JOINT MOMENT CONTRIBUTIONS TO SWING KNEE EXTENSION ACCELERATION DURING GAIT IN SUBJECTS WITH SPASTIC HEMIPLEGIC CEREBRAL PALSY

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INTRODUCTION

Inadequate peak knee extension during the swing phase of gait is a major deficit in patients with spastic cerebral palsy (CP), leading to a shorter stride length and decreased walking velocity. Our laboratory has shown that the ability to extend the knee during swing is dependent on the selective voluntary motor control (SVMC) of the subject. Subjects with good SVMC are more capable of extending the knee while flexing the hip during swing than subjects with poor SVMC [1]. The biomechanical mechanisms responsible for knee extension have not been thoroughly evaluated in CP.

Arnold et al. [2] used induced acceleration analysis (IAA) to examine muscle contributions to terminal-swing knee extension in nondisabled subjects and found that the swing limb vasti and hip extensors and stance limb hip extensors and abductors accelerate the swing knee toward extension. However, IAA results are dependent on body segment orientation; therefore, contributions to knee extension acceleration may differ in CP due to altered gait kinematics. The purpose of this study was to compare the contributions of lower extremity joint moments and gravity to swing phase knee extension acceleration in the hemiplegic and non-hemiplegic limbs in participants with spastic CP.

METHODS

Six participants with spastic hemiplegic CP were recruited for this study. Each participant was evaluated for his or her lower extremity SVMC using the Selective Voluntary Motor Control Assessment of the Lower Extremity tool (SCALE). A total score between 0 and 10 (0 = poor, 10 = normal) was given for each limb. Gait data were collected using an eight-camera system (Motion Analysis Corp.).

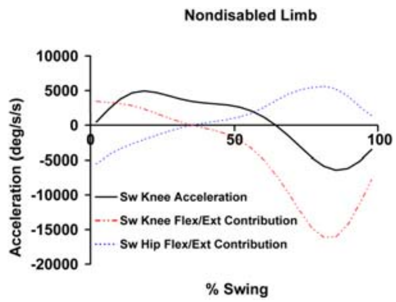

Figure 1: Swing hip and knee flexion/extension moment contributions to swing knee acceleration in an exemplar nondisabled subject.

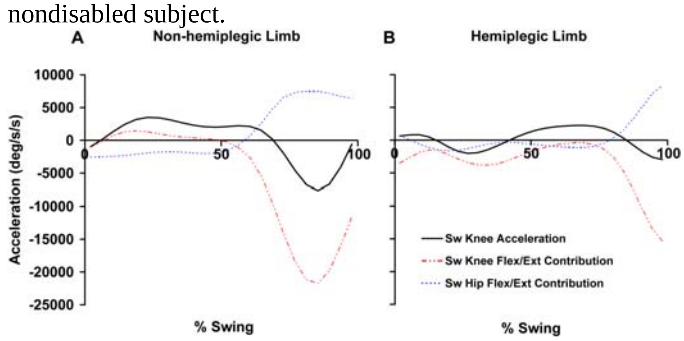

Figure 2: Swing hip and knee flexion/extension moment contributions to swing knee acceleration in a participant with CP for the A) non-hemiplegic limb and B) hemiplegic limb.

The most representative trial for each limb was selected. Kinematic and kinetic data were calculated from the experimental data. A biomechanical model described by Kepple et al. [3] was used. IAA was performed using the Induced Acceleration Analysis Module in Visual 3D (C-Motion, Inc.) to calculate the contributions of bilateral joint moments and gravity to swing knee acceleration [3]. The model was configured at each frame according to the experimental data. All joint moments and gravity were set to zero, and one joint moment (or gravity) was entered into the model at a time. The resulting knee acceleration of the swing limb was calculated for the input at each frame. The input moment was then set back to zero and all other joint moments and gravity were sequentially entered into the model. Joint moment and gravity contributions were averaged during the extension phase of swing, and contributions to swing knee acceleration in the hemiplegic and non-hemiplegic limbs were compared using paired t-tests.

RESULTS AND DISCUSSION

When comparing IAA results in the hemiplegic and non-hemiplegic limbs, the largest differences were found in the swing limb, specifically sagittal plane hip and knee moment contributions. In a typical nondisabled subject, the non-synergistic action of swing hip and knee sagittal plane moments is evident when assessing their contributions to swing knee acceleration (Fig. 1). Immediately following toe-off, a knee moment accelerates the knee toward extension while a hip moment accelerates the knee toward flexion. Approximately halfway through the extension phase of swing, the actions of these moments reverse, and the knee moment accelerates the knee toward flexion while the hip moment accelerates the knee toward extension.

In the non-hemiplegic limb of an exemplar participant (SCALE = 8), contributions to swing knee acceleration from the swing hip and knee sagittal plane moments are similar in their general pattern to that of a nondisabled subject (Fig. 2A). In the hemiplegic limb (SCALE = 4), both the knee and hip moments accelerate the knee into flexion for most of the extension phase, which indicates a synergy pattern, resulting in a substantially smaller swing knee acceleration compared to the non-hemiplegic limb (Fig. 2B).

For all participants, a significant difference was found between the negative contributions to swing knee extension from the swing limb joint moments of the hemiplegic limb and the non-hemiplegic limb with the hemiplegic limb having a greater magnitude of acceleration (Table 1). Significant differences were also found between the hemiplegic and non-hemiplegic limbs for the average knee acceleration, and differences approached significance for the average stance limb ankle joint moment contributions and average swing limb knee joint moment contributions (Table 1). On the stance limb, strategies varied by subject and limb; however, total stance limb contributions only differed by ~2% between limbs. No significant difference was found between limbs (Table 1).

CONCLUSIONS

While previous studies suggest that inadequate terminal-swing knee extension in subjects with CP may be caused by muscle weakness [2], our results do not support this concept. A greater contribution by the non-hemiplegic limb during stance to swing phase hemiplegic knee acceleration was not found. These stance phase contributions were similar for both limbs. In contrast, a significant difference was found between negative (or flexor) contributions from the swing limb of the hemiplegic and non-hemiplegic limbs. A greater average flexor acceleration was provided by the hemiplegic limb. These excessive negative contributions may be caused by impaired SVMC and/or spasticity. Treating the spasticity of the swing limb may improve swing knee extension, depending on SVMC ability [1]; however, strengthening specific muscle groups alone (e.g., the hip muscles) may not improve terminal knee extension in CP.

REFERENCES

1. Fowler EF and Goldberg EJ. *Gait Post* **29**, 102-107, 2009.
2. Arnold AS, et al. *J Biomech* **40,** 3314-3324, 2007.
3. Kepple TM, et al. *Gait Post* **6**, 1-8, 1997.

Table 1

	Non-hemiplegic	Hemiplegic	Mean Difference	95% Confidence Interval
Average Swing Knee Acceleration (in deg/s^2)	2226 ± 823	1471 ± 954	756	157 to 1355*
Average Contribution from:				
Gravity	336 ± 369	170 ± 246	166	-142 to 475
Stance Muscles	2183 ± 628	2219 ± 675	-37	-267 to 194
Stance Hip	809 ± 508	449 ± 294	360	-133 to 852
Stance Knee	70 ± 559	161 ± 300	-91	-900 to 717
Stance Ankle	1304 ± 491	1609 ± 566	-305	-661 to 51**
Swing Muscles	-1384 ± 658	-2147 ± 637	763	355 to 1170*
Swing Hip	-1425 ± 342	-997 ± 825	-428	-1579 to 723
Swing Knee	224 ± 813	-789 ± 990	1013	-264 to 2290**
Swing Ankle	-184 ± 201	-361 ± 445	177	-94 to 448

*indicates p < 0.05, **indicates p < 0.10, positive indicates extension accelerations (negative = flexion)