## AACPD Pre-Conference Workshop
**New Clinical Horizons and Emerging Mobility Technologies – A Research Driven Process**

**Wednesday, October 16, 2013 | 1:00pm – 5:00pm**

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|               |                                                                        | Adam Graf, MS                          |
| 1:15 – 1:25   | Upper extremity systems and models, instrumentation and assessment       | Brooke Slavens, PhD                   |
|               |                                                                        | Alyssa Schnorenberg, MS                |
| 1:25 – 1:45   | Upper extremity assisted-gait clinical application and results           | Brooke Slavens, PhD                   |
|               | Lofstrand Crutch mobility                                                 | Alyssa Schnorenberg, MS                |
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| 2:10 – 2:20   | Musculoskeletal modeling and simulation using OpenSim, SIMM, and EMG for quantitative upper extremity assessment. | Brooke Slavens, PhD                   |
| 2:20 – 2:30   | Questions                                                                |                                        |
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<p>|               | Demonstration                                                            | Susan Riedel, SM, PE                  |
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<td>Lower extremity (LE) motion analysis in Planovalgus and Equinovarus foot deformities. LE modeling concepts for hip, knee, ankle and segmental foot Kinematics.</td>
<td>Gerald Harris, PhD, PE Peter Smith, MD</td>
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<td>4:00 – 4:15</td>
<td>Dynamic Fluoroscopy</td>
<td>Ben McHenry, PhD Taly Gilat Schmit, PhD Janelle Cross, MS</td>
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<td>Deborah Gaebler-Spira, MD Li-Qun Zhang, PhD</td>
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<td>4:30 – 4:50</td>
<td><strong>IntelliStretch Demonstration</strong></td>
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**New Clinical Horizons and Emerging Mobility Technologies – A Research Driven Process**

**WELCOME AND INTRODUCTION**

Speaker: Gerald F. Harris, Ph.D., P.E.  
E-mail: geraldharris@msn.com

**Objective:** This course is designed to explore emerging clinical applications resulting from advances in mobility assessment and assisted therapy. These research driven applications integrate clinical need with novel technologies to offer more effective methods of mobility analysis and therapeutic treatment.

**Course Summary:** This course will provide significant exposure to emerging applications in human motion analysis and robotic assisted movement therapy. The research driven symposium will offer a balanced presentation of upper and lower extremity motion analysis applications which employ advanced modeling techniques and technologies to improve pre-treatment assessment and post-treatment follow-up. The upper extremity applications will address the internal joint demands of children and young adults who use anterior and posterior walkers, Lofstrand (Canadian) crutches, and manual wheelchairs. The lower extremity applications will address the segmental motion demands of the hindfoot, forefoot and hallux in children with equinovarus and planovalgus foot deformities who are candidates for both conservative and surgical care. Novel fluoroscopic technology will be discussed which allows in vivo examination of the talocrural and subtalar joints during walking while shod and with orthotics. An application example of robotic assisted movement therapy will be presented in terms of setting subject-specific goals which can be modified throughout the progression of treatment. The importance of integrated gaming strategies for upper extremity assessment and therapy with a markerless system will be presented and demonstrated. A 30 minute hands on opportunity will follow the presentations and demonstrations.

**Learning Objectives:**  
At the end of the symposium participants will be able to discuss:

1) how recent research is advancing our understanding of upper extremity mobility and the longer term implications of assistive device use in children

2) how recent research is advancing our understanding of segmental foot motion and how this knowledge is being used to make better clinical decisions

3) how novel fluoroscopic imaging of the hindfoot is increasing our knowledge of bony hindfoot dynamics and the potential for future clinical application

4) important features of robotic assisted movement therapy and how this technology can be useful in the clinician’s treatment arena

5) how gaming strategies are integrated with therapy demands in the current clinical environment
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CURRENT CLINIC AND MOBILITY TECHNOLOGY

Speaker: Adam Graf, M.S.
E-mail: agraf@shrinenet.org

Learning Objective: Important features of robotic assisted movement therapy and how this technology can be useful in the clinician’s treatment arena.

Presentation Summary: This is an overview of available technology used to assess mobility and assist with therapy in a clinical setting. The equipment will primarily be involved with the assessment and assistance for the following categories that represent functional ability:

- Joint Range of Motion (ROM)
- Strength
- Gait
- Posture
- Ability to Perform Activities of Daily Living

Assessment of:

- **ROM**
  - Smartphone Apps
  - Wearable Sensors/Inertial Sensors
  - 2D Motion Detection/Video Systems
  - 3D Motion Capture Systems
  - Fluoroscopy

- **Strength**
  - Hand Held Dynamometry
  - Computerized Dynamometry
  - Instrumented Devices Using Force Transducers (Walkers, Crutches, Wheelchairs, etc.)
  - Electromyography (EMG) Sensors

- **Gait**
  - 2D Video Systems
  - 3D Gait Analysis Systems
  - Pressure Mapping
  - Wearable Sensors/Inertial Sensors
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CURRENT CLINIC AND MOBILITY TECHNOLOGY

○ Posture
  ▪ Computerized Dynamic Posturography
  ▪ 6 Axis Force Platforms

○ Activities of Daily Living
  ▪ SHUEE
  ▪ AHA

Technology Used to Assist in Therapy:

○ Mobility Assistance
  ▪ Walk Aide – for foot drop
  ▪ Dynamic Assistive Orthotics
  ▪ Exoskeleton
  ▪ Push Activated Power Assist Wheels and Powered Wheelchairs
  ▪ Lokomat and Assistive Treadmills

○ Interactive Gaming
  ▪ Gamecycle

○ Biofeedback
○ Functional Electrical Stimulation (FES)
○ Virtual Reality
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PEDIATRIC ASSISTED MOBILITY: UPPER EXTREMITY BIOMECHANICS AND MODELING

Speakers: Brooke Slavens, PhD, Lawrence Vogel, MD, Alyssa Schnorenberg, MS
E-mail: slavens@uwm.edu, LVogel@shrinenet.org, paulaj@uwm.edu

Learning Objective: How recent research is advancing our understanding of upper extremity mobility and the longer term implications of assistive device use in children.

This session will begin with an overview of the mobility needs in youth with SCI, SB, OI, and CP, and the incidence of upper extremity pain in those with SCI. This will be followed by a discussion of biomechanical modeling and advanced evaluation in the motion analysis lab of upper extremity movement during manual wheelchair propulsion and use of assistive devices during walking.

Throughout the lifespan of individuals with disabilities, mobility is essential for mastery in all aspects of their lives. Mobility is one of the main vehicles by which individuals explore their world from their home, neighborhood and community and is critical to full participation and life satisfaction. Therefore it is critical that for individuals with mobility impairments, such as those with spinal cord injuries (SCI), spina bifida (SB), osteogenesis imperfecta (OI), or cerebral palsy (CP), that they maintain efficient modes of mobility throughout their lives.

Because individuals with mobility impairments are susceptible to over-use syndromes and premature aging as manifested by upper extremity pain and degenerative arthritis, preventative efforts are needed to preserve upper extremity function and reduce upper extremity pathology and associated pain. A major contributing factor to upper extremity pathology is excessive forces applied to the upper extremity during transfers, propulsion of manual wheelchairs and use of assistive devices.

The standard practice of rehabilitation of youth with mobility impairments includes instruction in the proper techniques of transferring, wheelchair propulsion and use of assistive devices. Despite these efforts, the high incidence of upper extremity pain in those with mobility impairment indicates that additional efforts are needed.

Interventions to preserve upper extremity function and reduce pain must continuously meet the evolving needs of youth as they grow and their modes of mobility change. Use of biomedical
techniques of evaluating upper extremity function can substantially supplement clinical interventions by more thoroughly identifying joint movement and stresses during activities such as manual wheelchair propulsion and ambulation with assistive devices.

References


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**ENHANCING UPPER EXTREMITY FUNCTIONAL ASSESSMENT WITH THE KINECT MOTION ANALYSIS SYSTEM**

Speakers: Joseph Krzak, PhD, PT, PCS, Susan Riedel, SM, PE, Jacob R. Rammer, BS
E-mail: jkrzak@shrinenet.org, susan.riedel@marquette.edu, jacob.rammer@marquette.edu

**Learning Objective:** How recent research is advancing our understanding of upper extremity mobility and the longer term implications of assistive device use in children.

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**Microsoft Kinect (Kinect) Project Objective:**

Develop software that detects and records upper extremity kinematics, extracts key measures of upper extremity function, and facilitates scoring of the Shriners Hospitals for Children Upper Extremity Evaluation (SHUEE).

**Description, Benefits, and Limitations of the SHUEE Clinical Evaluation:**

**Description:** The SHUEE is a clinical assessment tool of upper extremity function for children with hemiplegic cerebral palsy. A video recorded assessment of activities of daily living is scored to provide measures of Spontaneous Function, Dynamic Position, and Grasp/Release.

**Benefits:** The SHUEE offers video-based documentation of functional ability before and after therapeutic or surgical intervention, uses activities relevant to daily life, and provides valuable insight for planning interventions.

**Limitations:** The SHUEE is validated and shows excellent inter-rater and intra-rater reliability [1], but questions have been raised regarding its sensitivity to detect change following intervention.

**Description, Benefits, and Limitations of the Kinect Motion Analysis System:**

**Description:** The Kinect motion analysis system includes a Microsoft Kinect sensor (depth sensor, images surface map of the body), skeletal tracking and motion recording software (interpolates bone/joint locations and records 3D positions over time), and data processing & interpretation software (calculates/plots angular kinematics, statistics, and SHUEE scores).

**Benefits:** The Kinect system has a very low cost ($100-150) compared to typical clinical motion analysis systems and can be used with any modern Windows PC [2]. It captures motion with reasonable accuracy when compared to a calibrated Vicon system [3]. Its ultra-portable design requires a single Kinect sensor and laptop computer, so it can be used outside the traditional clinical environment. Its markerless operation is easy to use and provides increased subject comfort.
Figure 1: Microsoft Kinect (Kinect) System for Kinematic Analysis. The primary user interface (A) allows selection of Kinect (K) activities to launch the data collection application, (B) for hand and (C) for UE activities. Data is then processed in the hand analysis and whole-body analysis MATLAB software, which displays skeletal position (allowing the user to select the start and end of activity cycles to analyze [D]), calculates angular kinematics (position, velocity, acceleration) for all joints and presents the results as kinematic plots, maxima and minima, and activity performance scores for the SHUEE (E).

Limitations: Dropout can occur if the Kinect sensor view is occluded by objects or body segments. The current system cannot detect forearm pronation/supination and cannot differentiate shoulder flexion/extension, abduction/adduction, internal/external rotation or wrist flexion/extension and radial/ulnar deviation. The system provides limited hand detection depending on hand position and the presence of obstructions.

Pilot Study Preliminary Results and Insights:

Study Protocol: Participants included 16 adolescent subjects ages 12-17 with no current or past impairment of upper extremity function. The SHUEE was performed by the subjects and scored by a P.T, while the Kinect tasks were performed by the subjects and scored by an engineer. Example tasks included throwing a ball, unscrewing a bottle cap, donning and doffing socks and shoes, and cutting and pulling apart Play-Doh® as a food simulation.

Key Results: Population normal data allows visual kinematic plotting of future subject performance and development of SHUEE scoring algorithms. The study indicates viability of the Kinect system in clinical motion analysis and as a supplement to the SHUEE in terms of both kinematic output and qualitative ease-of-use observed throughout testing.

Observed Limitations: Lack of pronation/supination and wrist and shoulder planar differentiation detection limits parts of the SHUEE. Tracking dropout occurs in certain situations, such as hand detection with a flexed wrist or objects obstructing the Kinect view.
Future Directions:

- Improve system to keep pace with new hardware availability and features (Kinect 2.0).
- Detect isolated thumb kinematics and differentiate forearm and wrist movements by plane.
- Integrate gaming into the Kinect experience to combine rehabilitation & evaluation.
- Expand population to include adults with cerebral palsy and other populations with upper extremity dysfunction.

Key References:

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**MUSCULOSKELETAL MODELING LOWER EXTREMITY**

Speakers: Gerald Harris, PhD, PE, Peter Smith, MD  
E-mail: gerald.harris@marquette.edu, psmith@shrinenet.org

Learning Objective: How recent research is advancing our understanding of lower extremity mobility and the longer term implications of assistive device use in children.

This lower extremity section of the workshop will provide an overview of the clinical need for lower extremity (LE) motion analysis in children for pre-treatment assessment and post-treatment follow-up with a focus on the clinical treatment challenges presented by planovalgus and equinovarus foot deformities. This will be followed by a presentation of fundamental LE modeling concepts for assessment of hip, knee, ankle and segmental foot kinematics that address the clinical needs.

**Pes planovalgus** (flatfoot) is a condition characterized by a flattening of the medial longitudinal arch of the foot, along with hindfoot valgus. Physical observations of flatfoot include low arch structure, rear foot eversion, medial talar head prominence, altered gait, and calluses [1]. Positive clinical signs for planovalgus include the "too many toes sign" due to forefoot abduction and positive single limb "heel rise test" [1], [2]. Clinical gait observation is often used to assess the shape of the footprint, foot progression angle, calcaneal eversion, heel-to-toe contact, position of the knee, and the presence of a limp [1], [3]. Quantitative analysis of pes planovalgus beyond the assumption of a single rigid foot requires the use of segmental biomechanical models.

**Equinus and varus**, components of equinovarus, are two of the most common foot and ankle deformities in children with hemiplegic cerebral palsy [4]. Static or dynamic soft tissue imbalance of the ankle plantarflexors and invertors result in segmental deformities including hindfoot equinus and inversion, midfoot cavus, as well as, forefoot supination and adduction. These deformities are ultimately associated with deviations at more proximal segments, increased mechanical work, and increased energy expenditure during locomotion in children with cerebral palsy [5-7]. Quantitative gait analysis including multi-segmental foot and ankle kinematics can effectively characterize the equinovarus deformity during ambulation.

To develop and apply LE models, information acquired by marker sensing systems (typically optical/video) is used in conjunction with a biomechanical model to determine joint and segmental kinematics (motion). A virtually limitless number of biomechanical models can be used to calculate
limb orientation in space, with numerous modeling approaches reported in current literature [8-10]. Anthropometric models use positions of body-mounted markers to calculate the locations of virtual joint centers based on previously established regression equations. Cluster models rely on groups of rigidly fixed markers mounted on body segments and require technical-anatomical calibration to reference anatomical landmarks and segment axes to associated marker clusters. OJC (optimized joint center) models can be based on a variety of marker placement schemes. The OJC models rely on calibration trials for an optimized estimate of joint center locus. Collectively these modeling approaches support the development of customized models specifically tailored to the research study and/or clinical population of interest.

References
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**SEGMENTAL KINEMATIC ASSESSMENT OF PLANOVALGUS FOOT SECONDARY TO CEREBRAL PALSY**

Speakers: Joseph Krzak, PhD, PT, PCS, Katie Konop, MS  
E-mail: jkrzak@shrinenet.org, Katherine.reichardt@mu.edu

Learning Objective: How recent research is advancing our understanding of segmental foot motion and how this knowledge is being used to make better clinical decisions.

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Planovalgus = ‘flatfoot’
- Plantar flexed hindfoot
- Dorsiflexed forefoot
- Flattened medial-longitudinal arch, hindfoot valgus
- Most common foot deformity in children with cerebral palsy

Study goal
- Provide a quantitative three-dimensional description of the skeletal segmental foot kinematics in children with planovalgus secondary to cerebral palsy

Modified Milwaukee Foot Model (MFM)
- 4 segments: Tibia, Hindfoot, Forefoot, Hallux
- 3 x-ray views (sagittal, anterior/posterior, and modified coronal) used to index surface markers to underlying bony anatomy
- Three-dimensional kinematics of each segment calculated relative to the proximal segment

Study details
- N=5 children (8 affected feet) with planovalgus, and 10 typically developing children
- All participants presented with rigid planovalgus secondary to cerebral palsy, with planned surgical correction
- Static trial, weightbearing radiographs, and 3 acceptable walking trials performed
- Results (see figure)
- Flattened arch (Decreased hindfoot dorsiflexion and forefoot plantar flexion)
- Hindfoot eversion
- Forefoot abduction
- The model was able to account for abnormal bony anatomy to provide accurate segmental kinematic results
Figure: Hindfoot (relative to tibia) and forefoot (relative to hindfoot) kinematics in sagittal (column 1), coronal (column 2) and transverse (column 3) planes. Solid line is average for planovalgus group, dashed lines are +/- one standard deviation, shaded band is average normal +/- one standard deviation.

Future
- Larger sample size
- Characterize additional pediatric and adult foot and ankle pathologies
- Integrate with fluoroscopic analysis for dynamic skeletal assessment
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**Kinematic Subgroups of Equinovarus in Cerebral Palsy**

Speakers: Joseph Krzak, PhD, PT, PCS, Peter Smith, MD
E-mail: jkrzak@shrinenet.org, psmith@shrinenet.org

Learning Objective: How recent research is advancing our understanding of segmental foot motion and how this knowledge is being used to make better clinical decisions.

**Background:** Equinus and varus, often found in combination resulting in equinovarus, are the most common foot and ankle deformities in children with hemiplegic cerebral palsy (CP) [1]. Because many factors contribute to the complexity of the deformity, previous reports have identified a lack of uniformity in the gait kinematics of children with equinovarus [2]. Both the hindfoot and forefoot segments contribute to the deformity in the sagittal, coronal and/or transverse planes. In addition, equinovarus can be present during the stance and/or swing phases of gait. Finally, foot and ankle deformities in children with CP can be characterized by dynamic or static soft tissue imbalance with, or without, skeletal deformity [3]. Accurate identification of the involved segment(s), plane(s), timing, and the range of motion (ROM) of the deformity is important when defining types and causes of equinovarus deformity to make accurate and effective clinical decisions.

**Purpose:** To identify foot types in children with equinovarus using segmental kinematics.

Hypotheses: (1) A large set of kinematic variables can be reduced to a smaller set with minimal loss of essential information. (2) Clinical foot types can be identified where the individuals are similar within a group but different from individuals in other groups.

**Methods:**
- N = 44
  - 24 children with equinovarus secondary to hemiplegic cerebral palsy (12.0±4.1 yrs)
  - 20 typically developing children (11.8±2.7 yrs)
- Quantitative gait analysis:
  - Temporal-spatial data
  - Hindfoot and forefoot kinematics using the Milwaukee Foot Model
• A subset of forty variables were chosen
  • Hindfoot and forefoot kinematic variables
    • Kinematic Peaks
    • Position (Average or at initial contact)
    • Range of Motion (ROM)
    • Walking speed
    • Age at the time of the preoperative evaluation
• Principal component analysis (PCA) is a multivariate statistical procedure that converts a set of observations of possibly correlated variables into a smaller set of variables called principal components that are independent from each other.
• \( K \)-means Clustering is statistical procedure where cases are divided into subgroups (or clusters).
  • The subgroups are created to maximize:
    • The similarity within clusters
    • The variation between clusters

Results:

<table>
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<tr>
<th>Principal Component (PC)</th>
<th>Construct</th>
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<tbody>
<tr>
<td>PC1</td>
<td>Sagittal hindfoot and forefoot equinus</td>
</tr>
<tr>
<td>PC2</td>
<td>Transverse forefoot adduction and coronal forefoot ROM</td>
</tr>
<tr>
<td>PC3</td>
<td>Coronal hindfoot varus</td>
</tr>
<tr>
<td>PC4</td>
<td>Coronal hindfoot ROM</td>
</tr>
<tr>
<td>PC5</td>
<td>Sagittal hindfoot ROM</td>
</tr>
<tr>
<td>PC6</td>
<td>Coronal/Transverse forefoot supination and transverse ROM</td>
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<thead>
<tr>
<th>Cluster (n=44)</th>
<th>Description</th>
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<tr>
<td>#1 (n=18)</td>
<td>Control Group (Rectus)</td>
</tr>
<tr>
<td>#2 (n=5)</td>
<td>Flexible equinovarus deformity with hindfoot involvement</td>
</tr>
<tr>
<td>#3 (n=8)</td>
<td>Equinovarus deformity with both hindfoot and forefoot involvement</td>
</tr>
<tr>
<td>#4 (n=8)</td>
<td>Flexible varus deformity with both hindfoot and forefoot involvement (Cavus)</td>
</tr>
<tr>
<td>#5 (n=5)</td>
<td>Varus deformity with forefoot involvement</td>
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DYNAMIC FLUOROSCOPY

Speakers: Taly Gilat-Schmidt, PhD, Benjamin McHenry, PhD, Janelle Cross, MS
E-mail: tal.gilat-schmidt@marquette.edu, ben.mchenry@marquette.edu, janelle.cross@marquette.edu

Learning Objective: How fluoroscopic imaging of the hindfoot is increasing our knowledge of bony hindfoot dynamics and the potential for future clinical application.

Introduction to Fluoroscopy

- Overview of Fluoroscopy Imaging
  - Image formation
  - Systems components
  - Clinical use

- Ionizing Radiation
  - Dangers of ionizing radiation
  - Quantification of radiation dose
  - Estimates of radiation risk

Fluoroscopy in Foot Modeling

- Why?
  - Errors associated with external markers
  - Foot anatomy makes subcutaneous joints difficult to model
  - Alternative methods are invasive

- Hardware
  - Fluoroscopy unit
  - Walkway
  - Force plate
• Camera
• Image manipulation
  • Image correction
  • Image magnification
  • Global referencing
• 2D Fluoroscopic hindfoot model
  • Kinematics
  • Kinetics

**Biplane Fluoroscopy in Foot Modeling**

• Set-up
  • Walkway with force plate
  • X-ray sources and image intensifiers

• Calibration
  • Image distortion correction
  • Volume calibration

• Bone Models
  • MRI of foot
  • Segmentation of Bones

• Model-Based tracking
  • Input: Bone models and image sequences in virtual space
  • Output: Six degrees of freedom of bones

• Kinematics and Kinetics of talocrural and subtalar joints
  • Inverse Dynamics and ground reaction forces

• Clinical applications
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PASSIVE STRETCHING AND ACTIVE MOVEMENT TRAINING USING A PORTABLE REHABILITATION ROBOT IN CHILDREN WITH CEREBRAL PALSY

Speakers: Li-Qun Zhang, PhD, Deborah Gaebler-Spira, MD
E-mail: l-zhang@northwestern.edu, dgaebler@ric.org

Learning Objective: Important features of robotic assisted movement therapy and how this technology can be useful in the clinician’s treatment arena and how gaming strategies are integrated with therapy demands in the current clinical environment.

Ankle impairments are closely associated with functional limitations in children with cerebral palsy (CP). Passive stretching has been commonly used to increase range of motion (ROM) of the impaired ankle in children with CP. Improving motor control is also a focus of physical therapy in treating children with CP. However, there is a lack of convenient and effective ways to conduct controlled passive stretching and motivating active movement training with quantitative outcome evaluation.

The efficacy of combined passive stretching and active movement training with motivating games was investigated using a portable rehabilitation robot.

Twelve children with mild to moderate spastic CP participated in robotic rehabilitation three times per week for six weeks. Each session consisted of 20-minute passive stretching followed by 30-minute active movement training, and ended with 10-minute passive stretching. Passive ROM (PROM), active ROM (AROM), dorsiflexor and plantarflexor muscle strength, selective control assessment of the lower extremity (SCALE) and functional outcome measures (Pediatric Balance Scale, 6-min walk, and timed up-and-go) were evaluated before and after the six-week intervention.

It was found that significant increases were observed in dorsiflexion PROM, AROM, and dorsiflexor muscle strength. Spasticity of the ankle musculature was significantly reduced. Selective motor control improved significantly ($p=0.005$). Functionally, participants showed significantly improved balance ($p=0.0025$) and increased walking distance within 6 minutes.
Key Points, Supportive Information

- Passive stretching helped increase ROM and reduce stiffness in children with CP.

- Active movement training with engaging games motivates children in improving motor control.

- The passive and active training combination demonstrated improvements in joint biomechanical properties, motor control performance, and functional capability in balance and mobility.

Key References
