Capabilities

Communicating the Science of Prosthetics and Orthotics

NORTHWESTERN UNIVERSITY

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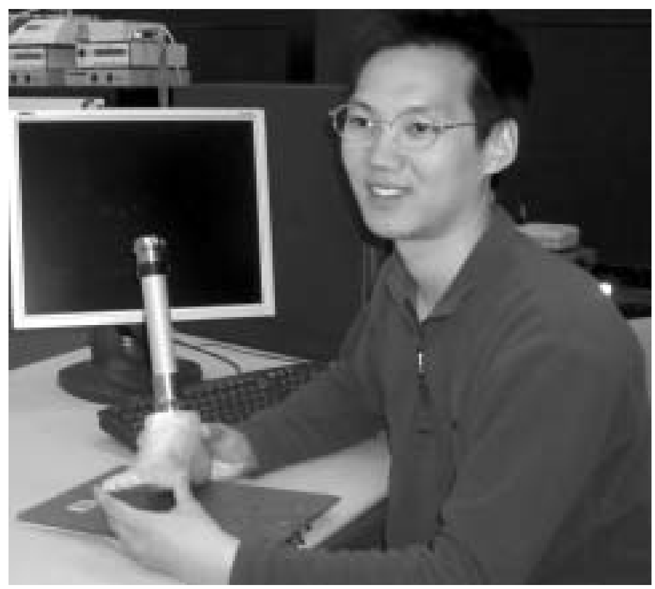
Focus on Research

This issue of *Capabilities* spotlights the work of two individuals, **Jonathon W. Sensinger, M.S.** and **Po-Fu-Su, M.S.**, both of whom recently defended their Master's theses in the Department of Biomedical Engineering at Northwestern University.



Capabilities features the research of **Jonathon W. Sensinger, M.S.** In 2002, he received a B.S. degree in Engineering from the University of Illinois, Chicago. For his doctoral work, he is investigating nonbackdrivable impedance control for use as a control paradigm in prostheses. Originally from Liverpool, New York, Jon enjoys backpacking, kayaking and reading. He and his wife reside in Chicago.

Capabilities features the research of **Po-Fu Su, M.S.** Following his graduation from National Taiwan University, Taipei, with a degree in Physical Therapy, Po-Fu focused on rehabilitation through biomedical research. His extracurricular interests include playing the strategy game, *go*, basketball and swimming. He enjoys traveling throughout the U.S.A. and Japan. Po-Fu and his wife, who is a Physical Therapist, have a 7-month old son and reside in Chicago.

May the Force Be with You:

Physiologically Appropriate Prostheses

Jonathon W. Sensinger, M.S.

Richard R. F. *ff* Weir, Ph.D.

Muscles generate force. Because they are linked to masses (your arm, for instance), motion may occur. Electrically powered prostheses start out on the right foot: they generate force too. The similarity ends there, however. DC motors work best when they spin fast, whereas muscles work best when they move at low speeds. As a result, muscles sacrifice force to get speed, whereas DC motors sacrifice speed to get force. The result is that DC motors are very good at positioning a device (since position error is reduced by the gear transmission), but at the same time have very bad force control (since any force error is amplified by the gear transmission). This means that by the time the user sees the motor in motion, it is no longer controlling force: it is now controlling position.

Why does it matter if force causes movement, or movement causes force? The answer depends on what you are trying to do, and whether or not you like to be in control. Let us assume you are tossing a football around. The football has inertia: when you exert a force on it, it moves. If it did not weigh anything, then you would not have to exert a force, but since before the apple struck Newton, people have had no choice but to generate force to toss footballs. Now imagine that the football in your hand suddenly turns into a rocket, a rocket that already has been ignited. The rocket generates a force, and you have two options: you can try to control the force, in which case one of you will have to give up; or you can allow the rocket to control the force, and you can control the position of the rocket instead.

What does all this mean? It means that if you toss rockets around for fun, then you probably want to control position. If you normally interact with inertial objects, however, then you want to control the force exerted on the object, though you certainly want to monitor the position. Such an approach is termed Impedance control, as advocated by Hogan (Hogan, 1976, Hogan and Mann, 1980a, b, Hogan, 1982).

Aside from the fact that most people would rather toss footballs than rockets, Impedance control has particular relevance to electrically controlled prostheses because they do not have proprioceptive feedback. Feldman and Bizzi's research has suggested that even in the absence of feedback accurate trajectories may be achieved (Bizzi, Hogan and Mussa-Ivaldi, 1992, Bizzi, Polit and Morasso, 1976, Feldman, 1966a, b, 1974, Mussa-Ivaldi, Hogan and Bizzi, 1985, Polit and Bizzi, 1978, 1979).

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The Effects of Increased Prosthetic Ankle Motions on the Gait of Persons with Bilateral Transtibial Amputations

Po-Fu Su, M.S.

Steven A. Gard, Ph.D.
Robert Lipschutz, CP
Todd Kuiken, M.D., Ph.D.

Introduction

The provision for prosthetic ankle motion may be important when fitting persons with leg prostheses, particularly if they have bilateral leg amputations. Increased prosthetic ankle motion appears to improve the gait of persons with unilateral transtibial (TT) amputation, but the improvements are limited and inconsistent between studies (Hafner et al., 2002; Lehmann et al., 1993). The purpose of this study is to determine if increased prosthetic ankle motion in persons with bilateral TT amputations significantly improves their walking performance. Information from this study may be useful for improving the designs of prosthetic ankles and feet, and for helping establish guidelines for prosthetists fitting persons with lower-limb amputation.

Figure 1: *Endolite Multiflex Ankles. This picture was taken from www.endolite.com/multiflex.htm*

Research Methods

Data were collected from 12 people with bilateral TT amputations. The subjects in the study were divided into two groups based on their etiology of amputation. The TRA group had their amputations due to trauma and the PVD group had their amputations due to peripheral vascular diseases. The average age of the six TRA subjects was 45.7 years old, and was 66.0 years old for the six PVD subjects. There were four phases in the study, each lasting a minimum of two weeks. Initially, subjects were fitted with Seattle LightFoot II feet and they walked with them for two weeks prior to the baseline gait analysis. During the gait analysis, subjects walked at their self-selected slow, normal and fast walking speeds while data were recorded. Afterwards, subjects were randomly fitted with either Endolite Multiflex Ankles ('flexion unit', Figure 1) or Otto Bock Torsion Adapters ('torsion

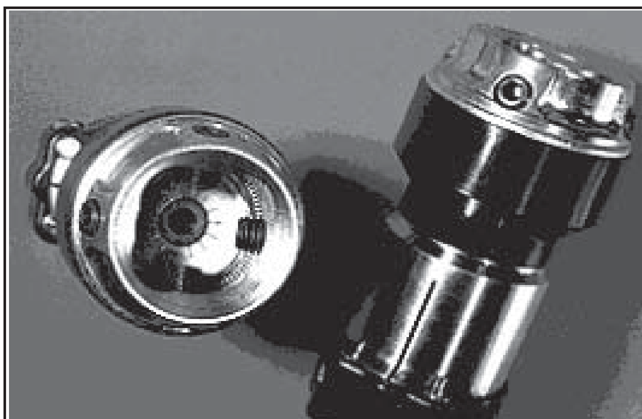

Figure 2: *Otto Bock Torsion Adaptors. This picture was taken from http://www.ottobockus.com/products/lower_limb_prosthetics/adapters_torsion.asp*

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Pratt and Williamson developed an elegant way to generate force control from traditional motors by inserting a spring on the end of the motor (Pratt, 2000, Pratt and Williamson, 1995, Pratt, et al., 1995, Williamson, 1995). Because $F = kx$, the accurate position input will be translated to an accurate force output. It seems like a great idea, but in the robotics community, most people are not comfortable with the concept of introducing compliance in the system, because adding a spring makes the system sluggish and uncontrollable. Pratt and Williamson were able to get around that requirement, at least in the frequency bandwidth that people normally operate at, by having the motor go limp when it is shut off. This is great news for the robotics community, but not useful to the prosthetics community, because most people like to get a cup of coffee and then turn their motor off so they do not have to recharge the battery every 20 minutes without spilling their coffee as their arm goes limp.

To accomplish force control while remaining stiff when the power is shut off, a design is proposed that uses a Harmonic Drive gear transmission to prevent backlash while at the same time creating a non-backdrivable transmission for small torques. Instrumenting the Harmonic Drive itself was investigated, but while the authors were able to decrease the inherent torque ripple associated with that technique, they concluded that the torque resolution was inadequate for low magnitude torque control (Sensinger, 2005, Sensinger and Weir, 2004a).

The stiffness of the torsional spring has a direct effect upon the large-force bandwidth of the actuator. At the same time, the torsional spring must be compliant in order to obtain large deformation to maximize the signal to noise ratio. Thus, a torsional spring with a highly resilient geometric cross shape is called for. The authors have modeled the cross-shape commonly used else where, and suggest an improved shape termed a *spandrel* that will be discussed later (Sensinger, 2005, Sensinger and Weir, 2004b).

A bench-top actuator, *BT1*, has been designed and fabricated to illustrate the feasibility of the concept, as shown in Figure 1.

The torsional spring was instrumented with strain gauges to provide torque control. The strain gauges were configured in a Wheatstone bridge and fed through an instrumentation amplifier.

Discussion

The actuator has larger maximum torque, speed, and power than the rotary *Series Elastic Actuator* created by Williamson (Williamson, 1995), but the cutoff frequency is not as high as that of Robinson's linear SEA (Robinson, 2000). Williamson did not report a single cutoff frequency, recognizing that the cutoff frequency is a function of generated torque. Williamson used a swept sine wave to generate his frequency response, something the author would not do as it creates a time dependent feature in the data.

Closed-form equations that accurately describe the stiffness and maximum shear stress placed upon the specialized elastic element were obtained during the

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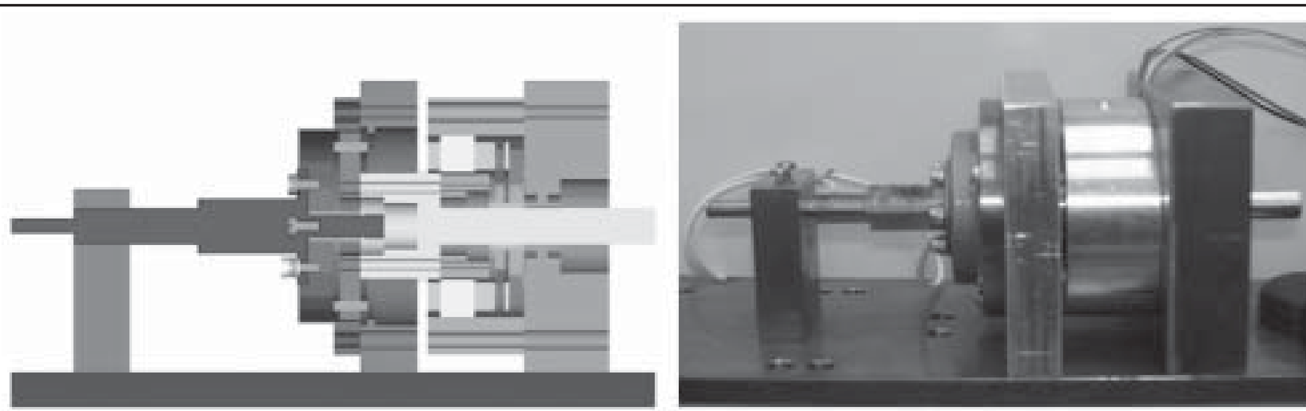

Figure 1: BT1: Bench-top prototype

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course of these experiments. The authors have found that a modified shape, termed a *spandrel*, offers improved resiliency, and propose to use this geometric cross section in future designs to increase the robustness of the design (Sensinger, 2005, Sensinger and Weir, 2004b). The cross section of the *spandrel* is illustrated in Figure 2.

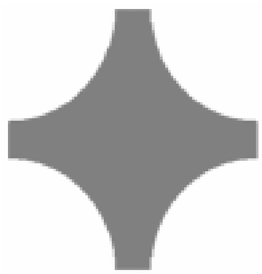

Figure 2: Spandrel Cross Section

Conclusions

In conclusion, this paper has demonstrated that non-backdrivable *Series Elastic Actuators* can be realized with adequate frequency resolution to have potential in the realm of prosthetics. Non-backdriveability is critical in the realm of prosthetics. The implementation of torque control will open new avenues of control of prosthetic devices and potentially make prostheses more biomimetic in the future.

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unit', Figure 2) for the 2nd phase. The flexion unit provides plantarflexion/dorsiflexion movement with a small amount of inversion/eversion and transverse rotation. The torsion unit provides up to 20° of internal and external rotation. Subjects returned two weeks later for the 2nd gait analysis, after which the first set of ankle units were removed and the subjects were fitted with the second set of ankle components. The protocol was repeated for the 3rd phase of the study. In the 4th phase, subjects walked with both sets of ankle components. Immediately following each gait analysis, questionnaires were administered to the research subjects to record their perceptions of walking with the different prosthetic configurations.

Our findings

The results of the study showed that the self-selected normal walking speeds of the PVD were about 0.65 m/s compared to 1.05 m/s of the TRA group. When they walked at comparable speeds, the PVD and TRA groups displayed similar gait characteristics, with both groups exhibiting symmetrical gait. The different ankle components had similar effects in both groups. The walking speeds, cadences, step lengths,

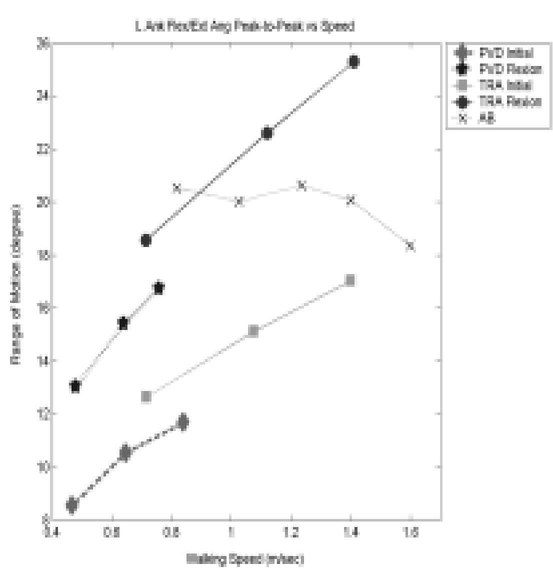

Figure 3: *Plot of left sagittal plane ankle peak-to-peak-value vs speed for the PVD, TRA and able-bodied (AB) subjects walking at various speeds with four different ankle configurations.*

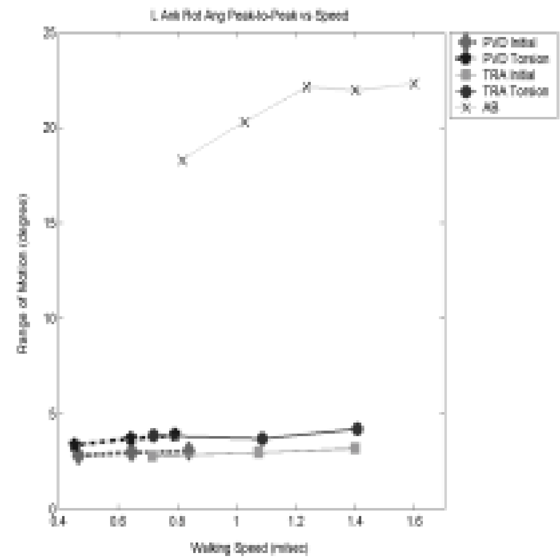

Figure 4: Plot of left transverse plane ankle peak-to-peak-value vs. speed for the PVD, TRA and able-bodied subjects walking at various speeds with four different ankle configurations.

step widths, single and double support time were not significantly different when the TT subjects (the PVD and TRA groups) walked with the four different ankle configurations.

When the TT subjects walked with the Endolite Multiflex Ankle, they showed a significant increase of several degrees in ankle plantarflexion angle during early stance phase, and about 7° of dorsiflexion during late stance (Figure 3). The flexion unit did not significantly affect other rotations of the ankle, knee, hip, or pelvis. During pre-swing phase, greater energy storage and return at the ankle were observed when the TT subjects walked with the flexion unit. However, the flexion unit did not have significant effects on moments about the knee, or hip joints.

When the TT subjects walked with the torsion unit, they displayed significantly increased transverse plane ankle range of motion (Figure 4). However, the amount of increase was only about 1° to 2°, and the increase did not affect other rotations at the knee, hip or pelvis or the moments about the ankle, knee, or hip joints. The stiffness of the torsion adaptor may have been too high to produce much motion during level walking.

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Another possible explanation was that TT subjects felt unstable walking with greater ankle transverse rotation, and they either adopted a walking pattern to avoid transverse motion or they requested that the prosthetist adjust the torsion unit to be stiffer.

The questionnaires' results indicated that all subjects liked the flexion and the torsion units equally well, but they preferred the combination of the two from among all the ankle configurations. Specifically, subjects indicated that the flexion unit was beneficial for going up/down stairs and inclines, while the torsion unit assisted turning. There were no differences in the responses between the PVD and TRA groups.

Clinical implications and future study directions

We believe that the quantitative and subjective results from our study indicate that the increased prosthetic ankle motion enabled persons with bilateral TT amputations to walk more like able-bodied persons. Many researchers and prosthetists concentrate on the importance of prosthetic ankle sagittal plane motions and overlooked the value of the motions in the transverse plane. Subjective results from the questionnaires suggested that the increased prosthetic motions in the sagittal and the transverse planes were probably equally important. The torsion unit may not be functionally important during straight level ground walking. However, it may provide greater comfort and stability when a person with amputation performs turning during walking and standing. Gait analyses with subjects walking on different terrains, or performing specific tasks, like turning, may further illustrate the advantages of increased prosthetic ankle motion.

The results of this study indicate that the PVD and TRA groups displayed similar kinematic, kinetic, and temporal-spatial data when they walked at similar speeds. The effects of the increased prosthetic ankle motion on their gait were comparable between two groups. Also, they demonstrated similar subjective assessments toward the various ankle configurations. These findings may suggest that prescriptions of prosthetic ankle and feet systems for persons with TT amputation(s) should not necessarily be different based on a patient's age or etiology of amputation.

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News from NURERP (RERC, PRL & NUPOC)

Awards

Thomas Karolewski, CP, FAAOP, of Northwestern University's Prosthetics-Orthotics Center, has received the Outstanding Educator Award from the American Academy of Orthotists and Prosthetists (AAOP) at their annual meeting, March 16-19, 2005.

Sara Kohler, M.S., Pinata Hungspreugs Sessoms, M.S. and Po-Fu Su, M.S. won awards for the original papers they submitted and presented to the 19th Annual Meeting of the Gait and Clinical Movement Analysis Society (GCMAS). As part of their award, GCMAS hosted their travel and accommodations for the meeting held in Portland, Oregon on April 4 through 6, 2005.

Theses Defenses

Po-Fu Su, M.S., defended his Master's thesis titled "Bilateral Below Knee (BBK) Amputees with Differential Ankles" for the degree of Master of Science in Biomedical Engineering at Northwestern University, Evanston, Illinois. Steven A. Gard, Ph.D., mentored his work.

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Register Now for ICORR 2005

The IEEE 9th International Conference on Rehabilitation Robotics (ICORR) will meet in Chicago on June 28 through July 1, 2005. Hosted by the Sensory Motor Performance Program (SMPP) at the Rehabilitation Institute of Chicago (RIC) and Northwestern University, this year's theme is "Frontiers of the Human-Machine Interface."

Consonant with ICORR objectives of developing devices to assist people with moderate to severe motor impairments, other ICORR topics will focus on recent advances in assistive robotics, therapeutic robotics, brain-machine interfaces for rehabilitation, robotics in Prosthetics and Orthotics, hardware and control developments for rehabilitation, evaluation methods and clinical experience, biorobotics and biomimetics, and sensory/motor control learning. Keynote speakers will be Paolo Dario, John Hollerbach and Andrew Schwartz.

Continuing Medical Education (CME) credits will be available for both Occupational and Physical Therapists. Travel awards are available for young investigators, women, minorities and investigators with disability. For registration information, please visit the website at http://www.smpp.northwestern.edu/ICORR2005/ or contact the ICORR 2005 Conference Secretariat, Mary Ellen Devitt, by telephone at (312) 238-2910 or e-mail at medevitt@rehabchicago.org Don't miss this exciting international event!

DVA and NIDRR Supported NUPRL Research Presented at ISPO 2004

Among the papers that were presented at ISPO 2004 in Hong Kong by the members of the Northwestern University Rehabilitation Engineering Research Center in Prosthetics and Orthotics, the following research was sponsored or supported by the Department of Veterans Affairs (DVA), Rehabilitation Research and Development Service; by the National Defense Science and Engineering Graduate Fellowship (NDSEGF); by the National Institute on Disability Rehabilitation Research (NIDRR), U.S. Department of Education; and by the National Institutes of Health (NIH). NUPRL recognizes and appreciates these institutions' ongoing and generous support that makes this research possible.

"Independence of Multiple Intra-Muscular EMGs for Implantable Myoelectric Sensors" by R. F. *ff* Weir, T. Kuiken, A. B. Ajiboye. *(Acknowledgement: This research was supported by DVA)*

"EMG Pattern Classification for Controlling Transradial Myoelectric Hand Prostheses" by A. B. Ajiboye, R. F. Weir, C. W. Heckathorne. *(Acknowledgement: This research was supported by DVA)*

"Externally-Powered Shoulder Disarticulation Fitting Following Targeted Muscle Reinnervation" by L. A. Miller, R. D. Lipschutz, T. A. Kuiken, K. A. Stubblefield, C. Heckathorne. *(Acknowledgements: This research was supported by the Whitaker Foundation #RG98-02-89, NIDRR, and NIH #HD01224-04)*

"Test Fitting of a Prototype Electric-Powered Partial-Hand Prosthesis" by C. W. Heckathorne, R. F. *ff* Weir. *(Acknowledgement: This research was supported by DVA)*

"Extended Physiological Proprioception (EPP) Control of a Powered Elbow Prosthesis – The Effects of Non-Linearities" by T. R. Farrell, R. F. *ff* Weir, C. W. Heckathorne, D. S. Childress. (*Acknowledgement: This research was supported by the NDSEGF and DVA)*

NUPOC Faculty Invited to Walter Reed Workshop

Mark Edwards, MHPE, CP, Director of the Prosthetics Education Program at Northwestern University, was invited to participate in the Military Amputee Advanced Skills Training (MAAST) Workshop on October 18-22, 2004. OSSUR North America of Aliso Viejo, California sponsored this advanced workshop, which was held at the Walter Reed Army Medical Center in Washington, D.C.

The purpose of the workshop was to share advanced fitting techniques and information among military, VA and civilian rehabilitation personnel. Invited physical therapists, prosthetists and physicians attended this workshop to learn about advanced fitting and rehabilitation techniques to improve the physical performance of soldiers with amputations.

A group of soldiers with lower limb amputations was selected to participate in the weeklong workshop. OSSUR donated a variety of high-tech components. The invited prosthetists measured, cast and fit the soldiers with special running feet, hydraulic knees, and newer suspension systems. On the second day of the workshop, while physical therapists learned about available prosthetic components, prosthetists accomplished alignment and fitting adjustments.

On the third day of the workshop, physical therapists learned military running techniques and obstacle course training. In pairs, therapists and soldiers performed basic techniques in spotting, balance and stride training. Also, Paralympic amputee athletes demonstrated proper training techniques and tips for running with a prosthesis. Mr. Edwards reported, "The highlight of the day was seeing 25 soldiers running in the gym within one day of being fit with the new designs."

On the final day of the workshop, soldiers learned special golfing techniques used for individuals with amputations. Physical therapists in attendance on the driving range also learned about adaptations that are used to improve the swing of amputee golfers.

A closing banquet honored the soldiers and recognized their participation that contributed to the success of the workshop. Future workshops like these are being planned for the new 29,000 square foot facility, which is being built at Walter Reed for the U.S. Army Amputee Patient Care Program.

News from NURERP (RERC, PRL & NUPOC)

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Jonathon Sensinger, M.S., defended his Master's thesis titled "Upper Extremity Control Systems to Develop Compliance" for the degree of Master of Science in Biomedical Engineering at Northwestern University, Evanston, Illinois. Richard F. *ff* Weir, Ph.D, mentored his work.

Meetings Attended

Dudley S. Childress, Ph.D., attended the US-International Society for Prosthetics and Orthotics (US-ISPO) Conference on Disabilities, "Reaching Beyond Our Borders," held on January 14 through 15, 2005 in Orlando, FL.

Richard F. *ff* Weir, Ph.D., participated as a member of the advisory panel for the Defense Advanced

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NEWS FROM THE DEPARTMENT OF VETERANS AFFAIRS

VA and DOD Working Together to Care for Our Returning Soldiers

by
Joseph A. Miller, CP, MS
1st Lt USAR MSC
Chief Clinical & Research Prosthetist
U.S. Army Amputee Patient Care Program
Walter Reed Army Medical Center
Washington, D. C.

Every time you turn around you see a VA prosthetist, and that's a good thing! Over the course of last year, Veterans Health Administration (VHA) prosthetists and Department of Defense (DOD) prosthetists have collaborated in various events.

The Military Amputee Advanced Skills Training Workshop (MAAST), sponsored by OSSUR Inc, held at Walter Reed Army Medical Center in October 2004 was one such collaborative event. The workshop evaluated the physical performance of Operation Enduring Freedom and Operation Iraqi Freedom OEF/OIF amputees through prosthetic fitting and therapeutic training and also educated the rehabilitation team in methods of advanced prosthetic and training techniques.

The event brought together twenty top prosthetists from around the country, including many VA prosthetists, twenty physical and occupational therapists, and faculty from accredited educational programs. The amputees received a running prosthesis and training; prosthetists received instruction in design and fabrication techniques for advanced skills prostheses; and physical therapists gained insight into the evaluation, fit and design of prostheses.

A central objective of the MAAST workshop was improvement of the physical performance of lower limb amputees. Associated objectives included education of DOD/VA prosthetists in socket fabrication, component selection and alignment for high activity prosthetics.

The rehabilitation team included physicians, physical therapists, occupational therapists and prosthetists, all of whom learned about adaptive equipment designed to enhance athletic performance, the biomechanics of amputee running, multi-directional tasks and sport specific training techniques. The rehabilitation team examined and implemented training techniques to improve the performance of military-related tasks and finally assessed prosthetic fitting techniques, prosthetic component selection and training methods employed during the clinic.

During the post-course review, all participants indicated an interest in future MAAST courses. Future sessions will include a retrospective look at those amputees who received new technology and training at the workshop. Over the next year, we may survey the participants to determine which techniques and technologies they began or improved

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as a result of participation. The psychosocial aspects of participation in strenuous physical activities, even to the point of active competition, were discussed many times during the workshop; future workshops will review and address this topic. All participants, both patients and professionals, thought the workshop was a tremendous success and that it should be repeated in 2005 and beyond.

In conjunction with the MAAST workshop, the National Amputee Golf Association (NAGA) was invited to present their "First Swing/Learn to Golf" program to military amputees and rehabilitation professionals.

In addition to the collaborative opportunities at the MAAST workshop, recently, VA prosthetists were invited to attend the annual meeting of the American Academy of Prosthetists and Orthotists (AAOP) in Orlando Florida in March 2005. VA prosthetists from around the country participated in a variety of educational courses, manufacturer seminars on the newest technology and, most importantly, interfaced with private sector counterparts with whom they regularly interact. Their inclusion enhanced discussion about the organizational structure of the VA, how the VA operates, and the roles of VA practitioners.

The prosthetic and orthotic industry is an ever-changing field. Many future advances will stem from federal grant money. Collaboration with private sector counterparts will be needed for clinical trials of these new devices. What better team to work with than the VA and DOD!

(Coordinated by Robert M. Baum, Prosthetic Program Manager; Prosthetic and Sensory Aids Program (113), VA Central Office, Washington, D. C.)

Addendum to U.S. Engineering Delegation to Viet Nam

Capabilities (Winter 2005, page 19) briefly reported on "U.S. Engineering Delegation to Viet Nam." We wish to add that Vo Van Toi of Tufts University led this NSF-sponsored team of invited biomedical engineers consisting of Dudley Childress of Northwestern University, Robert Jaeger of NIH, David Kaplan of Tufts University, Murray Loew of George Washington University, Gordana Vunjak-Novakovic of Harvard-MIT and John Webster of University of Wisconsin.

From January 2 until January 15, 2004, the U.S. team visited biomedical engineering departments in Viet Nam. They observed that graduates from the Hanoi University of Technology Biomedical Electronics Center work for private companies that import medical devices. The Ho Chi Minh City University of Technology has a biomedical engineering curriculum that began in 2002 and, currently, the Can Tho University College of Technology has no training program in biomedical engineering, but does conduct biomechanics research.

Reporting on biomedical engineering in Viet Nam, the U.S. team suggested that these programs would be assisted by funds for the acquisition of medical equipment to develop teaching laboratories, and by funds to enable Vietnamese instructors to obtain graduate degrees from universities with well-developed programs in biomedical engineering.

NUPRL Presents Research at AAOP and ACPOC Meetings

The 31st Annual Meeting and Scientific Symposium of the American Academy of Orthotists and Prosthetists and the Association of Children's Prosthetic-Orthotic Clinics were held concurrently in Orlando, Florida from March 16 through 19. This multidisciplinary meeting featured presentations by **Steven A. Gard,** Ph.D., **Margrit Meier**, Ph.D., CPO, **Stefania Fatone,** Ph.D., **Brian L. Ruhe**, M.S., **Regina J. Konz**, M.S., and **Sara R. Koehler**, B.S. from Northwestern University Prosthetics Research Laboratory and Rehabilitation Engineering Research Program. **Robert Lipschutz**, CP, in a joint ACPOC and AAOP session, discussed diagnostic and treatment options for multiple types of Proximal Femoral Focal Deficiency (PFFD). **Thomas P. Karolewski**, CP, FAAOP, an instructor at the Northwestern University Prosthetics Orthotics Center, was honored with the Outstanding Educator Award.

The Microprocessor Knee Symposium Research featured "Performance on an Obstacle Course: Otto Bock C-leg vs. Otto Bock 3R60 vs. Mauch SNS." This research by Margrit Meier, Ph.D., CPO,A. Hansen, Ph.D and S.A. Gard, Ph.D. evaluated the use of a microprocessor knee from various viewpoints. Participants in her study wore each joint for a period of four weeks before being tested while walking over an obstacle course (OC). Preliminary analyses indicate no significant time differences between the C-leg, the SNS and the C-leg and the 3R60 in completing the OC. *(Sponsor: Department of Veterans Affairs)*

As part of the American Academy of Orthotists and Prosthetists Certificate Program "Orthotic Management of Stroke Patients," Dr. Fatone presented a lecture, **"Biomechanics of Lower Limb Function and Gait,"** co-authored with S.A. Gard, Ph.D. Completion of several certificate programs enables Academy members to progress toward Fellow designation.

Brian L. Ruhe, M.S. and Steven A. Gard, Ph.D. reported on **Gait Characteristics of Persons with Bilateral Transfemoral Amputations.** The results of their gait analysis study on five persons with bilateral transfemoral amputations showed a high variability in the temporal-spatial and kinematic data. Kinematic data revealed significantly different pelvic movements when compared to able-bodied persons. When walking, all amputee subjects utilized bilateral 'hip-hiking,' a compensatory action that assists in toe clearance, but also increases energy consumption. Standardized gait training for persons with bilateral transfemoral amputations may increase their functional walking ability. *(Sponsor: NIDRR)*

Investigation to Determine the Effect of Increased Ankle Motion in Persons with Bilateral Transtibial Amputations by P. Su, B.S., S.A. Gard, Ph.D., R. Lipschutz, CP, T. Kuiken, M.D., Ph.D., analyzed the effects of increased prosthetic ankle motions in a population of persons with bilateral TT amputations to determine if the provision of prosthetic ankle motion significantly improves their walking performance. The absence of compensatory actions from a sound leg allows easier identification of the advantages and disadvantages of the prosthetic components. Results showed that the ankle units increased motion in the sagittal and transverse planes during gait, but did not significantly impact parameters such as walking speed or step length during level walking. Subjectively, the subjects indicated that the increased ankle motion was beneficial for going up/down stairs and inclines, and for turning. *(Sponsor: NIH)*

Quantitative Evaluation to Determine the Effect of Increased Ankle Motion in Persons with Bilateral Transfemoral Amputations by L.L. McNealy, B.S., S.A. Gard, Ph.D., R. Lipschutz, CP, T. Kuiken, M.D.,

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Ph.D. analyzed the gait of persons with bilateral TF amputations who walked with four different prosthetic ankle configurations. The primary aim of this study was to examine and quantify changes in gait resulting from the prosthetic ankle joints. Results showed that while users demonstrated increased ankle motion while walking, overall their gait was not significantly affected. Subjectively, most of the participants felt that the ankle units increased their comfort during walking, and permitted them to walk longer distances. The general consensus among the subjects was that the increased ankle motion was beneficial. *(Sponsor: NIH)*

Other NUPRL presenters at AAOP and ACPOC sessions focused on gait, the management of spinal instability, and shock-absorbing components for unilateral transfemoral amputees. Those studies are summarized below.

An Investigation of Shock-Absorbing Components in Persons with Unilateral Transfemoral Amputations by S.R. Koehler, B.S., S.A. Gard, Ph.D., and M.R. Meier, Ph.D., CPO The purpose of this study was to compare the effect of a shock-absorbing pylon (SAP) to a stance flexion knee unit on the gait of ten transfemoral amputees. We were particularly interested in relating perceptions of increased comfort with changes in quantitative gait data. This study found that walking speed, stance-phase duration, and cadence were unaffected by the addition of a SAC. Step length asymmetries increased with the SAP and decreased with the stance flexion knee unit. Stance-phase knee flexion did not appreciably increase with the addition of the stance flexion knee unit, and although subjects perceived the SACs to be more comfortable, an analysis of their GRF profiles did not indicate that either SAC provided a measurable benefit to the user during level walking. Further investigation is needed to relate perceptions of increased comfort with changes in kinematic and kinetic gait data. *(Sponsor: Department of Veterans Affairs)*

Effects on Gait of Ankle Alignment and Foot-Plate Length in Ankle Foot Orthoses (AFOs) by S. Fatone, Ph.D., A.H. Hansen, Ph.D., S.A. Gard, Ph.D., B.S. Malas, M.H.P.E., C.O.

The purpose of this study was to investigate the effect on gait of AFO ankle alignment and foot-plate length in people with hemiplegia following stroke. Twelve participants (mean age 53.7 ± 7.9 years; time since CVA 8.1 ± 4.6 years) underwent three gait analyses, each two weeks apart walking on: (1) a standard-aligned (ankle at 90°), thermoplastic, articulated AFO with 90° plantarflexion stop and full-length foot-plate; (2) the same AFO re-aligned so that the tibia is perpendicular to the ground; and (3) the same AFO as in (2) with ¾ length foot-plate. Standardized footwear ensured heel height was constant. All AFOs improved ankle position during gait, decreased the onset and magnitude of knee hyperextension if present, and increased excursion of the center of pressure (COP) compared to a Shoe Only condition. The first AFO condition had the longest COP excursion and most prolonged internal knee extension moment during stance, especially when knee hyperextension was present. It was concluded that small changes in ankle alignment and foot-plate length affect moments at the knee by altering the location of the COP. *(Sponsors: Department of Veterans Affairs, NIDRR)*

The Effect of a Thoraco-Lumbo-Sacral Orthosis on Gait by Regina J. Konz, M.S., Stefania Fatone, Ph.D., Steven A. Gard, Ph.D. The purpose of this study was to investigate the effect of spinal restriction on gait in able-bodied people. Ten participants were evaluated across a range of walking speeds using bilateral gait analyses with and without spinal restriction. Restriction of the spine resulted in decreased range of motion (ROM) of the pelvis in the coronal and transverse planes across all walking speeds; decreased sagittal plane pelvic ROM in half the subjects; and a small increase in stance-phase knee flexion. Cadence increased and step length decreased with restriction, so walking speed was unchanged between conditions. These results suggest that individuals compensate for reduced pelvic motion with increased knee flexion during stance, assisting in the reduction of impact forces. *(Sponsors: NIDRR, NIH)*

NUPRL Researchers Receive Awards at GCMAS Meeting 2005

Steven A. Gard, Ph.D, **Stefania Fatone**, Ph.D., **Rebecca Stine**, M.S., **Pinata Hungspreugs Sessoms**, M.S., **Po-Fu Su**, M.S., and **Sara Koehler**, B.S., attended the 10th Annual Meeting of the Gait and Clinical Movement Analysis Society (GCMAS) April 4 through 6, 2005 in Portland, Oregon. GCMAS is an international forum that promotes the exchange of information about human movement, the diagnosis of movement disorders, and the clinical application of technical advancements and scientific research to enhance the diagnosis and treatment of persons with movement disorders.

Congratulations are due Pinata Hungspreugs Sessoms, M.S., Po-Fu Su, M.S., and Sara Koehler, B.S., each of whose papers won a competitive 2005 GCMAS Student Conference Award from the Whitaker Foundation which supports development in the field of biomedical engineering. Summaries of the three award-winning presentations appear below.

"Effective Foot Length Ratios for Sound and Prosthetic Ankle Foot Systems of Unilateral Trans-tibial Prosthesis Users" by P. H. Sessoms, M.S., A.H.Hansen, Ph.D., M.R. Meier, Ph.D., CPO, S.A. Gard, Ph.D., and D.S. Childress, Ph.D.

The Effective Foot Length Ratio (EFLR) is a measure of the percentage of the total length of the foot under which the COP progresses between heel contact and opposite heel contact. EFLR may be an effective tool in distinguishing characteristics of persons with lower limb amputations. The effects of ankle foot (AF) roll-over shape arc length on subjects' gait were analyzed in this study. Ten subjects having unilateral trans-tibial amputations were fit with a Shape&Roll prosthetic foot on their current socket, and a gait analysis was performed with the subject walking at self-selected normal, slow, and fast speeds. Similar gait analysis was performed after the foot was modified to shorten its arc length by making cuts in the foot at approximately 70% and then 60% of the original foot length that did not allow the COP to progress past the cuts. Results from this study indicate that changing AF roll-over shape arc lengths can significantly affect parameters of gait. In the future, this should be a consideration when choosing prosthetic feet for persons with amputation.

"The Effect of Increased Prosthetic Ankle Motion on the Gait of Persons with Bilateral Transtibial Amputations" by Po-Fu Su, M.S., Steven A. Gard, Ph.D., Robert Lipschutz, CP, Todd Kuiken, M.D., Ph.D.

This study analyzes the effect of increased prosthetic ankle motion on the gait of persons with bilateral transtibial amputations. Endolite Multiflex Ankles (flexion unit) were used in the study to increase ankle sagittal plane motion and Otto Bock Torsion Adapters (torsion unit) were used to provide ankle transverse plane motion. For two weeks before a gait analysis, participants walked with the following prosthetic configurations: Seattle Lightfoot II only; torsion unit only; flexion unit only; both flexion and torsion units. When the subjects walked with the flexion unit, they displayed about 6° of increase in the peak-to-peak ankle sagittal plane motion, increased ankle plantarflexion moment and increased ankle energy absorption and return. When they walked with the torsion unit, they displayed only 1° to 2° of increase in the ankle transverse plane rotation.

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However, the increased ankle motion provided by both the flexion and torsion units did not affect the subjects' walking speed or their knee, hip and pelvis motions. Participants reported they benefited equally well when they walked with the flexion and torsion units, but they preferred the combination of both. This result suggested that increased prosthetic ankle motions in both the transverse and sagittal planes probably are important when prosthetists prescribe prostheses to amputees.

"The Effect of Shock-Absorbing Prosthetic Components on Ground Reaction Force Profiles in Persons with Transfemoral Amputations" by S.R. Koehler, B.S., S.A. Gard, Ph.D., M.R. Meier, Ph.D., CPO

One of the primary limitations of transfemoral prostheses is their inability to provide sufficient shock absorption during the loading response phase of gait. As a result, people with unilateral transfemoral amputations are susceptible to higher impact forces on their intact limb and joints proximal to their amputation. To address this issue, shock-absorbing components (SACs) have been designed to decrease the overall stiffness of the prosthetic limb. The purpose of this study was to compare the effects of two different SACs—a shock-absorbing pylon and a stance flexion knee unit—on the ground reaction force (GRF) profiles of ten transfemoral amputees during normal, freely selected walking. Although subjects indicated that walking was more comfortable on SACs, an analysis of their GRF vectors did not indicate that these components attenuated peak forces during the loading response phase of gait. Furthermore, walking with a SAC seemed to increase peak forces on the sound limb. Based on our analysis of vertical and fore/aft GRF profiles, there was no evidence that either SAC restored shock absorption in transfemoral amputees. Factors that may limit shock absorption in this population may include walking speed, gait habits, prosthetic alignment, and soft tissue compliance.

News from NURERP (RERC, PRL & NUPOC)

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Research Projects Agency (DARPA) Advanced Prosthesis Workshop, held in Maryland on January 10 and 11, 2005.

Dudley S. Childress, Ph.D., Steven A. Gard, Ph.D., Todd Kuiken, M.D., Ph.D., and Richard F. *ff* Weir, Ph.D., presented research overviews that addressed "*The New Artificial Limb Systems: A Help or Hubris?*" at the Northwestern University Domain Dinner held in the Dr. Daniel Hale Williams Auditorium and Atrium on January 19, 2005. Dr. Gard presented "Computer-control of Artificial Legs," Dr. Kuiken presented "Neuromuscular Reorganization for Improved Artificial Arm Control," and Dr. Weir presented "Implantable Sensors for Multi-Functional Artificial Hands." Dr. Childress served as Moderator for the session.

Dudley S. Childress, Ph.D., and **Steven A. Gard, Ph.D.,**attended the Rehabilitation Research and Development Service Scientific Merit Review Board Meeting on February 28 through March 1, 2005 in Washington, D.C.

Steven A. Gard, Ph.D., attended the Rehabilitation Engineering Research Centers (RERC) Outcomes Planning and Reporting Workshop on March 2, 2005 in Arlington, VA

Dudley S. Childress, Ph.D., and Steven A. Gard, Ph.D., attended the Directors' Meeting for National Institute on Disability and Rehabilitation Research (NIDRR) on March 3 through 4, 2005 in Washington, D.C.

Grants Awarded

Steven Gard, Ph.D., and **Stefania Fatone, Ph.D.,** were awarded a three year grant from the Department of Veterans Affairs for "An Investigation of Ankle Joints for Ankle Foot Orthoses (AFOs)."

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Northwestern University Prosthetics Research
Laboratory and Rehabilitation Engineering
Research Program
345 E. Superior Street, Room 1441
Chicago, IL 60611-4496

Phone Help Line: (312) 238-6524
FAX: (312) 238-6510
TTD: (312) 238-6530
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