group is to be commended." This impressive positive result and heartfelt feedback has fueled ongoing team work to further study this device. We aime to determine which children can most benefit, what modifications to the device would enhance its use and how it can be most effectively utilized to improve function, participation, health and wellbeing.

***Keywords*:** Model-Free, Sliding Mode Controller, Measurement Noise, Lyapunov

1. Introduction

For technology to help the people who can benefit most, clinical specialists and patients must work together with experts in biomedical assistive technology development. This citation highlights the clinicians who identify and facilitate evaluation in the appropriate populations, the engineers who create and understand the workings and limits of the device, and patients/families that can provide feedback to allow the expertise to grow. Ultimately, such a group led to a youth with Cerebral Palsy taking his first steps in two years.

2. The Population and Research to Date

In 2006, Cerebral Palsy (CP) was defined by leading Canadian Developmental Pediatrician Peter Rosenbaum and colleagues as, "a group of permanent disorders of the development of movement and posture causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain" [1, 2]. It is the most common cause of childhood disability and as individuals with CP grow, the children with greater physical involvement often have few options for functional mobility.

Cerebral Palsy can be classified according to the tonal abnormality and topography. The most common type, spastic CP, frequently occurs as a result of an insult to the motor cortex. There is rate dependent increase in tone and primarily flexor patterns of movement in the upper and lower extremities. The second type of CP, dyskinetic CP, commonly results from damage to the basal ganglia or thalamus and presents with athetoid movements (slow writing), chorea (random, rapid, jerky movements) and dystonia (sustained abnormal hypertonic positions). The third type, ataxic CP, occurs due to damage in the cerebellum affecting voluntary movement, balance, and depth perception. The final type, according to tonal

abnormality, is a mix of any of three main types as described above (spastics, dyskinetic, ataxic). Many cases of cerebral palsy may infact have a mixed pattern of hypertonicity.

Topographically determined subtypes of CP include, diplegia where lower extremities are involved more than upper extremities (most common 30-40%), quadriplegia where all four limbs are involved, hemiplegia when only one side of the body is affected, monoplegia with one limb involved, and tripelgia when three limbs are affected [1, 2].

Cerebral Palsy is a complex neuromotor condition. The motor disorders of CP are often accompanied by disturbances in sensation, perception, cognition, communication, and behavior. Epilepsy and secondary musculoskeletal problems are also common in children with CP. Rosenbaum and colleagues classified ambulation deficits, which are one of the most disabling mobility impairments in children with CP, with the Gross Motor Function Classification System (GMFCS). The GMFCS tool is broken down by age group, however, the below Table 1 outlines key features of GMFCS levels for adolescents aged 12-18 years of age [1, 2].

Table 1: GMFCS for ages 12-18 years.

LEVEL I	Walks without limitations
LEVEL II	Walks with limitations (difficulty on uneven surfaces)
LEVEL III	Walks using a hand-held mobility device (typically utilizes wheeled walker)
LEVEL IV	Self-mobility with limitations; may use powered mobility (typically utilizes manual or power wheelchair)
LEVEL V	Transported by care provider in a manual wheelchair

Gait impairment in children with CP has previously been described to include reduced speed, endurance, step length, stride length, and toe clearance in gait. [3, 4]. Literature on gait impairment and training with individuals with neuromotor disorders began with animal studies that have shown repetition of gait movements may improve an individual's ability to walk by improving spinal and supraspinal locomotor circuits in the brain [5]. Recent literature has also outlined several benefits that complement the need to improve gait in children and adolescents, including the promotion of independent mobility and self-help skills, bone health, as well as muscle contracture and obesity prevention [6,7,8,9]. These findings resulted in further studies and mobility aid prototypes, such as standard walking frames and partial body weight supported treadmill (PBWST) training [5, 9, 10, 11]. Traditional technologies including gait belts, walkers, harnesses, and sling-based walkers have been used along with orthotic devices during gait rehabilitation therapy. Although the cost effectiveness of traditional gait training technologies has been cited as an advantage, they may pose a risk for the health professional, particularly when the health professional bears the responsibility of physically supporting a patient.

Preliminary studies and case reports have now included robot-assisted treadmill training and electromechanical gait training [5, 11, 12]. The advantages of a robotic device include less risk to the user and trainer, and more efficient use of therapeutic time, as set up for some of the more traditional gait training approaches may be cumbersome and time consuming [12]. The principle current limitation to robotic walking devices is that the literature is limited as are pediatric prototypes [12].

3. Objective

This case study will demonstrate the effective use of the SoloWalk by an individual with spastic quadriplegia secondary to cerebral palsy GMFCS IV who has hasn't walked in two years.

The report will describe the technology utilized, demonstrate the strength of unique inter professional collaboration to bring technology forward to aid populations in need and highlight the youth's personal and family benefit.

Finally, a larger study will be introduced to identify advantages and potential barriers to use of this device in youth with Cerebral palsy. The ultimate goal will be to help determine how to adapt a current adult robotic walker device

prototype (SoloWalk) for youth and young adults with GMFCS level IV CP. The future intention of this collaborative work is to create a device that will benefit a large number of children with severe mobility challenges.

4. Case Study

Patient History and Clinical Status: AM is a 17 year old male with spastic quadriplegia GMFCS IV. He was born at 29 weeks gestation weighing 1100gms and was one of a twin gestation. His neonatal complications included bronchopulmonary dysplasia and infantile spasms (seizures). Later in life, he developed hip problems (subluxations) requiring surgery including femoral derotation osteotomies, pelvic osteotomies and muscle releases (hip adductors and hamstrings).

He has increased tone in all four limbs, a low tone trunk and despite aggressive stretch, casting, botulinum toxin injections and surgery; he developed severe lower extremity muscle shortening (contractures). His knees lack 100 degrees of extension with his hip at 90 degrees of flexion. He had 20 degree flexion contractures at the hips. With his knees flexed he achieves 20 degrees of dorsiflexion at the ankles. He is in severe crouch in supported stance.

AM has related developmental delay with autistic traits. He participates in a specialized educational program. He clearly indicates his wishes and enjoys movement and participation.

His primary mode of mobility is by wheelchair (power or manual). With body growth and increasing contracture, walking with a manual trunk support walker became increasingly difficult and for 2 years he has not been walking. He uses a standing frame to maintain weight bearing. He sits within his base of support using his upper extremities to assist and crawls upstairs.

Further surgery was considered for his knee contractures but with his present degree of contracture and mobility status, it was felt that he would require extensive intervention and has a high risk of recurrence. As a result, no further surgery is planned.

Patient Recruitment: AM was chosen using a purposeful approach from Dr. Anna McCormick's (Lead investigator and Pediatric Physiatrist) CP clinics at the Ottawa Children's Treatment Center (OCTC). Priorities for selection included the patient's ability to stand in a trunk support walker, ability to initiate forward motion of the lower extremities and ability to follow two step requests.

A consent form was completed and questions were fielded by Dr. McCormick or Dr. Alazem (Physiotherapist and Pediatric Resident) to ensure completion of the informed consent process. A multidisciplinary team assessed and collaboratively agreed the patient was appropriate to trial the device.

Structured Assessment:

Part 1: Focus group with Health Care Providers (HCP) (approximately 20 minutes)

- This includes a pediatric occupational therapist, pediatric physiotherapists, a physiatrist and engineers to identify the preliminary advantages, foreseen required adaptations/modifications, and limitations to the SoloWalk device before it is first tested by the patient.

Part 2: Interview with the patients (approximately 20 minutes)

- This is done separately with the patient to identify preliminary suspected advantages, adaptations and limitations to using the SoloWalk device prior to the first trial.

Part 3: First trial of the current SoloWalk (approximately 1 hour)

- The patient tests the walker with supervision of all HCPs in the study. An interaction videotaped analysis is used.

Part 4: Interview with each patient post trial of GaitEnable (approximately 20 minutes)

- This is done separately with each patient to collect feedback after the trial of the GaitEnable device in a semi-structured interview approach

Part 5: Focus group discussion with patient, HCPs, and engineers (approximately 30 minutes)

- This discussion is used to debrief and re-evaluate the advantages, required modifications and adaptations, and possible solutions to barriers.

The aim of this focus group was to determine if this device could be used in youth with severe mobility limitations secondary to CP and to provide the SoloWalk developers with pertinent information to modify and adapt the current adult SoloWalk prototype for pediatric use. The information will also be used to assist physiotherapists in their use of a plausible gait training device adolescents with GMFCS level IV CP.

5. The Device: SoloWalk Technology

SoloWalk technology was created by a biorobotic research laboratory at Carleton University's Advanced Biomechantronics and Locomotion (ABL) laboratory in consultation with adult medical and rehabilitation communities and in-depth study of haptic control systems issues through a doctoral research project. Initially the resulting technology was a robotic walking-assist device which was made to assist adults in early mobilization in acute or rehabilitation setting [13]. Figure 1 shows the model of SoloWalk used during this study.

Fig. 1: An image of the SoloWalk powered mobility training device.

SoloWalk's key features include [13] servo-powered omnidirectional wheels on the mobile base of the device, and a body-weight support (BWS) system used for lifting patients, and preventing falls.

SoloWalk's reactive control system is based on robotic force control techniques. This control system guarantees stable patient-device interactions, automatically synchronizes the device's motion with the user's motion, and that allows therapists to modulate certain motion characteristics in relation to a patient's need and therapy goals. A force sensor mounted between the frame of the device and the harness measures force inputs from the patient. The proprietary control system uses this information to command SoloWalk to move in the direction that the user wishes to walk in.

Therapists use a wired remote control to activate the key functions of the device. Other advanced features can be manipulated via a software interface. With the remote, therapists can allow a patient to initiate steps on their own (i.e., device automatically follows user's voluntary motion), or directly control the motion of the device in any direction to guide their motion more carefully.

While SoloWalk weighs nearly 275 pounds, the motors attached to its wheels propel the device in accordance to the patient's intended motion and make the device feel light and easy to move. When working with patients with very severe impairments, therapists can also opt to restrict SoloWalk's motion to a straight line. This mode of operation allows patients to practice stepping even if they have little ability to maintain their lateral balance. The footprint of the SoloWalk model used during the study is roughly 36" x 51".

SoloWalk is also equipped with numerous safety features as follows [13]:

Safety switches in control of the Health Care Professional (HCP) and patient that cause the device to lock into place during an emergency. This is an attractive feature for the use in children and adolescents with CP, who even with the necessary truncal support to prevent collapse, require external control as they tend to move their lower limbs in abduction/adduction, internal/external rotation of the hip, as well as excessive hip and knee flexion when attempting reciprocal walking activation which in turn, affects their stability and fall risk [9].

A harness system, which when properly fitted, prevents a patient from falling to the ground. This system comprises of a torso harness and a mating pelvis harness which attaches between a patient's legs. The pelvis harness provides support from below and relieves pressure on an individual's shoulders when a user is suspended in the device.

Software safety features for limiting the speed of the device/and or the direction of motion of the device. The HCP can customize the speed and motion limits according to each patient's need for support.

HCP injuries can be avoided since caregivers are no longer required to intervene and physically support a patient, or stabilize the patient if the patient loses their balance. The device monitors key data such as the patient's walking speed,

pelvis height, and the amount of support required to remain upright and quickly and automatically locks into place to support the patient and prevent a fall, in the event that the patient suddenly loses their balance.

The process for using SoloWalk is as follows [13]:

1. A HCP brings the device to the patient's bedside or chair, and secures the patient.
2. The HCP uses the lift/transfer feature of the device to safely transfer the patient from their bed/chair to a standing posture. The BWS's active assist system, if used during the transfer, ensures that the patient actively participates in the transfer task.
3. Only one HCP is needed to coordinate the therapy session, and supervises the patient while he/she uses the device independently.

6. Instrument Development

Kruger and Casey's interactive model for focus group design was used to develop questions aimed to facilitate a brainstorming discussion [14]. A discussion with health care practitioners and the SoloWalk developer occurred before and after a trial of the SoloWalk device with HCPs and the adolescent subject with GMFCS level IV CP. Both discussions will be audiotaped and trials of the SoloWalk device will be videotaped.

The aim of these focus groups is to determine if this device can be utilized in this population and to provide the SoloWalk developers with pertinent information to modify and adapt the current adult SoloWalk prototype for pediatric use.

7. Data Collection Technique

Relevant personal and basic medical history information is collected from the patient. Consent was obtained from HCPs, SoloWalk developers, and patient or substitute decision makers. Data from the focus groups was recorded and reported. For this study, the interviews and device trial were audio and video recorded then transcribed verbatim prior to analysis. Comments were grouped into relevant themes and these were reported.

SoloWalk is approved by Health Canada as a Class I medical device. The protocol was reviewed and approved by the Children's Hospital of Eastern Ontario's ethics committee and the ethics committee at the Ottawa Children's Treatment Center.

8. Results

This collaboration between therapists, physicians and engineers was extremely successful. A child who had not walked in 2 years was able to mobilize with the aide of the robotic walker. The feedback from the youth and family was quite positive. The focus group recordings indicated as follows:

The youth felt safe and comfortable in the harness. He stated that it was "fairly easy" to get into and he liked the way the robot "lifted him up". He felt well supported in the device, his arms and legs were comfortable and the movement of the robot was interpreted as smooth. The walker was responsive, it made it easier for him to walk and easy to turn. He was very happy to walk, described the device as "cool" and wanted to use it again!

The family feedback included a written communication to team stating "I have read articles over the years since my grandson was born and dreaming of the day that this might occur. Your group is to be commended" – Participant's Grandfather.

For design changes, overall AM was quite pleased but recommended more padding on the front and in the groin area of the harness and he did note that it was "big, but he could get used to it."

The clinicians noted that a child who could be passive in his approach appeared motivated to move in this device. They were surprised that a child with such physical and cognitive involvement could walk using this device for approximately 40 meters during his 60 minute assessment. He could use it with the assistance of the therapists and independently both facing the Tower, holding on to the handles and in reverse in a hands free position.

The therapists were also hopeful that the device could be made smaller and that the harness could be customized for comfort and support. Overall, it was not difficult for the therapists to get the patient into the device and the technique of preparing the patient was not perceived as difficult to learn. It was the opinion of the therapists that efficiency would be gained over time.

In an adolescent with CP, walking can be integral in promoting independence, self-help skills, bone health and in prevention of muscle contracture and obesity. Traditional manual gait trainers as well as PBWST systems have been shown to be physically challenging on HCPs and less efficient then robotic devices. This case study begins to identify advantages and barriers to adapting an adult robotic walker device (SoloWalk) for children with GMFCS level IV CP.

The results from this case study are extremely encouraging and will help us to pilot this device on further children and collect data to create future robotic walker prototypes that can provide effective, efficient and safe gait training and exercise in numerous settings. We have data forthcoming from a small cohort of five individuals and a plan for further collaboration on larger groups of youth with severe mobility limitation. The plan is to assess gait training, conditioning and facilitation of participation in school physical education programs and in community gym settings.

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