Skilled lower extremity motor development in children with spastic cerebral palsy

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Overview
1. Selective motor control = skilled movement of the lower extremities (legs)
2. Clinical assessment
3. Mirroring
4. Biomechanical assessment of SMC
5. SMC as a prognostic factor for interventions
6. Camp Leg Power intervention to improve SMC
   • Motor outcomes
   • Brain imaging outcomes

Selective Voluntary Motor Control
Ability to perform isolated joint movements upon request, without using mass flexor/extensor patterns and without undesired movement at other joints, such as mirroring

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Spastic Cerebral Palsy (CP) – Multiple Impairments
• Spastic CP is an injury to the developing brain
• Associated with premature birth & low birth weight
• Developmental disability

Corticospinal tracts
Control selective voluntary motor control

Corticospinal tract damage in spastic CP
• Commonly injured in spastic CP
• White matter damage of prematurity
• Periventricular leukomalacia (PVL)
• Responsible for voluntary movement
• Force
• Speed
• Timing
• Pattern
• Distal structures more vulnerable (foot / ankle)
• Mirroring - ipsilateral tract preservation
Clinical Assessment of SMC – Skilled Movement

Upper Extremity

"Fine motor"

Clinical Evaluations for CP? – MANY
1. ABL, HAN, 5. Box & Blocks
2. AHA, 6. Jilbert Taylor,
3. Melbourne, 7. 9-hole peg
4. Quest 8. Purdue Pegboard

Lower Extremity

Clinical evaluations for CP? NONE

• Selective Control Assessment of the Lower Extremity (SCALE)

Selective Control Assessment of the Lower Extremity

SCALE

• 10-15 minutes to complete
• Ask patient to perform selective movement for each joint
• Each joint is graded separately: hip, knee, ankle, subtalar and toes
• Divno movement or synergy, 1=impaired, 2=normal
• Max score for each lower limb =10 points
• Obligatory mirroring is a common reason for an impaired score

Clinical Example: “Impaired” SVMC at the Knee

Clinical Example: “Absent” SVMC at the Knee

Clinical Example: “Normal” SVMC at the Knee

Findings are consistent with increased vulnerability of the CST medial tracts.

Greater Distal Impairment

SCALE Score Hip >Knee >Ankle >STJ >Toes

Significant downward trend p < .0001

Fowler EG, Staudt LA, Greenberg MB. Developmental Med Child Neurol 51:607-614, 2009

Fowler EG, Staudt LA, Greenberg MB. Developmental Med Child Neurol 52:264-269, 2010
Studies have focused on upper extremity mirroring in spastic unilateral CP
• Preservation of ipsilateral corticospinal tracts (Friel research)
Less is known about lower extremity mirroring and in bilateral CP
• Critical for function as walking requires interlimb coordination
Cohort of 47 participants with bilateral spastic CP in our lab
• 25 (53%) exhibited mirroring at one or both knees
• 12 (26%) at the ankle

**Mirroring – Maladaptive Plasticity**

**Mirroring and Knee Joint Torque Production**

**Clinical Evidence of CST impairment**

• Greater distal impairment consistent with CST damage
• Mirroring experiment suggests that neural drive from one hemisphere is controlling bilateral muscle groups

**SMC required for skilled lower extremity movement**

Walking and kicking – swing phase (non weight bearing)
Normal Selective Motor Control: Independent Hip And Knee Coordination During Swing

Impaired Selective Motor Control: Reduced Step Length

Normal Selective Motor Control: Independent Hip And Knee Coordination During Swing

Absent Selective Motor Control: Markedly Reduced Step Length

Impaired Selective Motor Control: Reduced Step Length

Absent Selective Motor Control: Markedly Reduced Step Length
Hip and Knee Coordination

Angle-angle diagrams: exemplar limb data

Fowler and Goldberg
Gait Posture 29:102-107, 2009

Minimum Relative Phase (MRP) Analysis

One number to represent hip and knee coordination

Scale: 1 to 10

Fowler and Goldberg
Gait Posture 29:102-107, 2009

Scalar – MRP Correlation

Bilateral CP, GMFCS I-IV, n=15

r = -0.81,
p = 0.0001

N = 15

Task specific training
– asked to produce forceful knee extension moments during walking

Visual feedback

Does our clinical measure of skilled movement predict who does better with treatment?
Hamstring Lengthening Surgery

- Patients have shown more improvement in knee extension during stance as opposed to swing
  (Baumann et al., 1980, Carney et al., 2006, Thometz, 1989)

Case Examples: Similar Patient Characteristics

<table>
<thead>
<tr>
<th>Patient</th>
<th>Gender</th>
<th>Pre-Op Age (yrs)</th>
<th>Time Between Analysis (yrs)</th>
<th>GMFCS (Mobility)</th>
<th>Hamstring Spasticity Scores*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>10.5</td>
<td>1.8</td>
<td>III</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>9.6</td>
<td>2.3</td>
<td>III</td>
<td>2</td>
</tr>
</tbody>
</table>

*Ashworth Scale
### Pre-Post Hamstring Lengthening

<table>
<thead>
<tr>
<th>Patient</th>
<th>SCALE Score</th>
<th>Normalized Stride Length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left leg</td>
<td>Right leg</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

- If the goal is to improve stride length, good SMC is required (≥5 SCALE)
- Knee extension during stance improved in both patients

### Hip and Knee Moments during Robotic Walking

**Forceful Knee Extension Task**

- Uncoupled moments: Good SVMC
- Coupled moments: Poor SVMC

+ = extensor, - = flexor

### Gait Training: Improve Stride Length?

**Task specific training**
- asked to produce forceful knee extension moments during walking

**Visual feedback**

### Can we improve lower extremity motor function and CST outcomes?

- Short-term intensive therapy is appropriate for teaching skilled movement
- 15 sessions of intensive therapy over 1 month period, 3 hours/day
- Ambulatory children with spastic CP
- Selective motor control exercises: high dose and challenging
- Included sensory experiences without braces
- Outcomes: motor ability, parent perception, brain imaging of CSTs
Participants

3 Summer Camps
All children
- Ambulatory with spastic CP between 5 and 17 y.o.
- 23 children participated in the study
- Race: 16 White (6 Hispanic ethnicity), 4 Asian, 2 Black, 1 mixed

Brain imaging data (subset of children)
- Children with bilateral CP born premature with PVL on MRI (damage to CSTs)
- Able to lie still and meet criteria for MRI: no baclofen pumps, shunts, incompatible metal etc.
- 12 participants with CP, Prisma 3T scanner, age range 7-16 y.o.
- 12 typically developing children, age range 7-16 y.o.

High dose, robotics, gaming

Motor practice

Isolated knee extension
Step length

Motor practice & Sensory enrichment

Walking and exercising – dif. textures
Exercise and activities for all joints including toes

Ankle robot dosage

<table>
<thead>
<tr>
<th></th>
<th>Left Ankle</th>
<th>Right Ankle</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Sessions</td>
<td>Min/Day</td>
<td>Reps/Day</td>
</tr>
<tr>
<td>Mean</td>
<td>13.8</td>
<td>5.9</td>
</tr>
<tr>
<td>SD</td>
<td>1.2</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Maintenance: Home Exercise Program

3 months:
- Selective motor control exercises with parents at least 3 times per week
- Isolated joint motion: hip, knee, ankle, subtalar and toe joints
- Illustrations and written instructions provided
- Adherence
  - Parental calendars = 2.6 times weekly

Example: Ankle joint isolated joint exercises
Motor Outcomes

Assessments: Pre, Post and 4 month Follow-up
- Parental perception - Canadian Occupational Performance Measure
- Walking speed - 10 meter walk run
- Walking endurance - 6 minute walk distance
- Gross Motor Function Measure (GMFM-66)
- Knee strength and power: Biodex
  - Speed range = 0 - 300 deg/s
  - Grouped into low (0-4 pts) and high (5-9 pts) into SCALE score groups

Statistical analysis
- Repeated Measures ANOVA with post hoc paired t-tests - normal distribution
- Bootstrapping re-sampling method for data not normally distributed
- Significance level set at \( P < 0.05 \)

Parent Perspective (COPM)

- Performance
- Satisfaction

Clinically important difference = 2 pts

Law et al. 2005

Statistically significant improvement

Walking Speed: 10m Walk Run Test

No Change

Walking Endurance: 6 Min Walk Test

- Statistical significance indicated

Gross Motor Function Test

Knee Joint Extensor Torque – Left

Preliminary Results Years 1 & 2

High SCALE score group = 5 – 9 pts, n=7
Low SCALE score group = 0 – 4 pts, n=9

Mean ± SE
Summary: Motor Function Outcomes

Significant pre-post and pre to follow improvements (p < .05):
1. Parental perception of motor ability and satisfaction
2. Walking endurance
3. Gross motor function
4. Knee joint strength and power
   • better selective motor control led to improvement at more speeds and greater maintenance at follow-up

Brain Imaging Outcomes

A. Normal tract
   - FA = fractional anisotropy “structural integrity”
   - RD = radial (perpendicular) diffusion “myelination”
   - AD = axial (parallel) diffusion
   - MD = mean diffusion, average of RD and AD

B. Damaged tract
   - FA = loss of structural integrity
   - RD = diffusion in all directions
   - AD = diffusion perpendicular to damaged fibers

Diffusion Tensor Imaging – movement of water molecules

Methods – Diffusion Weighted Imaging

• BrainSuite – Shattuck et al. UCLA Brain Mapping Center

Tract Based Spatial Statistics (TBSS)

• Voxelwise statistical analysis of the FA, MD, RD, AD data
• Statistics: Pre post changes and correlations performed
• Voxels with significant increases (p<.05) in FA, MD, RD, AD values were projected onto the mean FA skeleton.

Corticospinal tracts

Control selective voluntary motor control
Can we measure the damage to the CSTs caused by CP?

**Decreased structural integrity**
(Blue = Control group FA > CP group, p<.05)

**Decreased myelination (RD)**
(Blue = Control group RD < CP group, p<.05)

Does the structure of the CSTs correlate with SCALE?

Correlates with structural integrity (FA)
(Blue = areas where FA increases with SCALE score, p<.05)

Are there changes in the CSTs post the intervention?

Significant increases in myelination (RD, MD) found
(Unpublished data – not shown)

**Brain Imaging Summary**

- Significant reduction in structural integrity and myelination of the CSTs in the CP as compared to the control group.
- Children with greater SVMC exhibited greater structural integrity of the CSTs.
- Evidence of neural plasticity post Camp Leg Power. Changes in CSTs were consistent with increased myelination.
- Currently recruiting a "no camp" control group to rule out changes that could be due to maturation.

**Future research**

- Early intervention
- Premature babies with CST damage can improve SMC (photo courtesy of Barbara Sargent PhD, PT, USC)
- Is it possible to prevent development of mirroring?
- Ankle – foot orthotics
- Common intervention
- Immobilizes the foot & ankle joints
- Should have time without braces for sensorimotor activities

**UCLA Research Team**

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Thanks for your attention!