Capabilities

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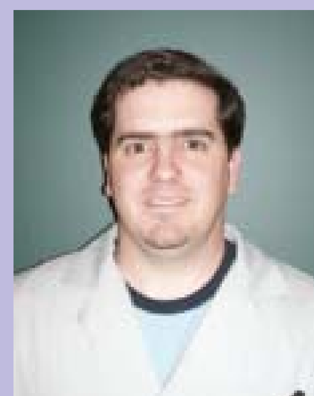
Inside This Issue:

These three researchers focus on marker placement when analyzing the gait of persons with partial foot amputation:



Andrew Hansen, Ph.D.

Michael Dillon, Ph.D.

Stefania Fatone, Ph.D.

Model Simulations of Partial Foot Amputation Gait While Wearing Shoes: Effect of Marker Placement on Measured Dorsiflexion

[1]**Andrew Hansen**, Ph.D., [2]**Michael Dillon**, Ph.D. and [1]**Stefania Fatone**, Ph.D.

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Introduction

The ankle dorsiflexion range of motion (ROM) in persons with partial foot amputations (PFA) is similar to that seen in able-bodied walkers when walking barefoot [1-3] and increases when wearing shoes or shoes with a below-ankle prosthesis-orthosis [2]. Observations suggest that differences in ankle kinematic data may arise from motion between the residual foot and the shoe/device (e.g., heel slippage, **Figure 1A**) [4], or bending between the end of the residuum and devices such as toe fillers (**Figure 1B**). Systematic investigations of marker placement protocols have not been conducted for persons ambulating with PFA; however, it is suspected that movements between markers that define the local coordinate system of the foot may result in greater measured dorsiflexion. Therefore, the purpose of this investigation was to use a mechanical model representing three levels of PFA to establish whether standard placement of markers on the shoe results in exaggerated ROM measurements at the ankle.

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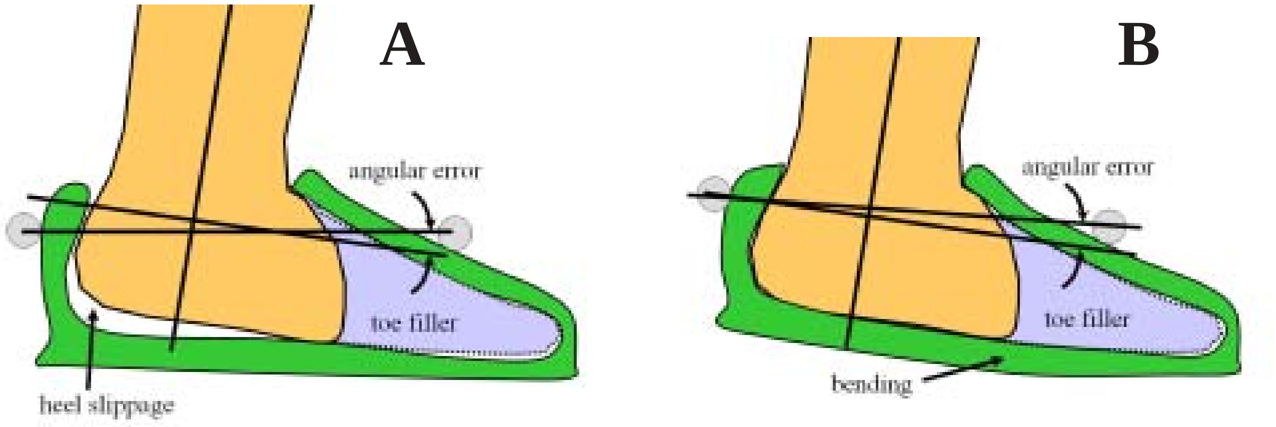

Figure 1: Possible sources of ankle dorsiflexion measurement errors that may occur in marker-based gait analysis of persons with PFA: (A) heel slippage and (B) bending of the shoe under the end of the residual foot.

Continued from page 1

Methods

Figure 2 shows an articulated mechanical model of the leg with three different lengths of foot residua corresponding to metatarsophalangeal, transmetatarsal, and Lisfranc amputations. Compared were kinematic data that were derived from a potentiometer (embedded in the ankle of the mechanical model) and conventional marker-based gait analysis system (using a Helen Hayes (HH) marker set). The mechanical model was constructed of a wood shank connected to a hinge joint that represented the ankle. The foot pieces were connected through steel uprights on both sides that were screwed into the wooden shank. The foot sections of the device consisted of 90 durometer polyurethane rubber (Smooth-On Inc., Easton, PA, USA) and included several threaded inserts to connect the foot extensions that mimicked three different levels of PFA. These foot lengths were modeled on anthropometric data from Dillon [5]. The ankle motion within the device was measured using a rotational potentiometer that was placed in line with the hinge joint. The housing of the potentiometer was affixed to the shank component with its shaft connected to the ankle joint shaft, which was connected rigidly to the partial foot piece. In this configuration, the rotation of the shank, with respect to the partial foot piece, turned the shaft of the potentiometer and thereby changed its electrical resistance. After the potentiometer was connected to the Motion Analysis system, the signal was synchronized with the marker data. Using markers on the unshod device, the potentiometer signal was calibrated and established as the 'gold standard' measurement of ankle joint motion in this study. With the ankle slightly plantarflexed, a strap that connected the posterior-superior aspect of the partial foot model and the top of the shank could be pulled taught and fixed over a screw on top of the shank piece. The strap coupled the movement of the shank and foot segments while the shank was rotated over the foot, simulating tibial rotation during stance phase. Ankle joint centers were estimated by the average of medial and lateral ankle marker positions; and a knee center was estimated by the average of medial and lateral markers placed near the top of the shank piece.

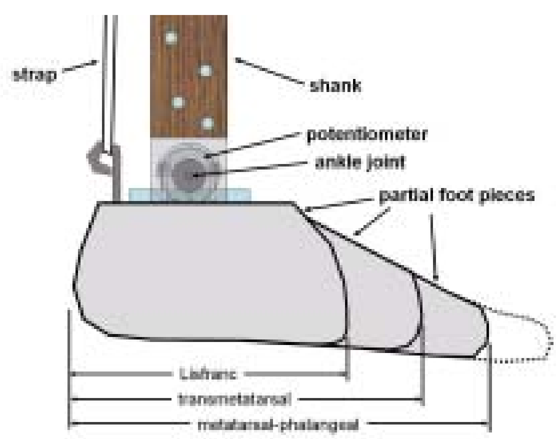

Figure 2: Diagram of the mechanical model of the partial foot used to investigate possible measurement errors that may occur in gait analysis of persons with PFA.

On the mechanical model, ankle markers were placed directly along the ankle shaft. For the HH marker set, a heel marker and toe marker were located on the shoe [6]. A unit vector was created between the ankle and knee centers

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and a second unit vector was created between the heel and toe markers. Finally, the arcsine of the dot product of these two vectors was calculated to determine the ankle angle for the HH marker set.

A nylon stocking was placed over each PFA foot piece and the foot was placed into the shoe, which was a men's size 8W, E.Z. Strider Walking Shoe with a synthetic leather upper, synthetic rubber sole and two Velcro® straps along the dorsal surface. During the experiments a toe-filler was inserted to create a snug fit of the partial foot model. Velcro® straps on the shoe were pulled to a force level of 12 lbs (~54 N) using a spring scale and fastened [7].

Data collection began with the partial foot model in a relatively plantarflexed angle. During the four trials that were conducted for each amputation level, a technician pushed the shank downward and forward to simulate the dorsiflexion that would occur between the mid- and late-stance phase of walking. Data were analyzed for potentiometer-measured angles ranging from neutral (0^o) to approximately 15-20^o of dorsiflexion. In order to examine the amount of error due to bending of the shoe, the toe marker was relocated proximal to the point at which the shoe bent (**Figure 1B**). Finally, the experiments were repeated with the forefoot marker relocated so that it was just proximal to the end of the residual foot inside the shoe.

Results

Figure 3 compares the ankle angle measured using the potentiometer and the HH marker set for the three simulated PFA levels. Using the HH marker set, the ankle angles for the metatarsophalangeal and transmetatarsal levels were closely approximated; however, the HH marker set at the Lisfranc PFA level overestimated the actual ankle dorsiflexion as measured by the potentiometer. Errors in ankle dorsiflexion measurement at the Lisfranc level were greatly reduced by moving the toe marker proximally (**Figure 4**).

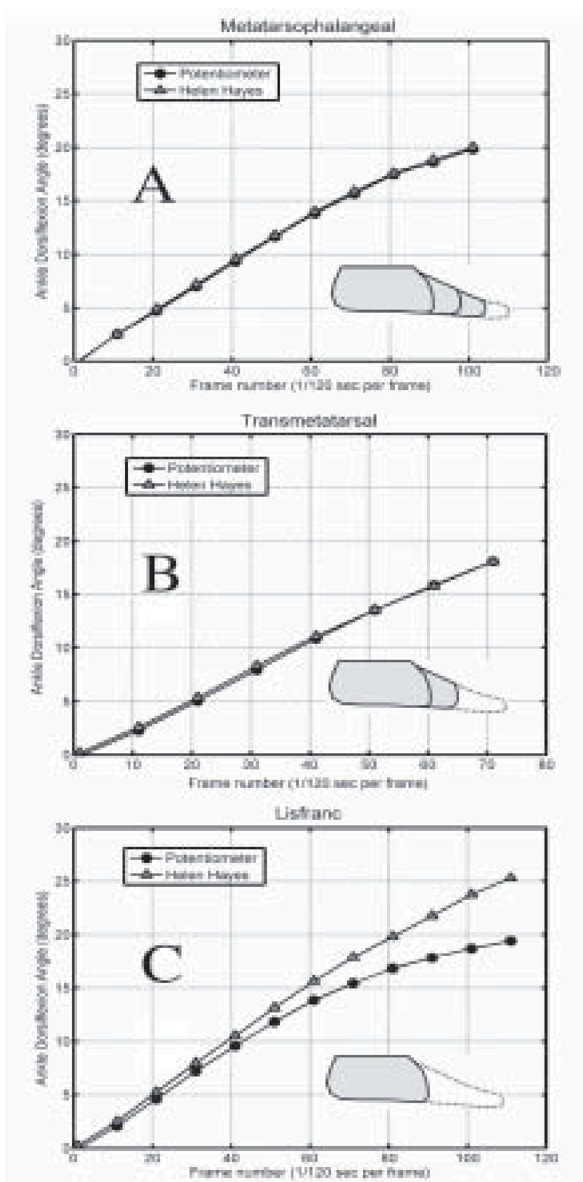

Figure 3: Ankle angles in the mechanical model were measured using the Helen Hayes marker set and a potentiometer. Data are shown for the three simulated amputation levels: (A) Metatarsophalangeal, (B) Transmetatarsal, and (C) Lisfranc.

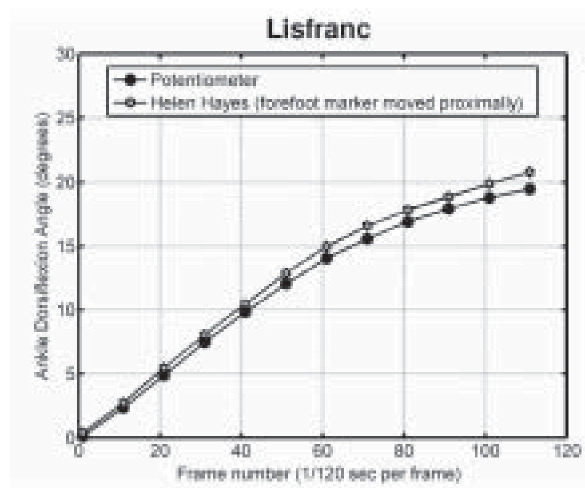

Figure 4: Comparison of ankle dorsiflexion measurements using the potentiometer and the HH marker set moved to the proximal end of the Lisfranc residual foot model.

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Discussion

The results of this experiment using three PFA levels in a mechanical model strongly suggest that the source of ankle dorsiflexion measurement error was due to bending in the forefoot (**Figure 1B**). Proximal relocation of the toe marker would not logically affect errors due to "heel slippage" as shown in **Figure 1A**. The results shown here may vary for different partial foot devices. Notably, devices with poor suspension may lead to the heel slippage and errors shown in **Figure 1A**. Investigators involved in collecting and reporting kinematic data of PFA should consider the appropriateness of the marker set given the type of device being studied, the level of amputation and the errors that are likely involved. Studies that report kinematics need to identify the marker sets used and describe explicitly how markers were placed in the absence of forefoot landmarks and the presence of a prosthesis/orthosis [7]. For devices with good suspension, errors associated with measurement of ankle dorsiflexion can be reduced by moving the forefoot marker to a position just proximal to the end of the residual foot. Also, movement of the heel marker may be necessary to indicate an appropriate neutral alignment of the ankle. Dillon *et al.* [8] provide more information on this study and another marker set that can be used in studies of partial foot prostheses.

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Where Education and Engineering Meet

amputation. It is harder than it looks. A prosthetic arm doesn't work like our biological arms. Whenever I see a person with an amputation, I will remember how hard it is."

Ms. Valkanas, a veteran teacher who has taught at Bateman for 12 years, discovered Get-a-Grip! on a science list serve for Chicago Public Schools. She intends to teach it again. "It was exciting to see how many of my students responded enthusiastically to the material. They were very competitive and rose to the challenge. I definitely plan to teach this again."

Northwestern University's Get-a-Grip! offers 8th graders an opportunity to learn new concepts within the context of engineering. In addition to a multidisciplinary curriculum, the program incorporates the educational and leadership skills of BME graduate students such as NURERC's Ms. Koehler, Ms. Zissimopoulos, and others who volunteered their expertise. Ultimately, Get-a-Grip! inspires young scientists and ensures that all participants are winners. Learn more about Get-a-Grip! at www.ideanet.org/get-a-grip.

Where Education and Engineering Meet
R. J. Garrick, Ph.D.

From left to right are **Brandon Tefft**, M.S., **Vasiliki Valkanas**, science teacher at Bateman School, **Angelika Zissimopoulos**, M.S., and **Sara Koehler**, M.S. These are three of the students from Northwestern University's Biomedical Engineering who volunteered to help teach engineering concepts and evaluate the completed Get-a-Grip! prosthetic arms.

Eighth grade science classes at Newton Bateman School in Chicago participated in Northwestern University's **Get-a-Grip!**, an interdisciplinary unit that introduces students to engineering concepts and the possibility of pursuing engineering as a career choice. By the end of the unit, student teams use common materials to build, test and evaluate a working prosthetic arm that can accomplish specific tasks.

Designed and developed by Northwestern University's **Suzanne A. Olds**, Ph.D. (Assistant Chair of Biomedical Engineering) and **David Kanter**, Ph.D. (Research Assistant Professor of Education and Social Policy) and in collaboration with the Center for International Rehabilitation, the program is funded by a National Science Foundation grant. The online teacher training program provides guided lesson plans, PowerPoint slides, handouts, assessments, and suggestions for related activities. Lessons in Get-a-Grip! meet or exceed requirements by the Illinois Learning Standards in science, math, English language arts and social science.

Shielding their design secrets from competing teams, students feverishly fine-tuned their prosthetic limbs for performance and cosmesis. Teams sported names such as *Phalanges* and *Humerus*. Their goal was to prove which prosthetic arm designs could successfully pick up and transfer olives to the mouth and then lift and carry a heavy bucket in the shortest time. Volunteer judges from NURERC, **Sara Koehler**, M.S., and **Angelika (Kiki) Zissimopoulos**, M.S., and bioengineering graduate student **Brandon Tefft**, M.S., evaluated the designs according to function, comfort, durability, water resistance, and others. Ms. Koehler remarked, "On the final day, I was impressed to see how well most of the prosthetic arms stood up to the design challenge."

Excitement and enthusiasm were palpable as science teacher Ms. **Vasiliki Valkanas** timed each team's efforts. Resounding cheers turned to groans of disappointment as one limb cracked under the weight of the bucket. Ms. Valkanas encouraged the flagging contestant, "Don't give up! Keep trying!" Then, like good teachers everywhere, she turned to the class and urged, "Never, never give up. Always keep trying."

Eighth grader **Lucia Lopez** explained what she learned while participating in Get-a-Grip! "We read *Pinto's Hope* (by Deborah A. Harrell) about a boy who had an amputation due to a land mine. I was impressed by his determination to return to school and succeed. The process of building a prosthesis was really interesting. Our goal was to restore lost function. It was difficult to design a feature that could pick up olives without puncturing them. The most challenging part was to make it look natural."

Classmate **Miriam Silva** reflected on her experience in Get-a-Grip! "I recognized the difficulty of living with an

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Get-a-Grip prosthetic arm performs a required task: pick up and transfer olives.

This Get-a-Grip prosthetic arm features a capture loop between a metal bracket and a PVC platform.

This Get-a-Grip prosthetic arm uses sponges that can passively grip and transfer olives.

UNAM Mechatronics Group Visits NURERC
R. J. Garrick, Ph.D.

A group from the Universidad Nacional Autónoma de México (UNAM) visited NURERC on January 17, 2008. Lead by UNAM Mechatronics Department Chief, **J. Manuel Dorador-Gonzalez**, Ph.D., the group included Mr. **Ulises Peñuelas-Rivas**, M.S., (Lecturer of Mechatronics Design), Ms. **Socorro Armenta-Servin** (Computer Coordinator), and Ms. **Itzel Flores-Luna** (graduate student in Mechanical Engineering).

The staff of the Prosthetics Research Laboratory presented detailed presentations of ongoing research projects. Mr. **Craig Heckathorne**, M.Sc., presented upper limb prosthetics research; **Andrew Hansen**, Ph.D., presented development and fabrication of the Shape&Roll Foot; **Stefania Fatone**, Ph.D., Ms. **Rebecca Stine**, M.S., and Mr. **Brian Ruhe**, M.S., presented motion and gait analysis systems in the VA Chicago Motion Analysis Research Laboratory of the Jesse Brown VA Medical Center; and Mr. **Kerice Tucker**, Research Engineer, presented Squirt Shape Technology.

Dr. J. Manuel Dorador-Gonzalez emphasizing a concept when he spoke at NURERC.

Following their tour, Dr. Dorador-Gonzalez presented an overview of UNAM. The Engineering School focused on mining in 1792 when it was founded and today offers twelve specializations within engineering. Currently, UNAM research projects actively link research and development in the academic and industrial sectors with the aim of producing improved technologies and human resources that will benefit their nation. A graduate of Loughborough University (U.K.), Dr. Dorador-Gonzalez expressed his interest in enhancing UNAM's offerings in mechatronics through international exchange and collaboration. He envisions developing design projects in biomedical engineering that will promote client-centered solutions. Reciprocal and collaborative research projects between NURERC and UNAM may develop in the future.

Dr. Dorador-Gonzalez, **Ulises Peñuelas-Rivas**, M.S., and Ms. **Itzel Flores-Luna** closely examine components of an upper limb prosthesis demonstrated by Craig Heckathorne, M.Sc. (back to the camera).

Elizabeth Hsiao-Wecksler, Ph.D., Visits NURERC

Elizabeth Hsiao-Wecksler, Ph.D., (Assistant Professor, Department of Mechanical Engineering, University of Illinois at Urbana-Champaign) toured NURERC on Friday, February 1, 2008. Dr. Hsiao-Wecksler met with NURERC faculty and staff, including **Steven A. Gard**, Ph.D., **Andrew Hansen**, Ph.D., **Craig Heckathorne**, M.Sc., and Mr. **Kerice Tucker**, Research Engineer. Also, Dr. Hsiao-Wecksler met with Sensory Motor Performance Program (SMPP) researchers, **Keith Gordon**, Ph.D., and Mr. **James Sulzer**, M.S.

NURERC's **Stefania Fatone**, Ph.D., facilitated the tour. She and Dr. Hsiao-Wecksler initially met during a virtual conference that was hosted by the National Science Foundation (NSF) when they identified a mutual interest in orthotics research. In October 2007 Dr. Fatone visited Dr. Hsiao-Wecksler and her colleagues at the University of Illinois to learn more about their research.

Elizabeth Hsiao-Wecksler, Ph.D.

As part of a NSF funded Engineering Research Center for Compact and Efficient Fluid Power, Dr. Hsiao-Wecksler and her group are developing a fluid powered and actuated ankle joint for ankle foot orthoses. While visiting NURERC, Dr. Hsiao-Wecksler presented some of her work entitled "Improving Gait: Development of a Power-harvesting AFO and Tools for Quantifying Gait Asymmetry." NURERC looks forward to exploring avenues for future collaboration with Dr. Hsiao-Wecksler.

Hugh Herr, Ph.D., Visits NURERC

NURERC, the Northwestern University Rehabilitation Engineering Research Program and Prosthetics Research Laboratory (RERP/PRL) hosted **Hugh Herr**, Ph.D., (Associate Director, Media Arts and Sciences; Associate Professor, MIT-Harvard Division of Health Sciences and Technology; Director of the Biomechatronics Group) on March 5-6, 2008. Among Dr. Herr's research products that have improved the lives of persons living with a physical disability are the *Variable-Damper Knee Prosthesis* (now available through Ossur as the RHEO KNEE®) and the *Active Ankle-Foot Orthosis*. After touring the NURERC laboratories, Dr. Herr and NURERC researchers exchanged information about mutual research interests.

Hugh Herr, Ph.D.

NURERC NEWS

NURERC Director Awarded Honor

Steven A. Gard, Ph.D., (Director, Northwestern University Prosthetics Research Laboratory) was awarded Honorary Membership to the American Academy of Orthotists and Prosthetists (AAOP) at the 34th Academy Annual Meeting and Scientific Symposium, Orlando, FL.

AAOP Features NURERC Research

NURERC's research was well represented at the 34th Annual Meeting & Scientific Symposium of the American Academy of Orthotists & Prosthetists that was held from February 27 through March 1, 2008 in Orlando, FL. NURERC researchers whose work was selected for presentation at the symposium include **Dudley Childress, Stefania Fatone, Steven Gard, Andrew Hansen, Pinata Sessoms, Brian Ruhe and Ryan Williams.**

Stefania Fatone, Ph.D., was invited to present two sessions at the American Academy of Orthotists & Prosthetists 34th Annual Meeting & Scientific Symposium in Orlando, FL on February 27 through March 1, 2008. Dr. Fatone presented "Application of Marker-based Motion Analysis Systems to Prosthetics and Orthotics" as part of a session sponsored by the American Academy of Orthotists and Prosthetists Gait Society titled "Discovering Prosthetics and Orthotics through Instrumented Gait Assessment." Dr. Fatone also presented "Biomechanics of Ambulation after Partial Foot Amputation: A Systematic Literature Review" as part of the Instructional Course "Evidence Reports: Findings from the State of the Science Conference on Biomechanics of Ambulation after Partial Foot Amputation."

Invited Lectures and Presentations

Joshua S. Rolock, Ph.D., was an invited participant in the "Red Team DRAFT Department of Defense (DOD) Orthotics & Prosthetics Roadmap" that was sponsored by the DOD Office of the Secretary of Defense Manufacturing Technology Program and the Navy Manufacturing Technology Program in Washington, D.C., on December 11-12, 2007.

Steven A. Gard, Ph.D., was an invited presenter at the Hanger Education Fair, held in Sparks, NV, January 30-February 1, 2008. The American Academy of Orthotists and Prosthetists sponsored Dr. Gard's presentation, "Considerations for Performing Quality Research in O & P/ Critical Review of the Literature," for a course on evidence-based practice.

Stefania Fatone, Ph.D., was an invited speaker at the National VA Interdisciplinary Conference – Current Clinical Concepts in Prosthetic & Orthotic Rehabilitation: Advances in Clinical and Technological Research, held in San Pedro, CA, on February 6-8, 2008. Dr. Fatone presented two talks, one on "Functional Evaluation of Ankle Foot Orthoses in Adults with Post-Stroke Hemiplegia," and another, on behalf of **Andrew Hansen**, Ph.D., on "A Review of Principles and Clinical Implications of Roll-over Shape."

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NURERC Graduate Students Conduct Outreach in Prosthetics Engineering

NURERC graduate students (left) **Sara Koehler**, M.S., and (right) **Kiki Zissimopoulos**, M.S., represented prosthetics engineering when they volunteered their engineering knowledge in Northwestern University's problem-solving educational module, Get-a-Grip! (See page 5)

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