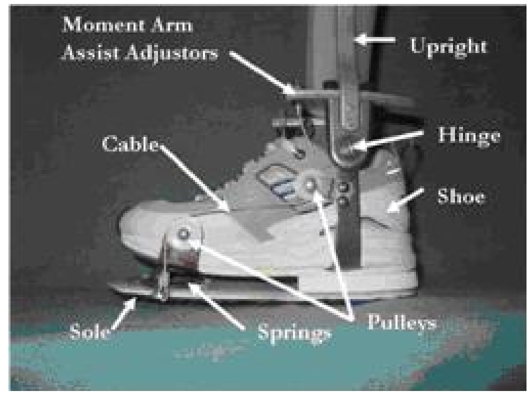
NSF Highlights

5342 - Bennett - Energy Returning Ankle Foot Orthosis

Highlight ID: 16763



Protoype III built into shoe employing coil springs for energy return for dorsiflexion assist.

Permission Granted
Credit: Bradford C. Bennett, University of Virginia

Background: Individuals with walking disabilities, as a result of cerebral palsy (CP), stroke, muscular dystrophy, brain injury, and many other conditions, are often prescribed ankle foot orthoses (AFOs) to aid in their walking. The large number of individuals with CP that use AFOs highlights the magnitude of the problem. United Cerebral Palsy reports that an estimated 764,000 people in the United States have one or more symptoms of CP. It has been reported that more than 50% of these individuals are prescribed orthoses. Even with AFOs children with CP commonly expend two to three times as much energy to walk as typically developing children. This large effort to walk can limit their participation in society and even lead to dependence on a wheelchair. There is a major need to provide mechanically advanced and optimized orthoses that can improve the walking capabilities of individuals with disabilities.

The research focuses multi-disciplinary expertise to develop an adaptive energy returning AFO design that is customized to an individual and the characteristics of their gait.

Results: This project has made significant progress in the understanding of gait of children with CP and the ability of AFOs to assist in their gait. In the last year a third energy returning prototype was developed by the Bennett research team at the University of Virginia. This prototype was unique in that it was built into a shoe and it focused on the ability to assist dorsiflexion during swing. Dorsiflexion assist is important to promote heel strike over an equinus gait[**1**] and thus reduce the metabolic cost of walking. Many children with CP have an equinus gait where foot contact does not occur at the heel, but on the forefoot. The research team showed in earlier work[**2**], which was partly funded by this NSF project, that even adults without disability had a more than 50% increase in metabolic costs when they had an equinus gait. Testing is currently ongoing.

A parallel effort has included development of patient specific biomechanical models of walking, with the ability to incorporate devices and their effects into the models. The Lifemod/MSC.ADAMS software package was used to develop these models.

In the past year the research team has examined the possibility of using angular momentum for forward dynamic walking simulations. The Bennett team analyzed data of individuals walking at 0.7, 1.0 and 1.3 times their comfortable walking speed and discovered that angular momentum primitives were invariant with velocity and a suitable candidate for controlling simulations. Specifically, the team found that the non dimensional angular momentum of all the body segments about the body's center of mass were similar between individuals with a correlation coefficient[**3**] of 0.94 or greater in each of the frontal, transverse (crosswise), and sagittal (side) planes. A principal component analysis (PCA) revealed that a reduced set of three basis vectors could explain more than 95% of the angular momentum data of the 12 body segments used to model the body.

In addition, the unit basis vectors generated by the PCA were similar at the different walking speeds, as the dot products of the basis vectors of the first three PCs between speeds for each subject was 0.97 or greater. Thus, the angular momentum primitives were found to be similar between individuals, independent of walking velocity, and could be represented by a reduced set of information. Hence they would seem to be excellent candidates for control parameters for forward dynamic walking simulations. The team is presently exploring this option. The research team also examined the relationship of angular momentum of children with CP compared with typically developing children and found similar results.

Definition and References for above:

[**1**] **Equinus gait**, a common movement abnormality among individuals with stroke and cerebral palsy, has initial foot contact on the forefoot instead of on the heel during normal gait. It relates to a shortened calf muscle length and often develops into a fixed deformity that requires surgical correction.

[**2**] Herndon SK, Bennett BC, Wolovick A, Filachek A, Gaesser GA, Weltman A, Abel MF, "Center of mass motion and the effects of ankle bracing on metabolic cost during submaximal walking trials." Journal of Orthopaedic Research 2006; 24: 2170-2175

[**3**] Gerstenfeld EP, Dixit S, Callans DJ, Rajawat Y, Rho R, Marchlinski FE, "Quantitative comparison of spontaneous and paced 12-lead electrocardiogram during right ventricular outflow tract ventricular tachycardia." J Am Coll Cardiol 2003; 41: 2046-2053

This work was presented at meetings:

1) Bennett BC, Russell SD, Ledoux A, Sheth P &. Abel MF, "Angular Momentum During Gait Of Children With Cerebral Palsy," GCMAS Annual Meeting, April 2008.

2) Russell SD, Bennett BC, Ledoux A, Sheth P &. Abel MF, "Angular Momentum Control Of Forward Dynamic Walking," GCMAS Annual Meeting, April 2008.

3) Alexandre Ledoux, Bradford Bennett, Shawn Russell, Pradip Sheth, Mark Abel, "Angular momentum control of forward dynamic walking," 2007 Annual Meeting of the American Society of Biomechanics, Stanford University, August 2007

This work was the subject of one PhD Thesis and one Senior Thesis:

1) Ledoux AF, "Subject-specific dynamic modeling of normal and pathological human gaits," PhD Dissertation, Department of Mechanical and Aerospace Engineering, University of Virginia, May 2007.

2) Marie Adeyemi, "Design and Evaluation of Passive and Active Ankle Bracing Devices for Cerebral Palsy," Senior Thesis, Department of Mechanical and Aerospace Engineering, University of Virginia, May 2007.

Related papers are in preparation:

1) Bennett BC, Russell SD, Ledoux A, Sheth P, and Abel MF, "Characterization of pathological gait using angular Momentum," In preparation.

2) Ledoux A, Sheth P, Bennett BC and Abel MF, "3-D human modeling procedure using PD control to compute ground reaction forces", In preparation.

3) Bennett BC, Russell SD, Sheth P &. Abel MF, "The invariance of angular momentum primitives with walking speed," In preparation.

Primary Strategic Outcome Goal:

- Disciplinary/Interdisciplinary Research (Anything not covered by one of the 12 categories below.)

Secondary Strategic Outcome Goals:

- Undergraduate Education
- Graduate Education

How does this highlight address the strategic outcome goal(s) as described in the NSF Strategic Plan 2006-2011?:

This highlight addresses the strategic outcome goals of the NSF Strategic Plan 2006-2011 as follows:

1) **Discovery**: This research advances both the design of ankle foot orthoses and the ability to perform forward dynamic walking simulations without the use of supercomputers. Currently, the properties of ankle foot orthoses for children with CP are made to general subjective criteria. The Bennett team has developed metrics, angular momenta and the corresponding internal and external work for gaits which will allow a more objective evaluation of the gaits of children with CP and the effects of interventions on their gait. In addition, the modeling will allow the team to "implement" interventions in the model to assist clinicians in determining the optimal intervention, i.e. the stiffness of an ankle foot orthosis, for each individual. This will eventually benefit children with CP and others with walking disabilities obtain improved customized walking aids.

2) **Learning**: This project includes participation of undergraduate students, graduate students from engineering and medicine.

Does this highlight represent transformative research? *If so, please explain why.*
The National Science Board has defined transformative research as "Research that has the capacity to revolutionize existing fields, create new subfields, cause paradigm shifts, support discovery, and lead to radically new technologies." National Science Board: Enhancing Support of Transformative Research at the National Science Foundation

Yes

The development of computationally inexpensive forward dynamic walking simulations will change the way in which walking disabilities are evaluated and treated.

Does this highlight represent Broadening Participation? *If so, please explain why.*
The concept of broadening participation includes: individuals from underrepresented groups, certain types of institutions of higher education, geographic areas (e.g. EPSCoR states), and organizations whose memberships are composed of institutions or individuals underrepresented in STEM or whose primary focus is on broadening participation in science and engineering. It is important to note that underrepresented groups vary within scientific fields.

Yes

Three female undergraduate students have worked on this project.

Are there any existing or potential societal benefits, including benefits to the U.S. economy, of this research of which you are aware? *If so, please describe in the space below.*
It is important for NSF to be able to provide examples of NSF-supported research that have or may have societal benefits.

Yes

This project benefits society by creating devices that can increase the participation of children with CP, and other walking disabilities that need ankle foot orthoses, in society. A patent has been filed on the technology in the United States. Additional benefits could be achieved by applying the modeling technology to improve other assistive devices.

ENG/CBET 2008

Program Officer: Marshall Lih

NSF Award Numbers:

0503256

Award Title:	Optimized Variable Stiffness Energy Returning Ankle Foot Orthosis
PI Name:	Bradford Bennett
Institution Name:	University of Virginia Main Campus
PE Code:	5342

NSF Contract Numbers:

NSF Investments: Understanding Complex Biological Systems (including the interfaces of life, physical, and computational sciences)

Submitted on 03/12/2008 by H. R. Gage
CBET: Approved 03/12/2008 by Robert M. Wellek
ENG: Approved 03/12/2008 by Joanne D. Culbertson