HOW MUCH MUSCLE STRENGTH IS REQUIRED TO WALK IN A CROUCH GAIT?

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INTRODUCTION
Individuals with cerebral palsy (CP) who walk in a crouch gait often receive strength training as part of their therapy. An underlying assumption is that these individuals do not have adequate muscle strength to walk in an upright posture, and strengthening weak muscle groups will enable these individuals to improve their knee extension. However, outcomes from strength training programs for individuals with cerebral palsy and crouch gait are inconsistent [1,2]. The purpose of this study was to determine how much strength is required to walk in a crouch gait and compare this to unimpaired gait. Identifying which muscle groups require more or less force to maintain a crouch gait versus an upright gait can provide guidance for designing effective strength training programs for individuals with CP who walk in a crouch gait.

METHODS
Musculoskeletal simulations were created for 3 unimpaired subjects who walked with normal kinematics, and 9 subjects with cerebral palsy who walked in a crouch gait (Table 1). The crouch gait subjects were divided into three groups based upon minimum knee flexion during stance (Figure 2): mild (15-30°), moderate (30-50°), and severe (>50°).

Table 1: Subject characteristics

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unimpaired</td>
<td>10 ± 3</td>
<td>144 ± 16</td>
<td>36 ± 9</td>
</tr>
<tr>
<td>Mild Crouch</td>
<td>9 ± 1</td>
<td>124 ± 10</td>
<td>24 ± 4</td>
</tr>
<tr>
<td>Moderate Crouch</td>
<td>11 ± 2</td>
<td>136 ± 6</td>
<td>43 ± 31</td>
</tr>
<tr>
<td>Severe Crouch</td>
<td>14 ± 2</td>
<td>157 ± 12</td>
<td>41 ± 8</td>
</tr>
</tbody>
</table>

A generic model [3] with 19 degrees of freedom and 92 musculotendon actuators was scaled to each subject (Figure 1). The maximum isometric force of all musculotendon actuators was scaled according to each subject’s height squared [4]. The muscle force required to drive the model according to each subject’s kinematics was estimated using the computed muscle control algorithm (CMC) [5]. The strength of each muscle group of interest was then decreased by reducing the muscle’s maximum isometric force. Each muscle group was weakened and CMC was rerun until the model could no longer track the subject’s kinematics without the moment produced by reserve actuators at each degree of freedom exceeding 10% of maximum joint moments. The muscle groups of interest included the ankle plantarflexors (gastrocnemius and soleus), anterior tibialis, vasti, bi-articular hamstrings, gluteus maximus, and gluteus medius.

Figure 1: Musculoskeletal models in unimpaired gait and mild, moderate, and severe crouch gait.

Figure 2: Average hip, knee, and ankle flexion angles.
RESULTS AND DISCUSSION
The maximum isometric force of the major muscle groups investigated in this study could be reduced significantly during unimpaired gait and crouch gait (Figure 3). This indicates that the system was generally robust to weakness of individual muscle groups and synergist muscles were able to compensate for the reduced strength.

Crouch gait was less sensitive to weakness of the gluteus medius and ankle plantarflexors than unimpaired gait. During unimpaired gait, gluteus medius activity was required in mid and terminal stance when high abduction moments are required. During crouch gait the required hip abduction moments were reduced and therefore required less gluteus medius strength. The ankle plantarflexion moment was reduced during terminal stance in crouch gait and therefore required less gastrocnemius and soleus strength.

The required strength of the vasti increased quadratically with crouch severity (Figure 4). During moderate and severe crouch gait, greater vasti muscle strength was required due to larger knee flexion moments during stance. The primary muscles that compensated for reduced vasti strength included the rectus femoris, gluteus maximus, gluteus medius, and hip adductors.

Crouch gait also required greater gluteus maximus strength, to extend the hip during stance, than unimpaired gait. The maximum isometric force of anterior tibialis could be reduced to zero in all cases except severe crouch gait.

CONCLUSIONS
Crouch gait is more robust to weakness of the ankle plantarflexors and gluteus medius compared to unimpaired gait but requires greater quadriceps and gluteus maximus force. These results suggest that crouch gait could be a compensation for weak plantarflexors or gluteus medius. Current strength training programs designed for individuals with crouch gait commonly target the hip and knee extensors. However, a crouch posture requires greater force from the hip and knee extensors than unimpaired gait, suggesting that these muscles would be strong enough to walk in an upright posture. Strength training programs that target the ankle plantarflexors and gluteus medius may be more effective for individuals with cerebral palsy and crouch gait, since these muscles require greater strength during upright gait.

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REFERENCES