The effect of walking speed on hamstrings length and lengthening velocity in children with spastic cerebral palsy

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1. Introduction

Children with cerebral palsy (CP) often walk with reduced knee extension in terminal swing, which can be associated with short length or slow lengthening velocity of hamstrings muscles during gait. This study investigated the role of two factors that may contribute to such short and slow hamstrings: walking speed and spasticity. 17 children with spastic cerebral palsy and 11 matched typically developing children walked at comfortable, slow, and fast walking speed. Semitendinosus muscle-tendon length and velocity during gait were calculated using musculoskeletal modeling. Spasticity of the hamstrings was tested in physical examination. Peak hamstrings length increased only slightly with walking speed, while peak hamstrings lengthening velocity increased strongly. After controlling for these effects of walking speed, spastic hamstrings acted at considerably shorter length and slower velocity during gait than normal, while non-spastic hamstrings did not (all \( P < 0.001 \)). These data are important as a reference for valid interpretation of hamstrings length and velocity data in gait analyses at different walking speeds. The results indicate that the presence of spasticity is associated with reduced hamstrings length and lengthening velocity during gait, even at constant walking speed.

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and second because walking speed may influence the effects of spasticity, due to its velocity-dependency [8]. Therefore, studying speed effects in spastic children is particularly relevant.

The aims of this study were:

1. to investigate the effect of walking speed on hamstrings length and lengthening velocity during gait in children with CP;
2. to investigate to what extent spasticity as measured in physical examination is related to hamstrings length and lengthening velocity during gait; and
3. to study the interacting effects of walking speed and spasticity.

2. Methods

2.1. Subjects

17 children with spastic CP and 11 typically developing (TD) children, matched in age, height and weight, participated in this study. Characteristics of the children with CP (mean ± standard deviation) were: age 8.9 ± 2.1 years (range 6–12); height 136 ± 13 cm; weight 33 ± 10 kg; and of the TD children: age 8.2 ± 1.8 years (range 6–12); height 134 ± 12 cm and weight 32 ± 13 kg. All children with CP were clinically diagnosed with spastic CP (13 bilateral, 4 unilateral), were able to walk independently, and had no prior botulinum toxin treatment within the previous 16 weeks. All children and their parents provided informed consent. The study protocol was approved by the Medical Ethics Committee of the VU University Medical Center.

2.2. Design

The children walked along a 10 m walkway, first at self-selected comfortable walking speed (CWS), and subsequently at 70 ± 5% (SLOW) and 130 ± 5% (FAST) of CWS, in random order. Walking speed was recorded online and controlled by giving instant feedback to the children. After sufficient practice attempts, three successful trials were collected for each speed condition. The children were measured twice in two separate sessions, in order to obtain a large and reliable data sample per child, and as part of a larger study. This resulted in a total of six trials per condition. The sessions took place at the same time of day, 17.6 ± 11.6 days apart, without any interventions in between the two sessions. For logistic reasons, two children could be measured only once.

3D kinematic data were collected for the trunk, pelvis, thigh, shank and foot, using a motion capture system (Optotrak, Northern Digital, Waterloo, ON). Data on the right leg were collected in the TD group and on both legs in the CP group. A technical cluster of three markers was attached to each segment. While standing in anatomical position, bony landmarks were indicated in order to anatomically calibrate the technical cluster frames [10].

All children with CP underwent a standard physical examination in one of the two sessions, all performed by the same person. Spasticity was measured in the hamstrings with a standardized clinical spasticity test (SPAT) [11], which is based on the Modified Tardieu Scale [12]. In this test muscles were stretched at slow and fast speed. Based on these measurements, the muscles were grouped according to the level of spasticity: SPAS2 = severe spasticity (presence of a clear catch at fast stretch, SPAT score 2 or 3); SPAS1 = mild spasticity (increase in muscle resistance somewhere in the range of motion at fast stretch, without a catch, SPAT score 1); SPAS0 = no spasticity.

2.3. Analysis

3D kinematic data were analyzed with open-source software (www.BodyMech.nl; MatLab®; The Mathworks). Initial contact (IC) was calculated from the forward foot velocity, and defined as the instants at which this velocity became lower than 20% of its maximal value [5]. One successful stride (IC to IC) was collected for each trial, and left and right legs were included separately. The difference between the CP groups and TD at a speed of 0.40 (main effect of group); B2 the slope of the outcome measure versus speed curve for TD (main effect of speed); and B3 the difference in slope between groups (interaction). Post hoc analyses were performed with SPAS0 and SPAS1 as reference groups to determine the significance of all pair-wise comparisons between groups. P-values of less than 0.05 were considered to be statistically significant.

3. Results

Based on the physical examination, 6 of the 33 semitendinosus muscles were assigned to SPAS0, 15 to SPAS1 and 12 to SPAS2. Of the ‘sound’ limbs of the unilaterally involved children, 3 muscles were assigned to SPAS0 and 1 to SPAS1.

Nondimensional walking speed differed significantly between the three conditions (P < 0.001, Table 1). The CP group walked slower than the TD group (P < 0.001); CWS in the CP group was close to SLOW in the TD group (P = 0.25), and FAST in the CP group was close to CWS in the TD group (P = 0.85). Walking speed in SPAS2 was significantly slower than in SPAS0 and SPAS1 (P < 0.05). Stride length was longer in the CP group than in the TD group, and decreased with increasing levels of spasticity (P < 0.001, Table 1).

Peak ST length and lengthening velocity both increased with walking speed (Figs. 1 and 2, Table 2: B2, P3). The effect of walking speed on ST length was small (Fig. 2A). B2, which indicates the slope of the peak length versus walking speed curve, was 0.029 ± 0.012 in the reference group TD. This means that peak ST length increased with 2.9% of reference length for each unit of nondimensional walking speed. Or in more meaningful terms: as walking speed almost doubled from slow (0.36) to fast speed (0.66), peak length increased with approximately 1% of reference length, which came down to about 3.5 mm. The effect of walking speed on peak lengthening velocity was more pronounced (Fig. 2B). B3 was 0.174 ± 0.022 for the TD group. Thus, as walking speed almost doubled from slow to fast speed, peak ST velocity increased with approximately 0.050, or 40%.

Peak ST length and lengthening velocity were lower in more spastic muscles (Figs. 1 and 2, Table 2: B1, P1). Both SPAS1 and SPAS2 had shorter peak length and slower peak velocity than TD. Null.
Non-spastic muscles in CP were not shorter or slower than normal. At the average nondimensional walking speed of 0.40, peak length in TD was 7.6 ± 0.4% longer than reference length ($B_0$). Peak length in SPAS2 was 2.9 ± 0.7% of reference length shorter than in TD ($B_1$). Peak lengthening velocity in SPAS2 was 0.028 ± 0.008 or about 20% lower than normal.

Peak ST velocity showed a significant overall interaction effect of walking speed and spasticity, and a similar trend was seen for

### Table 1

Nondimensional walking speed and stride length (means ± S.D.).

<table>
<thead>
<tr>
<th>Condition</th>
<th>TD</th>
<th>CP-ALL</th>
<th>SPAS0</th>
<th>SPAS1</th>
<th>SPAS2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLOW</td>
<td>0.36 ± 0.07$^{*12}$</td>
<td>0.26 ± 0.06$^{*1}$</td>
<td>0.30 ± 0.02$^{*2}$</td>
<td>0.28 ± 0.05$^{*2}$</td>
<td>0.23 ± 0.06$^{*2}$</td>
</tr>
<tr>
<td>CWS</td>
<td>0.51 ± 0.04$^{*112}$</td>
<td>0.39 ± 0.07$^{*1}$</td>
<td>0.42 ± 0.03$^{*2}$</td>
<td>0.41 ± 0.06$^{*2}$</td>
<td>0.35 ± 0.08$^{*2}$</td>
</tr>
<tr>
<td>FAST</td>
<td>0.66 ± 0.05</td>
<td>0.51 ± 0.07$^{*1}$</td>
<td>0.56 ± 0.03$^{*2}$</td>
<td>0.53 ± 0.05$^{*2}$</td>
<td>0.47 ± 0.08$^{*2}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Condition</th>
<th>TD</th>
<th>CP-ALL</th>
<th>SPAS0</th>
<th>SPAS1</th>
<th>SPAS2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative speed (speed/CWS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLOW</td>
<td>0.71 ± 0.03</td>
<td>0.68 ± 0.06</td>
<td>0.73 ± 0.02</td>
<td>0.67 ± 0.07</td>
<td>0.67 ± 0.05</td>
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<tr>
<td>CWS</td>
<td>1.00 ± 0.00</td>
<td>1.00 ± 0.00</td>
<td>1.00 ± 0.00</td>
<td>1.00 ± 0.00</td>
<td>1.00 ± 0.00</td>
</tr>
<tr>
<td>FAST</td>
<td>1.29 ± 0.03</td>
<td>1.34 ± 0.13</td>
<td>1.33 ± 0.10</td>
<td>1.30 ± 0.12</td>
<td>1.37 ± 0.14</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Condition</th>
<th>TD</th>
<th>CP-ALL</th>
<th>SPAS0</th>
<th>SPAS1</th>
<th>SPAS2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stride length</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>SLOW</td>
<td>1.60 ± 0.13$^{*12}$</td>
<td>1.27 ± 0.25$^{*1}$</td>
<td>1.46 ± 0.12$^{*2}$</td>
<td>1.32 ± 0.28$^{*2}$</td>
<td>1.14 ± 0.31$^{*2}$</td>
</tr>
<tr>
<td>CWS</td>
<td>1.87 ± 0.12$^{*12}$</td>
<td>1.46 ± 0.25$^{*1}$</td>
<td>1.61 ± 0.04$^{*2}$</td>
<td>1.58 ± 0.18$^{*2}$</td>
<td>1.28 ± 0.31$^{*2}$</td>
</tr>
<tr>
<td>FAST</td>
<td>2.11 ± 0.13$^{*12}$</td>
<td>1.68 ± 0.23$^{*1}$</td>
<td>1.85 ± 0.08$^{*2}$</td>
<td>1.76 ± 0.12$^{*2}$</td>
<td>1.39 ± 0.30$^{*2}$</td>
</tr>
</tbody>
</table>

Abbreviations: TD, typically developing; CP-ALL, all cerebral palsy patients grouped together; SPAS0, 1 and 2: increasing levels of spasticity in CP; CWS, comfortable walking speed.

$^{*12}$ indicate significant difference ($P < 0.05$) of subgroup to TD($T$), SPAS0($0$), SPAS1($1$) and SPAS2($2$), respectively.

All speed conditions were significantly different from each other ($P < 0.001$).
peak length (Table 2; B3, P3). Peak velocity increased more with walking speed in SPAS0 than in all other groups, but no difference was found between SPAS1 or SPAS2 and TD. Peak length increased more with walking speed in SPAS0 than in SPAS2.

4. Discussion

This study investigated the role of two factors that may contribute to hamstrings length and velocity during gait, i.e. walking speed and spasticity. When walking speed was reduced, both peak ST length and velocity decreased, with relatively small changes in peak length. Spastic muscles were shorter and slower during gait than non-spastic muscles, even after controlling for walking speed.

We studied the effect of walking speed in CP patients, since it can differ considerably between gait analyses pre- and post-treatment, or between subjects, for many reasons. For good interpretation, it is important to understand the separate effects of walking speed on gait parameters. Our result that peak ST length increased only slightly with walking speed indicates that differences in peak length between patients and control subjects, or between pre- and post-treatment analyses mostly reflect deviations in pelvic or leg positioning in terminal swing, or differences in step length, that are not attributable to differences in walking speed per se. As derived from Table 1, stride length was or between pre- and post-treatment analyses mostly reflect differences in peak length between patients and control subjects, increased only slightly with walking speed indicates that walking speed on gait parameters. Our result that peak ST length was found between SPAS1 or SPAS2 and TD. Peak length increased more with walking speed in SPAS0 than in all other groups, but no difference was found between SPAS1 or SPAS2 and TD. Peak length increased more with walking speed in SPAS0 than in SPAS2.

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with a broader range of walking speeds could reveal a more complex relationship of muscle-tendon lengths and velocities with walking speed, as has been shown for other kinematic, kinetic and electromyographic variables [21]. This may also reveal more significant interaction effects of walking speed and spasticity.

5. Conclusions

This study investigated the separate effects of walking speed and spasticity on hamstrings length and lengthening velocity in children with CP. Peak hamstrings length increased only slightly with walking speed; therefore, differences in peak hamstrings length between patients and control subjects, or between pre- and post-treatment analyses will mostly reflect deviating pelvis or leg positioning in terminal swing, or differences in step length, and can only for a small part be attributed to differences in walking speed per se. Peak hamstrings lengthening velocity increased strongly with walking speed; therefore differences in hamstrings velocity can to a large extent result from differences in walking speed. These data are important as a reference for valid interpretation of hamstrings length and velocity data in gait analyses at different walking speeds. Even when controlled for walking speed, spastic hamstrings were considerably shorter and slower during gait than normal, while non-spastic hamstrings were not.

Acknowledgements

We wish to thank Tanneke Vogelaar, Kim van Hutten, Esther Suurland, Carrey Doeven, and Alexander Reeuwijk for their assistance in data collection.

Conflict of interest statement

The authors declare that they have no conflicting interests.

References