REQUEST FOR PILOT GRANT PROPOSALS IN NINE POTENTIAL AREAS OF ORTHOTIC AND PROSTHETIC (O&P) RESEARCH

(This form should be used as the first page of your application.)

The Center has identified nine areas for potential submission of proposals.

Areas for submission are:

a. Microprocessor Knee – Stumble Recovery Benefit for Non-Variable Cadence Ambulators, and Does Restricted Access for K-1 and K-2 to Hydraulic Controls Adversely Impact Patient Safety?
b. TLSO/LSO: Utilization and comparative effectiveness of TLSO/LSO. Pre and post operative use. Efficacy of custom vs OTS relating to clinical outcome, analyses of providers credential.
c. Socket Interface: Methods for Measuring Proper Socket Fit and Alignment.
d. Vacuum-Assisted Socket Suspension Systems
e. AFO/KAFO: Utilization and comparative effectiveness of custom vs OTS AFOs and KAFOs. Investigation and analyses of patients who receive custom orthosis subsequent to OTS AFO fitting.
f. L0631 bracing—Performance and Outcomes Data That Differentiate Patient Results from What Could be Achieved with an OTS Orthosis that is Provided without any Fitting, Trimming or Clinical Care?
g. Quality of Life, Wellness, Patient Satisfaction and/or Outcomes Studies of Patients Who Have Received O&P Care vs. Those Who Have Not.
h. Outcomes Measures, Evaluation and Quality of Life Metrics Related to Orthotic Management (Note: Submissions Should be Pathology and/or Condition Related,.e.g. Stroke, Cerebral Palsy, Multiple Sclerosis, Polio, OA)
i. Open Topics – Beyond the Above Priorities, Top Quality Clinical O&P Research Topics Considered

AOPA reserves the right not to select for funding any of the proposals received. While funding is available, decisions will be made on the merits of the proposals.

TITLE OF PROJECT: Influence of Spasticity on Asymmetric Gait

INVESTIGATORS:

Name(s): (list Principal investigator on line 1)
1. Kyle B. Reed
2. Seok Hun Kim
3.
4.

FUNDS REQUESTED: $15,000

NAME OF RESPONSIBLE INVESTIGATOR: ______________________
(to be completed if Principal Investigator is a trainee)

IRB STATUS:

Approved	Pending	Approval Not Required
	X	

CONFLICT OF INTEREST:

None	Potential	Yes
X		

As the principal (or responsible investigator, if applicable), I agree that if this grant proposal is funded, I will acknowledge the AOPA's support in all publications that arise from the research. I also will submit to AOPA a final report within 12 months after the date of the award.

Signature of Principal Investigator: ______________________

Signature of Responsible Investigator (required if Principal Investigator is a trainee):

____

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Abstract

Individuals who have had a stroke often have neuromuscular weakness or paralysis on one side of the body caused by some muscles disengaging and over-excitation of other muscles. This study involves the development of a small and lightweight knee orthosis consisting of a variable spring-damper mechanism that adds stiffness and damping at the knee joint. This orthosis could be fitted onto one leg of an able-bodied person to simulate stroke-like gait. Using able-bodied individuals reduces many of the confounding effects that present in stroke patients. These different effects lead to dissimilar compensatory mechanisms, which lead to contradicting results in the literature. The proposed orthosis will allow researchers to systematically study how different levels of stiffness and damping correlate to a commonly used measure of spasticity: the Modified Ashworth Scale (MAS). A physical therapist who is blinded to the damping/stiffness level of the orthosis will evaluate the subject who is wearing the orthosis using the MAS. The dynamic effects that will be investigated are damping, catch, hysteresis, and stiffness. The force and range of motion data of the subjects fitted with the orthosis during walking will be collected using the Computer Assisted Rehabilitation Environment System.

Research Grant Proposal

1.1. Specific Aims

The goal of this research is to quantify the Modified Ashworth Scale (MAS) (Bohannon and Smith 1987) and to understand how spasticity affects asymmetrical gait patterns. To achieve this goal, this project will use a stroke simulator to evaluate how different levels of spasticity change one's gait patterns on healthy subjects. Using healthy subjects will allow a more systematic change compared to the variability of individuals who have gait impairments from stroke.

Aim 1: Knee Orthotic with Variable Damping and Stiffness

The damping and stiffness of a joint on a person with a stroke is often described using the MAS, which is a clinical measure of spasticity ranging 0-4 levels but this scale has never been quantified with physical measures, only subjective measures (Bohannon and Smith 1987; Abolhasani et al. 2012). Having specific values associated with the MAS would allow for a more personalized design of orthotics that could lead to better functional walking. This proposed research aims to develop a custom knee brace that has a variable stiffness and damping at the joint. The knee brace would enable investigators to systematically measure and obtain a physical therapy perspective on the damping and stiffness of various levels of spasticity following stroke. **The results will help objectively quantify the MAS measurements.** Figure 1 shows an initial prototype of the stroke simulator, which will be modified to enable variable damping and stiffness.

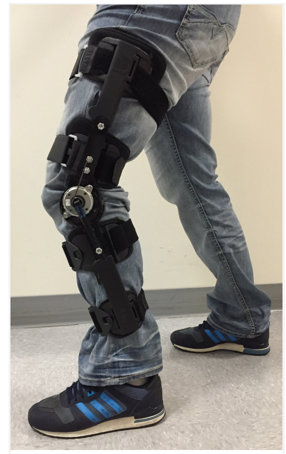

Figure 1: Stroke simulator prototype consisting of a damper and spring mounted at the knee joint.

Aim 2: Analyzing Asymmetries in Gait Patterns

Much of walking is dictated by the passive dynamics of the legs and body (Donelan et al. 2002), which generally leads to symmetric walking when the physiological conditions of both sides of the body are the same. In an asymmetrically impaired individual, asymmetric control effort is needed to generate symmetric motions. These compensatory motions (i.e., using alternate movements to make up for disabilities) are common in individuals with unilateral disabilities and often cause premature deterioration, back pain, and stresses on the sound limb. This aim focuses on how asymmetric physical properties affect gait patterns. **Hypothesis: An individual with unilateral lower limb spasticity cannot sustainably achieve a temporally, spatially, and kinetically symmetric gait.**

1.2. Background/Significance

The smooth coordinated control of the limbs during walking is frequently impaired following central nervous system damage, such as stroke, or physical changes, such as wearing a prosthesis. Able-bodied adults take equal-sized steps with each leg, offset by 180º (i.e., out-of-phase coordination). Individuals who have had a stroke or lower-limb amputation often deviate from perfect out-of-phase walking and have asymmetries in temporal (e.g., time spent in double-limb support) and spatial (e.g., step length) measures of interlimb coordination (Balasubramanian et al. 2007; Brandstater et al. 1983). An asymmetric gait pattern is common in amputees, but is more evident in transfemoral amputees (Gitter et al. 1995; Hoffman et al. 1997). The asymmetric effort causes wearers to exert a great deal of effort compensating for unwanted motions (Huang et al. 1979). In an individual with a stroke, the propulsive force of the paretic limb is less than the nonparetic limb, as are work and power of the paretic plantar flexors (Balasubramanian et al.

2007; Bowden et al. 2006). Vertical ground reaction forces also are decreased on the paretic limb relative to the nonparetic limb (Kim and Eng 2003), reflecting diminished weight-bearing by the paretic limb.

Asymmetric gait rehabilitation methods include circular treadmill locomotion (Gordon et al. 1995), split-belt treadmills (Reisman et al. 2005), split-motion training (Handzic et al. 2011), rhythmic cuing (Roerdink et al. 2007), balance training (Vashista et al. 2013; Kim and Reed 2013), and others (Belda-Lois et al. 2011). Traditional rehabilitation interventions typically are not effective at restoring symmetry (Vasudevan and Kirk 2014). Much of the recent work investigating gait rehabilitation has focused on two main outcome measures: velocity and symmetry. Walking velocity is indicative of overall gait performance and can differentiate levels of disability (Lord et al. 2004; Perry et al. 1995; Bowden et al. 2006). Symmetry, in contrast, measures the quality of gait (Dewar and Judge 1980; Patterson et al. 2008). Normal gait tends to be symmetric in the kinematics, dynamics, vertical forces, and spatiotemporal parameters between the two legs (Herzog et al. 1989; Titianova and Tarkka 1995). This proposed study will help us better understand how asymmetric spasticity affects these measures of gait.

This study will use the Computer-Assisted Rehabilitation ENvironment (CAREN) system. The CAREN has a split-belt treadmill system mounted on a six-degree of freedom motion base with motion capture cameras and instrumented force plates. The split-belt treadmill system has two separate moving belts that are able to move at two differing velocities. Split-belt treadmills are often utilized for rehabilitation of stroke patients that suffer from hemiplegia due to their ability to push one foot at a faster rate than the other, thus aiding in the correction of asymmetric gait patterns (Reisman et al. 2005, Handzic and Reed 2013). Spatial and temporal asymmetries in gait occur when the step length of one foot is not equal to that of the other (Olney and Richards 1996). While more exaggerated asymmetries occur in stroke patients and those who suffer central nervous system damage, some asymmetries are inherent in able-bodied persons.

2. Research Plan

Aim 1: Knee Orthotic with Variable Damping and Stiffness. Individuals with stroke have several confounding factors that affect their gait, such as spasticity, stiffness, muscle weakness, and impaired balance. Each of these factors causes some asymmetric alteration in the gait, but experiments on individuals with stroke make it difficult to disambiguate the effect of individual alterations. To control for these factors, we will use a stroke simulator that will be modified to include three levels of damping/stiffness applied to the knee joint ranging from minimal to medium encumbrance, approximating the levels of MAS corresponding to 1, 1+, and 2 (Bohannon et al. 1987). These three levels on the MAS correspond to individuals that are able to walk independently. The device will be designed to accommodate three levels of damping: ranging from 1 to 7N/m/rad in equal increments. The damping and stiffness will allow for the flexion at the knee joint to correspond with the limiting ranges of motion and nonlinear effects related to the varying levels of the MAS.

Aim 2: Analyzing Asymmetries in Gait Patterns. The proposed experiment will lead to the following expected results:

a. A quantification of the MAS to specific stiffness and damping values.
b. An evaluation of how gait patterns change as a function of known stiffness and damping.
c. An understanding of how physical asymmetries impact the adaptation of gait.

<u>Experimental procedure</u>: Six healthy participants will be made asymmetric by adding the stroke simulator to one of their knees. The protocol consists of the subjects performing the following:

1. Walk for 4 minutes without the stroke simulator (baseline).
2. Put on the stroke simulator and a physical therapist (blinded to stiffness/damping level) will evaluate the subject's knee on the MAS.
3. Walk for 4 min while wearing the stroke simulator (randomized MAS level of 1, 1+, or 2).
4. Repeat steps 2 and 3 for a total of three 4 minute walking sessions using different stiffness/damping levels.
5. Using only one level of stiffness/damping, the subject will then walk for ten minutes on the split-belt treadmill with the treads at different speeds as shown during 10-20 minutes in Figure 2(b). Data from a preliminary experiment (healthy male) with the stroke simulator prototype worn on the left leg is shown in Figure 2(a).

<u>Sample size justification</u>: Six subjects will be used in this experiment to counterbalance the order of application of the three levels of damping/stiffness for the 4 minute walking tests. Each level of damping/stiffness will be tested on two subjects for the final 10 minutes. A between-subjects design is used for the split-belt portion to reduce fatigue in the subjects.

<u>Preliminary results</u>: In an initial test, the stroke simulator demonstrated an asymmetric effect on the individual when wearing the orthosis on his left leg, as shown in Figure 2. When walking on tied belts (time<10min), the step length is about 5% asymmetric. Throughout all belt speed ratios, the peak pushoff forces were consistently shifted toward the left leg and the braking forces were consistently shifted toward the right leg. In addition, the step length does not respond equally in the two directions of asymmetric belt speeds. At time=12min, the step length difference is about 33%, but at time=17min, the difference is only about -15%. A symmetric person would be expected to have the same percentage asymmetry in each direction of belt asymmetry. Thus, there is a combined effect caused by wearing the stroke simulator and walking on the split-belt treadmill at the same time. The stiffness and damping of the subject's leg that was wearing the stroke simulator was estimated to be a 2 on the MAS.

<u>Future work</u>: This research will lay the foundation for future work on an actively-controlled orthosis that applies negative damping to assist individuals with stroke. Such an orthosis would counteract the effects of spasticity and enable more control. The research proposed here is a necessary first step since we first need to quantify and better understand the effects of spasticity on gait function.

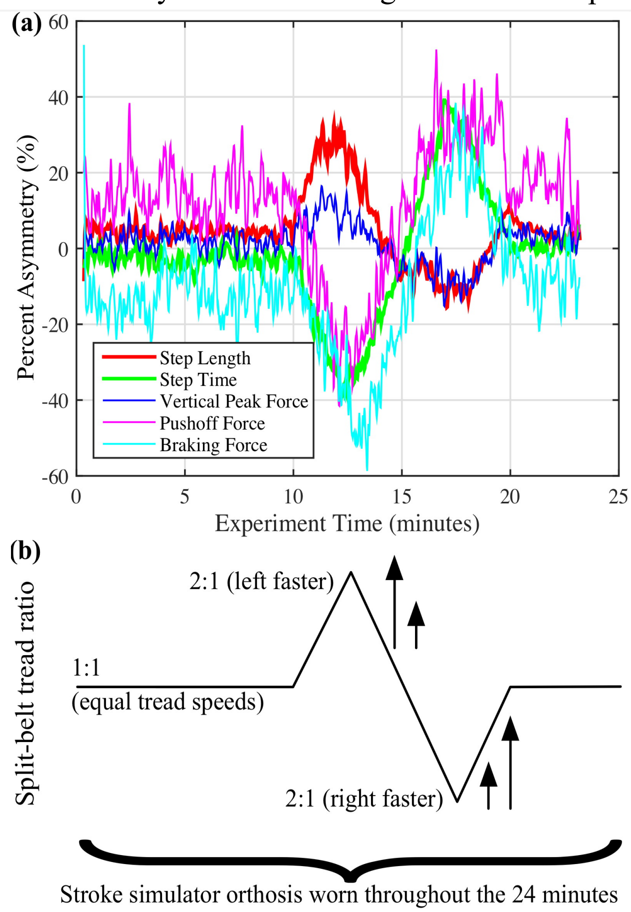

Figure 2: Preliminary results (a) of wearing the stroke simulator while walking on tied (0-10 min) and with 2:1 ratio speed treads (e.g., left fast from 10-15 min and right fast from 15-20 min), shown in (b).
% asymmetry=100*(Left–Right)/{mean(Left,Right)}

References

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Vashista, V.; Reisman, D. & Agrawal, S. (2013), "Asymmetric Adaptation in Human Walking using the Tethered Pelvic Assist Device (TPAD)" IEEE International Conference on Rehabilitation Robotics".

Vasudevan, E. V. & Kirk, E. M. (2014), Improving Interlimb Coordination Following Stroke: How Can We Change How People Walk (and Why Should We)? "Replace, Repair, Restore, Relieve–Bridging Clinical and Engineering Solutions in Neurorehabilitation," Springer, pp. 195–202.

Budget and Justification

Personnel Roles on Project:

- Graduate student (TBA co-advised by Dr. Reed and Dr. Kim), will work on device design and human experiments. Support of $12,241 is requested to cover the research assistant position.

Supplies:

- Funds of $2,759 are requested to cover the components necessary to build and test the stroke simulator as well as other lab incidentals used on this project.

Other Support

Current Support (Kyle B. Reed)

Grant: Moterum, LLC.
Principle Investigator: Kyle B. Reed
Dates: 6/16/2014 – 6/15/2015
Title: *Gait Enhancing Mobile Shoe for Stroke Rehabilitation*
This research will determine if gait training with the gait enhancing mobile shoe can benefit walking ability in individuals with stroke.

Grant: National Science Foundation (NSF) (1319802)
Principle Investigator: Kyle B. Reed
Dates: 8/1/13 – 7/31/16
Title: *HCC: Small: Perception of Accurate Interactions through Bimanual Integrated Forces and Motions*
The goal of this proposed research is to enable a person to recreate the actions performed and fully experience the forces that result from those actions as performed by another person. The proposed solution uses the inherent ability of humans to synchronize motions on both sides of their bodies. In contrast to methods that make the physical interaction with an environment realistic, this research aims to make the *perception* true to the original interaction.

Grant: National Science Foundation (NSF) Innovation Corps (I-CORPS) (1449772)
Principle Investigator: Kyle B. Reed
Dates: 7/1/14 – 6/31/15
Title: *Walking Crutch/Cane for Enhanced Walking Dynamics*
We interviewed 100 individuals that use crutches about their needs and desires related to walking on crutches. During this process, our concept changed to a more simplified and cost-effective add-on tip to a crutch that is able to generate an assistive force while walking. The concept is based on a Kinetic Shape that generates a rolling force based on the vertical force applied by the user's weight.

Grant: National Science Foundation (NSF) (1229561)
Principle Investigator: Rajiv Dubey
Role: co-PI
Dates: 9/1/12 – 8/31/15
Title: *MRI: Acquisition of a CAREN Virtual Reality System for Collaborative Research in Assistive and Rehabilitation Technologies*
This grant establishes a Virtual Reality (VR) system for interdisciplinary research, including the arts, physical therapy, medicine, and engineering. The VR system consists of a 180° screen, an instrumented split-belt treadmill mounted on a six degree-of-freedom movable base, and an optical motion tracker so the environment can respond to the individual's motions. This VR system will be an integral part of the research proposed here and will be used for some of the evaluation.

Grant: Orthotic and Prosthetic Education and Research Foundation (OPERF)
Principle Investigator: Seok Hun Kim
Role: co-PI
Dates: 12/2/14 – 12/1/15
Title: *Gait adaptation in transfemoral amputees using split-belt treadmill training*
Individuals with a transfemoral amputation frequently have an asymmetric gait. This project will evaluate if split-belt treadmill training can be used to change their gait patterns and induce a more symmetric gait pattern.

Completed Research Support (Kyle B. Reed)

Grant: National Institute of Health (NIH) (1R21HD066200-01)
Principle Investigator: Kyle B. Reed
Dates: 9/13/10 – 8/31/12
Title: *Gait Enhancing Mobile Shoe for Rehabilitation*

The objective of this research is to develop and test a passive shoe capable of long-term correction of individuals with asymmetric walking patterns. It is based on the concept of split-belt treadmills, but attaches the motion to the foot of the individual so rehabilitation can occur while walking over ground in any location, which improves the transference of the restored motion to walking over ground. A clinical trial (not funded as part of this NIH grant) is currently underway to evaluate the effectiveness of this shoe on stroke rehabilitation.

Current Support (Seok Hun Kim)

Grant: OPERF-2014-SGA-1
Principle Investigator: Seok Hun Kim
Dates: 12/2/14 – 12/1/15
Title: *Gait adaptation in transfemoral amputees using split-belt treadmill training*
The objective of this grant is to examine if a 2-week gait training program using a split-belt treadmill can enhance symmetry of gait patterns in people with unilateral transfemoral amputation.

Grant: Moterum, LLC.
Principle Investigator: Kyle B. Reed
Role: co-PI
Dates: 6/16/2014 – 6/15/2015
Title: *Gait Enhancing Mobile Shoe for Stroke Rehabilitation*
This research will determine if gait training with the gait enhancing mobile shoe can benefit walking ability in individuals with stroke.

Grant: National Science Foundation (NSF) (1229561)
Principle Investigator: Rajiv Dubey
Role: co-PI
Dates: 9/1/12 – 8/31/15
Title: *MRI: Acquisition of a CAREN Virtual Reality System for Collaborative Research in Assistive and Rehabilitation Technologies*
This grant establishes a virtual reality system for interdisciplinary research, including the arts, physical therapy, medicine, and engineering.

Completed Research Support (Seok Hun Kim)

Grant: DOD W81XWH-11-1-0748
Principle Investigator: William Quillen
Role: co-PI
Dates: 9/15/2011 – 9/14/14 (no-cost extension)
Title: *Metabolic and biomechanical measures of gait efficiency of three multi-axial, vertical shock and energy storing-return prosthetic feet during simple & complex mobility activities*
The objective of this grant is to determine if gait training with the gait enhancing mobile shoe can benefit walking ability in individuals with stroke.

Grant: DOD W81XWH-11-1-0634
Principle Investigator: William Quillen and Paul Sandberg
Role: co-PI
Dates: 9/15/2011 – 9/14/14 (no-cost extension)
Title: *Occurrence of Impairments in Balance, Gait, Vestibular & Hearing Functions*
This research will examine the occurrence of impairments in balance, gait, vestibular and hearing functions in USF student OEF and OIF veterans compared to a control group of non-veteran students

BIOGRAPHICAL SKETCH

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person. **DO NOT EXCEED FIVE PAGES.**

NAME: **Kyle B. Reed**

eRA COMMONS USER NAME (credential, e.g., agency login): **KYLE.REED**

POSITION TITLE: **Assistant Professor of Mechanical Engineering**

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	Completion Date MM/YYYY	FIELD OF STUDY
University of Tennessee, Knoxville, TN	B.S.	05/2001	Mechanical Engineering
Northwestern University, Evanston, IL	M.S.	12/2004	Mechanical Engineering
Northwestern University, Evanston, IL	Ph.D.	05/2007	Mechanical Engineering
The Johns Hopkins University, Baltimore, MD	Postdoc	2007-2009	Medical Robotics

A. Personal Statement

Based on my broad background in Mechanical Engineering with training in biomechanics of movement and experience on numerous interdisciplinary research teams, I am well suited to work on this research on gait rehabilitation for individuals with stroke. My research on physical human-robot interaction involved collaborations among several fields, so I am accustomed to working with psychologists, neuroscientists, and physical therapists. The project team proposed here combines my expertise in developing devices related to rehabilitation and human-robot interfaces with Dr. Kim's expertise in balance control and rehabilitation.

B. Positions and Honors

Positions and Employment

1998 – 2001	Research Engineer, Los Alamos National Laboratory
2002 – 2007	Research Assistant, Northwestern University
2007 – 2009	Postdoctoral Fellow, The Johns Hopkins University
2009 – present	Assistant Processor, University of South Florida

Honors and Professional Memberships

2001	National Science Foundation Graduate Research Fellowship Awarded
2005 – present	Member, Institute of Electrical and Electronics Engineers (IEEE)
2006 – present	Member, American Society of Mechanical Engineers (ASME)
2010 – present	Charter member of the IEEE Robotics and Automation Society Florida West Coast Section

C. Contributions to Science

Asymmetric Gait Rehabilitation with the Gait Enhancing Mobile Shoe (GEMS):
Certain types of central nervous system damage, such as stroke, can cause an asymmetric walking gait. One rehabilitation method uses a split-belt treadmill to help rehabilitate impaired individuals. The split-belt treadmill causes each leg to move at a different speed while in contact with the ground. The split-belt treadmill has been shown to help rehabilitate walking impaired individuals on the treadmill, but there is one distinct drawback; the corrected gait does not transfer well to walking over ground. To increase the gait transference to walking over ground, we designed and built a passive shoe that admits a motion similar to that felt when walking on a split-belt treadmill. The gait enhancing mobile shoe (GEMS) alters the wearer's gait by causing one foot to move backward during the stance phase while walking over ground. No external power is required since the shoe mechanically converts the wearer's downward and horizontal forces into a backward motion. This shoe allows a patient to walk over ground while experiencing the same gait altering effects as felt on a split-belt treadmill,

which should aid in transferring the corrected gait to walking in natural environments. A clinical trial (NCT02185404) is currently underway to evaluate the effectiveness of the shoe on individuals with stroke.

1. I. Handzic, E. Barno, E. V. Vasudevan, and **K. B. Reed**. "*Design and Pilot Study of a Gait Enhancing Mobile Shoe*," Journal of Behavioral Robotics, Special Issue on Assistive Robotics, Vol. 2, Num. 4, pp. 193-201, 2011.
2. I. Handzic, E. Vasudevan, and **K. B. Reed**, "*Motion Controlled Gait Enhancing Mobile Shoe for Rehabilitation*," Proc. of the 12th Intl. Conf. on Rehabilitation Robotics (ICORR), Zurich, Switzerland, June, 2011.
3. I. Handzic and **K. B. Reed**. "*Kinetic Shapes: Analysis, Verification, and Applications*," ASME Journal of Mechanical Design, Vol. 136, No. 6, pp. 061005(1-8), 2014.
4. "Gait-Altering Shoe," **K. B. Reed** and I. Handzic, patent pending, 2012.

<u>Asymmetric Passive Dynamic Walking:</u>

A Passive Dynamic Walker (PDW) is a mechanical biped that walks down a declined slope solely by the energy added by gravity, swinging its lower limbs just as human would while walking. In contrast to humanoid robots, which are typically in static equilibrium, humans and the PDW have a portion of the gait cycle in dynamic equilibrium (i.e., controlled free fall). People that have experienced a stroke or neurological trauma often develop an asymmetric walking pattern (hemiparesis), inhibiting their everyday mobility. This research is evaluating the dynamics of such impairments and how to apply the most effective rehabilitation dynamics for proper rehabilitation. The PDW model is used to simulate and analyze the walking dynamics and the effectiveness of various rehabilitative dynamics (split-belt treadmills, GEMS, etc.) onto the "impaired" model, hence, rehabilitating it back to normal gait. Unlike other approaches, this approach focuses on the mechanical kinematics and kinetics while intentionally leaving out the cognitive variable. The cognitive aspect will be tested on humans using the methods that have the highest likelihood of working based on the dynamic analysis, thus reducing the amount of human subject testing required. The model has also been used to evaluate how people perceive asymmetric impairments to find out how much asymmetry can be present without being noticeable.

- J. Sushko, C. Honeycutt, and **K. B. Reed**. "*Prosthesis Design Based on an Asymmetric Passive Dynamic Walker*," Proc. of IEEE RAS/EMBS Intl. Conf. on Biomedical Robotics and Biomechatronics (BioRob), Rome, Italy, June, 2012.
- I. Handzic and **K. B. Reed**, "*Validation of a Passive Dynamic Walker Model for Human Gait Analysis*", in Intl. Conf. of the IEEE Engineering in Medicine and Biology Society (EMBC), Osaka, Japan, 2013.
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<u>Human-Robot-Human Interactions</u>

In many everyday tasks two people interact with each other. People move a large object, an instructor helps a student learn to swing a tennis racquet, and physical therapists help a patient learn to move correctly after an accident. Many of these tasks could potentially be replaced with a robot teaching an individual that task. A necessary first step is to understand human-human physical cooperation, so this research measures the haptic interaction of dyads jointly working on a task. This work has discovered that dyads are faster than individuals, dyad members temporally specialize, and similar key differences between human-human and human-robot interaction that should enable improved human-robot interaction.

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Needle Steering

This work focuses on improving the accuracy of steerable needles for prostate brachytherapy and liver biopsies. As the steerable needle is pushed into a tissue, the bevel at the needle tip generates asymmetric forces. Rotating the needle controls the direction of the asymmetric forces and, thus, which direction the needle will bend. Due to friction between the tissue and the needle, the angle at the needle tip lags the angle at the needle base causing the needle to veer off course. Part of this work includes the development of a compensation controller to correct the trajectory of the needle by analyzing the mechanics of the needle and tissue-needle interaction. This controller is integrated with a visual servoing control algorithm and a non-holonomic path planner to maneuver the needle tip into a prescribed target while avoiding obstacles.

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Bimanual Haptics

Humans have an inherent ability to synchronize the motions of both hands in space; note how easy it is to simultaneously draw a circle with both hands. This ability is being explored in two domains: upper-limb rehabilitation and in training of new skills. When teaching a physical skill, it is difficult to simultaneously convey the subtle forces and motions of a task to another person. One reason for the difficulty is that a force applied passively to a person is perceived differently than the same force when a person actively applies it. The proposed bimanual method allows one person to independently generate the desired path while feeling the task-related forces actively. In this way, one arm will both receive forces while actively generating motions and will fully experience the task forces. In rehabilitation, the same ability allows the healthy arm to self-rehabilitate the impaired arm when externally coupled through a training device. Self-rehabilitation using bimanual rehabilitation is ideal for home use since much of the required force could be provided by the person’s sound limb and minimal, or no, external assistance would be required from a caregiver or a motor.

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