Gait coordination in children with hemiparetic Cerebral Palsy: Control of angular momentum.

1 Sjoerd M. Bruijn, 1Pieter Meyns, 1Ilse Jonkers, 2Guy Molenaers and 1Jacques Duysens
1 Research Center for Movement Control and Neuroplasticity
Dep. of Biomedical Kinesiology, K.U.Leuven. Email: s.m.bruijn@gmail.com
2 Clinical Motion Analysis Laboratory, CERM, University Hospital Leuven, Leuven, Belgium

SUMMARY
Children with hemiparetic Cerebral Palsy (CP) walk with marked asymmetries, which could lead to significant increases in total body angular momentum about the vertical, a variable believed to be tightly controlled in human gait. We tested whether children with hemiparetic CP are able to regulate total body angular momentum by compensatory movements of the unaffected arm. We measured gait kinematics of 24 healthy children and 11 children with hemiparetic CP. We found significant increases in angular momentum of the affected leg and unaffected arm, but no significant increase in total body angular momentum. These findings suggest that angular momentum about the vertical during walking is a controlled variable, even in children with hemiparetic CP.

INTRODUCTION
Children with hemiparetic Cerebral Palsy (CP) walk with marked asymmetries. For instance, we have recently shown that they have less arm swing on the affected side [1]. Such a reduction in arm swing may lead to an increase in total body angular momentum about the vertical axis, which leads to a higher energetic cost of walking [2]. Still, it has been suggested that angular momentum about the vertical is a tightly controlled variable in human walking. In line with this, we found concurrent increases in arm swing of the unaffected arm in our aforementioned study. In healthy walking, experimentally restricting arm swing in one arm also leads to an increased arm swing in the other arm [3], which may be a mechanism to keep total body angular momentum to a minimum, although it was never investigated in this regard.

Thus, in the current study, we investigated if subjects with hemiparetic CP control total body angular momentum about the vertical by compensatory movements of the unaffected arm and leg. We hypothesize that (1) angular momentum generated by extremities on the affected side would be larger, (2) that compensatory increases in angular momentum of the unaffected arm will be present, and (3) that these increases will cancel the extra momentum generated by the affected leg, so that total body angular momentum will remain similar to that in healthy subjects.

METHODS
11 children with hemiparetic CP (age 7.83 ± 2.98 years, weight 23.9 ± 7.6 kg and length 1.22 ± 0.15 m) and 24 healthy control children (age 9.40 ± 2.16 years, weight 31.7 ± 8.6 kg and length 1.38 ± 0.14 m) participated in the experiment. All subjects were asked to walk down a 10 m walkway at their self-selected pace. 3D gait kinematics were recorded using a Vicon system, and segment inertial parameters were calculated using a geometrical model [4]. Using gait kinematics and inertial parameters, a 15 segment 3D model was constructed, and the angular momentum of each segment with respect to the total body centre of mass was calculated.

To reduce between subject variance, all angular momenta were normalized to dimensionless values using length, mass, and gravitational acceleration [2]. Next angular momenta of segments belonging to one extremity were summed, and angular momentum over the stride cycle for each extremity, both extremities at one body side, and total body was calculated and plotted. For statistical analysis, the mean absolute of these curves was calculated. Unpaired t-tests were used to test for difference between average control subject values (left and right side averaged), and values of the unaffected and affected side.

RESULTS AND DISCUSSION
There were significant differences in mass (P=0.01) length (P=0.008) and stride times (P=0.02, CP = 0.87 ± 0.10 s healthy = 0.94 ± 0.06 s) but not in age (P=0.09) and walking speed (P=0.2 CP: 1.13 ± 0.15 m/s healthy: 1.20 ± 0.17 m/s) between the groups. Note that the first two differences will not affect our results, as we normalized angular momenta to be non-dimensional.

Figure 1 shows angular momenta curves over the stride cycle, for total body, the different extremities and the two body sides. From this figure, it becomes clear that there is little difference in total body angular momenta between the groups (Figure 1A), despite substantial increases in angular momentum of the affected leg (Figure 1B), and smaller increases of the unaffected leg. This is most likely due to corresponding increases in unaffected arm angular momentum (Figure 1C). Figure 1D nicely illustrates how changes in angular momentum of the affected side are counteracted by changes in angular momentum of the unaffected side.

Figure 2 shows the averaged absolute angular momenta of total body, the different extremities, and the two body sides. This figure largely confirms the findings observed in Figure 1; increased angular momentum at the affected side (Figure 2B, P<0.001), due to increases in affected leg momentum.
(P=0.001, accompanied by a smaller increase in angular momentum of the unaffected leg, P=0.02) is counteracted by an increase in angular momentum of the unaffected arm (P<0.001), so that total body angular momentum remains more or less similar to that in healthy subjects (Figure 2A, P=0.3).

CONCLUSIONS
Children with hemiparetic CP seem to counteract the substantial increases in angular momentum generated by the affected leg, by increasing arm swing at the unaffected side. In general, this led to no significant increase in total body angular momentum, although the shape of the angular momentum over the stride cycle was different between groups. These findings support the idea that angular momentum during walking is a controlled variable.

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