The Optimization of Stiffness in Lycra Suits to Enhance Knee Extension and Hamstring Strength in Children with Cerebral Palsy

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Cerebral Palsy

- Worldwide, 2 to 4 infants per 1,000 live births are diagnosed with the disorder each year [1].
- Cerebral palsy has two classifications, spastic and non-spastic.
- Spastic CP is the most common form and is marked by hypertonia.

[Graph showing walking ability among 8-year-old children with cerebral palsy, spastic and non-spastic types.]

https://www.cdc.gov/ncbddd/cp/data.html
What is a Lycra Suit?

Postural Correction Orthoses (PCO) claims that the lycra suit provides deep, core compression and normalizes muscles tone. It is believed that the elasticity and pressure aids in the improvement of body coordination and gait [13].

Our goal is to prove the biomechanics behind the suits functionality.

Previous Investigations
Gait Deficiencies Due to Cerebral Palsy

- **Graph A** - Knee remains flexed during load bearing stage (0%-50%)

- **Graph B** - At 40% gait cycle a healthy gait results in a negative ground reaction force (GRF) while CP remains (>0).

- Results are due to lack of knee extension and increase in muscular forces and joint stiffness to overcome reduced range of motion.

Legend

- Dotted line - control group
- Solid line - cerebral palsy group
Previous Investigations by Diane Damiano

(Strength Training)

- The objective of Damiano’s research was to determine clinical effectiveness of strength training in children with spastic cerebral palsy [6].
- The study concluded that the short term strength training program had a positive outcome in children with spastic CP [6].

Fig 1. Change in mean strength of target muscles and their antagonists (n = 24; force measured in Newtons) and change in percent of normal strength for the target muscles (expressed as a percent) in the diplegia group before and after the strengthening program.
Previous Investigations by Diane Damiano (Crouch Gait Model)

**Knee Moment Feature** | **Predictive Equation**
---|---
Weight Acceptance Peak (KEM\(_{WA}\), Nm) | \( KEM_{WA} = -25.0 + 0.55 \cdot W + 0.41 \cdot \theta_{WA} + 0.99 \cdot \Delta \theta_{WA} \)
Mid-Stance Minimum (KEM\(_{MS}\), Nm) | \( KEM_{MS} = 7.64 + 0.026 \cdot W \cdot \theta_{MS} \)
Late Stance Peak (KEM\(_{LS}\), Nm) | \( KEM_{LS} = -25.4 + 0.50 \cdot W + 0.86 \cdot \theta_{LS} \)
Flexion Stiffness (k\(_{F}\), Nm/deg) | \( K_F = -2.33 + 0.082 \cdot W + 0.11 \cdot \theta_{WA} - 0.20 \cdot \Delta \theta_{WA} \)
Extension Stiffness (k\(_{E}\), Nm/deg) | \( K_E = 0.21 + 0.055 \cdot W + 1.37 \cdot \theta_{WA} - 1.38 \cdot \theta_{MS} - 1.38 \cdot \Delta \theta_{MS} \)

**Measured Variables**
- \( W = \text{weight} \)
- \( \theta_{WA} = \text{peak knee flexion angle during weight acceptance} \)
- \( \theta_{LS} = \text{knee angle @ contralateral heel strike} \)
- \( \theta_{MS} = \text{minimum knee flexion angle during stance} \)
Previous Investigations by Diane Damiano (Crouch Gait Model)
Proposed Research
Specific Aims

1) Evaluate the effects of adding an additional stiffness coefficient to the model of gait through the use of a personalized lycra suit for children with cerebral palsy. Does the addition of a stiffness coefficient improve crouch gait efficiency?
2) Measure and record the progression of hamstring strength from lycra suit strength conditioning.

Participant Criteria for Trial Selection

The participants of this study will be chosen based on age, gait, weight and Gross Motor Function Classification (GMFCS) level.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Control (n=12)</th>
<th>Experimental (n=12)</th>
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</thead>
<tbody>
<tr>
<td>Age</td>
<td>6-12</td>
<td>6-12</td>
</tr>
<tr>
<td>Weight</td>
<td>45-92 lbs</td>
<td>45-92 lbs</td>
</tr>
<tr>
<td>Gait</td>
<td>Healthy</td>
<td>Crouch Gait</td>
</tr>
<tr>
<td>GMFCS</td>
<td>Healthy</td>
<td>Level I or II</td>
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Equipment for Baseline Testing

With the utilization of an isometric torque sensor, initial hamstring strength will be measured and recorded for individuals in the experimental group.

http://www.e-kjsb.org/archive/detail/65
Equipment for Baseline Testing

https://netbeans.org/community/articles/interviews/bio-mechanics.html?print=yes


Baseline Testing

- Gait Analysis using motion capture for control and experimental group
- Musculoskeletal Modeling in OpenSim to compute the following joint kinematics using inverse dynamics
  - $\theta_{WA}$ = peak knee flexion angle during weight acceptance
  - $\theta_{LS}$ = knee angle @ contralateral heel strike
  - $\theta_{MS}$ = minimum knee flexion angle during stance
- Generate Knee Moment vs. Weight Acceptance graph for both groups
Optimizing Lycra Suit Stiffness ($K_L$) for Improved Moment

- Modified equation for knee flexion and extension stiffness ($K_F$) and ($K_E$) including the lycra suit stiffness ($K_L$).

\[ K_F = -2.33 + 0.082 \times W + 0.11 \times \theta_{WA} - 0.20 \times \Delta \theta_{WA} + K_L \]

\[ K_E = 0.21 + 0.055 \times W + 1.37 \times \theta_{WA} - 1.38 \times \theta_{MS} - 1.38 \times \Delta \theta_{MS} + K_L \]

- Identify optimal lycra suit stiffness for a specified weight group to improve the experimental Knee Moment vs. Weight Acceptance graph for the crouch gait group.
Experimental and Testing Timeline

1. Subjects wear the suit for >5 hours a day for a total of 6 weeks
2. Repeat motion capture and isometric torque measurement
   - Testing will be completed two times (suit on vs suit off).
3. Subjects wear the suit for >5 hours a day for a total of 6 weeks
4. Repeat motion capture and isometric torque measurement
   - Testing will be completed two times (suit on vs suit off).
Expected Results

We hypothesize that the suits’ stiffness constant creates an added resistance to muscular moments surrounding the knee which strength conditions the hamstring. Furthermore, the elasticity of the lycra suit can *store and return energy* during flexion and extension phases of weight acceptance to improve gait efficiency.
References