THE USE OF CENTER OF MASS ANALYSIS FOR GAIT ASSESSMENT IN CHILDREN WITH CEREBRAL PALSY

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INTRODUCTION

There has been considerable interest in the movement of the center of mass (CoM) in walking as an important indicator or collective variable of energy costs in both normal and pathological gait. It has been suggested that healthy walkers have developed movement strategies, which limit the vertical excursion of the CoM to minimize energy consumption. This view is reinforced by the fact that in typical walking more than half of the total energy consumed is lift work on the CoM(Duff-Raffaele *et al.*, 1996). Inverted pendulum models of walking suggest another manner in which energy costs are minimized is through the passive transfer between potential (PE) and kinetic energy (KE) of the COM. The CoM mechanics of walking have not been studied in children with cerebral palsy (CP).

This study examined the work performed, energy recovery factor, and the phasic and magnitude relationships between KE and PE of the COM at preferred walking speed of children with CP and age matched controls.

METHODS

Kinematic data (3-D) were collected on 15 children with spastic diplegia CP and five able bodied children at their preferred walking speed. The average age of the children was 10.5 ± 3.6 years. COM position was determined from anthropometric measurements, estimates for segment masses(Jensen, 1986), and kinematic data. The COM vertical excursion was computed and normalized by the excursion of a compass gait model to account for both leg and step length variation. The KE per unit mass ($0.5 \bullet |v|^2$) was computed and compared to the potential energy (PE) per unit mass ($g \bullet h$). The continuous relative phase of the PE relative to the KE was computed with the cross-spectral density function(Duarte, 2002). The energy recovery factor*(R)* for the CoM was determined. *R*, the percentage of energy recovered via passive exchange between KE and PE is defined as(Winter, 1990):

$$R = 100 * \frac{(W_{ne} - W_{ext})}{W_{ne}}$$

where W_{ext} is the external work performed and W_{ne} is the work done assuming no energy exchanges.

Repeated measures ANOVA's were used to test for between group differences of the dependent measures.

RESULTS AND DISCUSSION

The children with CP performed more external work to walk than the controls (1.31 vs 0.54 J/kg/m, $p < 0.003$). The normalized vertical CoM excursion of children with CP was 70% greater ($p<0.03$) than that of the controls, while there was no difference in lateral excursion. The larger change in PE combined with the tendency of the patients to walk slower resulted in a larger ratio of PE to KE than the controls (2.15 vs. 1.3, $p < 0.003$). In addition, the relative phase of PE to KE was 165° in the able bodied children (Figure 1a) vs. 144°, ($p <0.04$) in the

children with CP (Figure 1b). The closer the relative phase is to 180°, the better the passive energy transfer, which conserves energy. This is clearly seen in the energy recovery factor which encompasses the effects of both phasing and energy ratios. The children with CP recovered only 43% of the possible energy while the controls recovered 69% ($p < 0.001$).

CoM analysis also provided insight into walking strategies. Figure 1 shows where energy transfers can and cannot occur relative to the phases of walking. For an able-bodied child (Figure 1a) there is very little time during which energy transfer cannot occur because the relative phase of the two energies is nearly 180°. This can be contrasted with a plot of energies of a child with CP, Figure 1b. While there is much diversity in energy plots of children with CP, typically the peak in KE occurs before the minimum in PE. This results in a period of time where the CoM is "falling" and the walker is decelerating, meaning there can be no energy transfer. In this case the child flexes the knee of the front leg upon foot contact thus lowering the CoM while decelerating. Thus the poor energy use of children with CP is a combination of large vertical excursions of the CoM and poor timing of this movement.

The greater energy use by children with CP has been well documented, but its sources are much less well understood. The ratio of work on the CoM is quite similar to differences in metabolic cost found measuring O_2(Unnithan *et al.*, 1999), suggesting the importance of external work in the increase in metabolic cost. In addition, these results show that the increase in work is a result of both excessive vertical motion of the CoM and the timing of this motion.

SUMMARY

The results of this study show that CoM analysis can provide insights into walking strategies of children with CP. This information is important as it can be used to understand the effects of interventions to improve walking in patients with CP. Current research is examining the effects of ankle foot orthoses on CoM mechanics. Future work will also quantify the relationships between CoM work and O_2 consumption.

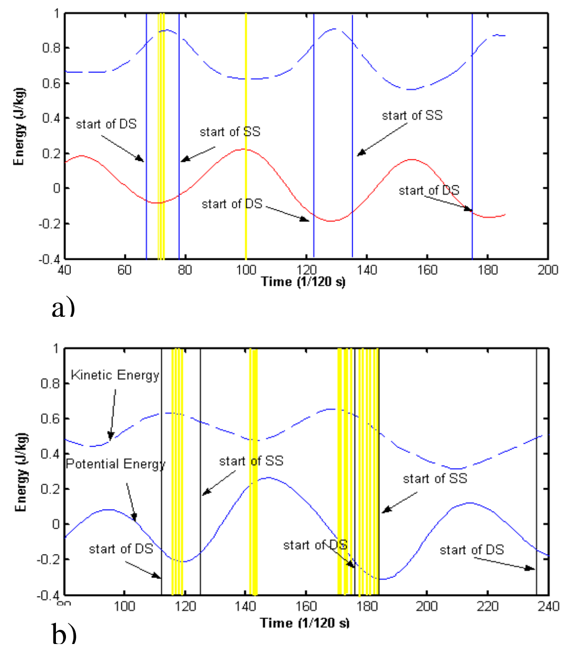

Figure 1 Plots of KE (dashed line) and PE (relative to mean CoM position) during walking. Shaded areas are times when energy transfer cannot occur. DS = Double Support, SS = Single Support a) Able-bodied child walking. b) Child with CP walking.

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