The Cost and Spring-Like Behavior of Walking: Are Children Scaled Down Versions of Adults?

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***Abstract*— Despite our natural tendency to adapt our walking pattern to minimize metabolic cost, the cost of walking is up to 33% higher in children [1] and 2-3 times more in children with disability [2]. Reducing the cost of walking dysfunction is a main goal of assistive prosthetic and orthotic devices. Therefore, understanding the biomechanical basis for the higher cost of walking in children is critical in helping those who require these devices. As a first approach, we used a simple spring-mass model [3] to compare net cost of transport (COT) and spring adaptation in typically-developing children aged 5-6 and in young adults as they walked at their preferred speed but at varying step frequencies. We tested the idea that when compared to adults, the higher net COT in children can be coupled to differences in how they operate the spring-like behavior of their legs. Preliminary results show that children operate their legs with a more compliant spring and significantly higher net COT.**

Keywords—child, walking, spring, biomechanics, cost of transport

I. Introduction & Methods

Prosthetics and orthotic devices are made to improve walking function and lower metabolic cost. While many devices succeed in improving function, there is mixed evidence on how well these devices lower cost in children [2]. Unfortunately, most devices built for children are scaled down versions of adult devices, which is based from the assumption that children move in effectively the same way as adults. Despite significant differences in physiological and biomechanical development, there has been little effort to model and translate these differences to the design of devices intended to normalize movement in children. A child-specific biomechanical framework that can guide the design of assistive devices would aid physicians, prosthetists, and orthotists in helping children achieve maximum walking function.

A. Spring Model of Walking

A spring-based model of walking recognizes the importance of storing and releasing energy in the body's elastic elements and has proven useful in scaling for robotic applications and advanced walking simulations of adults [3,4]. In the bipedal spring-mass model [3], two independent spring legs are attached at the center of mass (COM). Changes in touchdown angle and spring constant, k, produce realistic ground reaction force (GRF) patterns at different speeds. In our experiment, changes in step length led to changes in touchdown angle, which allowed us to calculate changes in k and empirically test the parameters and scaling of the bipedal spring mass model.

B. Experimental Procedure and Analysis

Subjects (8 children/8 adults) walked on an instrumented treadmill for 5 minutes at 3 step frequencies (75%, 100%, and 125% of preferred). Metabolic consumption was measured during each trial with indirect calorimetry (Parvo Medics). Marker positions placed on the lower body and subject-specific location of the COM were recorded with a Vicon 12-camera system. We used the double integration method to obtain the change in position of the COM and defined a vector to the center of pressure to represent the spring in the sagittal plane. We then calculated k from the slope of the GRF vs. spring length curve. We used a general linear model design to compare net cost of transport (COT) between children and adults, and in the future will compare k and touchdown angle of the leg.

II. Initial Results and Discussion

From our preliminary results, plots of GRF vs. spring length during single support show typical spring-like behavior. Slopes representing k are within the range of values predicted by the model for adults, while child plots are less consistent and exhibit more hysteresis (data not shown). As expected, the net COT across all 3 step frequencies was higher in children ($p<0.001$) and higher in both groups when walking at non-preferred step frequencies ($p=0.001$;Table 1). After completing analysis, we expect to better understand: 1) whether children walk in a similar spring-like manner as adults, 2) how children modulate k at different step frequencies, and 3) how changes in k are related to changes in net COT.

TABLE I. COST OF TRANSPORT VS STEP FREQUENCY

Group	Mean Net Cost of Transport J/kg/m (SEM)		
	Preferred frequency	***75%***	***125%***
Child	4.09 (0.32)	5.04 (0.41)	4.78 (0.31)
Adult	2.24 (0.09)	3.62 (0.16)	2.88 (0.15)

References

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