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Stance-Control Knee Ankle Foot Orthoses

Angelika Zissimopoulos, M.S., Stefania Fatone, Ph.D., and Steven Gard, Ph.D.

Funds from the National Institute of Disability and Rehabilitation Research (NIDRR) of the Department of Education under Grant H133E030030 supported this work.

Introduction

Knee-ankle-foot orthoses (KAFOs) encompass the thigh, knee, lower leg, ankle, and foot; and they are prescribed to manage an unstable knee, as well as to provide ankle and foot control [1]. Until recently, knee-ankle-foot orthoses typically were fabricated with a knee joint that was locked for ambulation but could be unlocked while sitting. While these orthoses provide support to the unstable anatomical knee joint and prevent it from collapsing during stance phase, the locked knee joint also prevents swing phase knee flexion. Therefore, users must create adequate ground clearance for the toe during swing phase by hip hiking, circumducting, and/or vaulting, resulting in increased energy expenditure during walking [2-6].

"Stance-control" knee-ankle-foot orthoses employ knee joints that prevent flexion during the stance phase, while allowing flexion during the swing phase of gait. However, scant research evaluates these devices. We hypothesized that the user would exhibit fewer compensatory mechanisms and require less energy to walk with the stance control device compared to a locked knee orthosis. This study evaluates the biomechanical effects of providing stance-control during ambulation; and quantifies and compares the metabolic energy expenditure required for walking with and without stance-control.

Methods

We chose to evaluate the Stance-Control Orthotic Knee Joint (SCOKJ®) from Horton Technology Inc. as a representative stance-control device. This knee joint can operate in three modes: 1) auto (stance-control), 2) unlocked, or 3) locked. We recruited nine healthy adult volunteers with no known lower limb pathologies. Each subject was fitted with a custom fabricated KAFO that incorporated the SCOKJ® (Figure 1). After training to use the device, subjects participated in gait and energy expenditure analyses. Data were collected while subjects walked in all three modes at both their self-selected speed and a speed-matched condition.

Figure 1: Custom fabricated stance-control KAFO.

Results

At self-selected walking speeds, subjects walked faster and with a higher cadence in the unlocked mode compared to the locked mode (p=0.005 and p=0.011, respectively). Speed and cadence were not significantly

Continued on page 2

Continued from page 1

different between the unlocked and auto modes (p=0.087) or between the locked and auto modes (p>0.999).

Analysis of the speed-matched walking trials indicated that stance phase knee flexion on the orthotic side was significantly smaller for the locked mode compared to the unlocked and auto modes (p<0.001

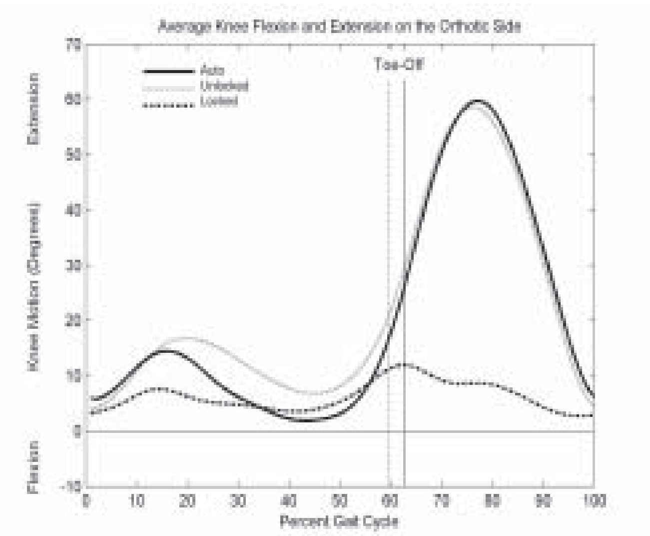

Figure 2: Average orthotic side knee motion.

and p=0.009, respectively) and also was significantly smaller for the auto mode compared to the unlocked mode (p<0.001) (Figure 2). Swing phase knee flexion on the orthotic side was not significantly different between the auto and unlocked modes (p=0.9), but was significantly smaller in the locked mode compared to the auto mode and unlocked modes (p<0.001). In the locked mode, all subjects compensated for the loss of orthotic side swing phase knee flexion by hip hiking to provide toe clearance. Three subjects also utilized circumduction as a compensation for the extended knee in the locked mode. These compensations were not observed in the auto mode. Finally, the unlocked mode resulted in the lowest average oxygen cost (p<0.007), while the auto and locked modes were not significantly different (p>0.999). Results from the energy expenditure analysis varied with four subjects using more energy in the auto mode compared to the locked mode and five subjects using more energy in the locked mode compared to the auto mode.

Conclusion

The SCOKJ® provided swing phase knee flexion and alleviated the compensatory actions associated with locked knee gait when operating in the auto mode, but it did not consistently improve energy expenditure. Perhaps the benefits of improved walking kinematics and improved gait aesthetics are worthwhile regardless of reductions in energy expenditure. Alternatively, significant reduction of energy expenditure in the auto mode may require a longer training period than that provided in this study. Further studies are necessary to confirm the impact of stance-control orthoses on persons with pathology.

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Preliminary Findings for a Study of the Dynamics of RGO Gait

William Johnson, B.E.

Funds from the National Institute of Disability and Rehabilitation Research (NIDRR) of the Department of Education under Grant H133E030030 supported this work. The author would like to acknowledge the use of the VA Chicago Motion Analysis Research Laboratory of the Jesse Brown VA Medical Center, Chicago IL.

The Reciprocating Gait Orthosis (RGO) is an assistive device that enables people with lower limb paralysis to walk with the use of crutches or a walker. The RGO is a type of Hip-Knee-Ankle-Foot-Orthosis that immobilizes the knee and ankle joints and limits motion at the hip to flexion and extension. The distinguishing feature of an RGO is a mechanical linkage between the hip joints that forces one hip into extension when the other is flexed and vice versa.

Compared to able-bodied walkers, people who use RGOs tend to walk very slowly and consume a larger amount of energy. Such slow and exhausting ambulation limits the utility of the RGO in daily life. Many researchers have documented the large energy consumption related to walking with RGOs [1]; however, few have analyzed the mechanics of the gait of RGO users and how it might affect energy consumption. Our study examines the gait mechanics of RGO users in order to guide efforts to improve the functionality of RGOs.

We performed gait analyses on four RGO users (2 children and 2 adults) with a video motion capture system and a series of force plates. The video motion capture system consisted of infra-red cameras that tracked reflective markers placed on the subjects, enabling us to quantify the motion of their body segments while they walked. Force plates embedded in the floor recorded the forces acting on the subjects' feet and crutches. We used these data to calculate joint angles as well as the forces and moments acting at the joints.

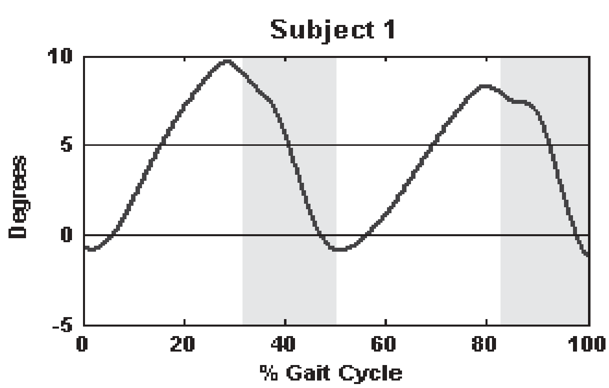

Figure 1: Trunk flexion over the course of a gait cycle where flexion is positive and extension is negative. Shaded regions demarcate single support phases.

Despite having a diverse sample population, we observed several gait characteristics in all of the subjects. Firstly, all subjects walked with a flexed trunk posture where they extended their trunk during the single support phase, but scarcely extended beyond vertical (Figure 1). Secondly, all subjects bore less than half of their body weight on their legs during portions of the single support phase (Figure 2).

The reduction in weight bearing on the legs leads to an increase in weight bearing on the crutches or walker. Since arm muscles do not produce power as efficiently as leg muscles [2], the increased weight bearing on the arms may help explain the higher energy consumption of RGO users compared to able bodied people. However, weight bearing on the arms may be necessary due to the flexed trunk posture that RGO users adopt. During the single support phase of gait, all RGO users extended their trunks. In a flexed trunk posture, forces acting through the legs tend to flex the trunk, while forces acting through the arms tend to extend the trunk; therefore, in order to extend their trunks during the single support phase, RGO users reduce the weight borne on their legs and increase the weight borne on their arms.

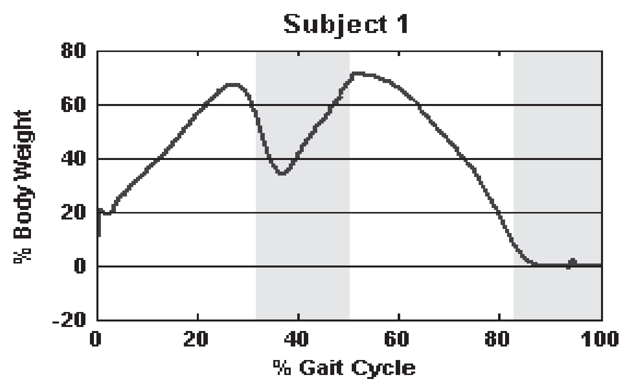

Figure 2: Force acting on the foot of one our subjects as a percentage of body weight. The shaded areas represent single support phases.

These case studies have provided important insights about the gait patterns of RGO users that we hope to expand in future studies.

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NEWS FROM THE DEPARTMENT OF VETERANS AFFAIRS

In this second of a two-part article, Robert Baum provides an overview of the VA's role in providing assistive technology and restoring abilities to disabled veterans. See Part I in *Capabilities* (Winter 2007).

VA's Prosthetic and Sensory Aids Service: High Standards and the Development of New Assistive Devices (Part II)

By
Robert M. Baum
Program Manager
Prosthetics and Clinical Logistics

Prosthetic and Sensory Aids Service (PSAS) serves disabled veterans by relying equally on new assistive items that are being developed and tested at VA; and on VA's rehabilitation care and long-term support.

Assistive Technology and Anatomical Integration

A recent trend in prosthetics aims to integrate body, mind and machine. VA's Center for Restorative and Regenerative Medicine at the VA Medical Center and Brown University (Providence, R.I.), is at the leading edge of a movement to create artificial limbs that will function more like anatomical ones. Current research focuses on bion technology. Bions are microchips that act as bionic neurons. Bions can be injected into the muscles of a residual leg or arm and transmit signals from the brain to the prosthesis. Bion technology can send commands telling the prosthesis what to do, and also will provide sensory feedback, so the prosthesis can report back to the brain.

In addition to robotics and engineering, VA is testing new medical techniques. These include surgery to lengthen bone in the residual limb, thus improving prosthetic fit and providing greater mobility. Another surgical technique anchors a titanium bolt in the bone of a residual limb, potentially providing an attachment site for a prosthesis that can integrate with the human body.

VA Develops and Tests Assistive Devices

Some assistive devices do not replace parts of the body but adapt mainstream technology to compensate for lost physical function. For example, at Walter Reed Army Medical Center in Washington, D.C., VA's vocational rehabilitation and employment program provides voice-recognition computers so that veterans who have lost a hand can learn computer skills, even without having full typing capability.

Testing new assistive devices is important to ensure that they will work in the real world. For example, before authorizing its prescription, in 2003-2004 the VA tested the iBOT stair-climbing wheelchair. Currently, the C-Leg is popular among U.S. amputee veterans returning from Iraq and Afghanistan and VA is conducting rigorous tests to determine whether the C-Leg makes walking easier than other prostheses. Also, VA is testing a knee prosthesis equipped with sensors that can measure force, position and movement, and send that information to an embedded microprocessor. The knee uses electromagnets to control a magneto-rheologic fluid that modulates the impedance of the knee unit to provide users with improved stability during stance phase and more appropriate knee resistance during swing phase.

Rehabilitation Care and Long-term Support

VA is committed to continuing veterans' rehabilitation care for months or even years, after injury or amputation. At VA, rehabilitation care for amputees and other injured veterans is as important as new technology, prostheses, and other assistive devices. Restoring abilities to disabled veterans begins at VA facilities where teams of specialists deliver excellent rehabilitation care. "Amputee Clinic Teams" include many physicians, nurses, physical and occupational therapists, as well as prosthetists and orthotists. This team evaluates each veteran's medical condition and lifestyle to prescribe the best prosthesis or orthosis available. Orthotists design, fabricate and fit custom and non-custom orthoses or braces, while prosthetists design prostheses, fabricate custom sockets, and order components. They assemble the products in a Prosthetics and Orthotics Lab. Prosthetists fit the prosthesis to the veteran's residual limb and align it to ensure comfort

Continued on page 5

Continued from page 4

and function. Even after fitting a prosthesis and training the veteran in its use, the Amputee Clinic Team continues to see and assist the veteran. VA's multi-disciplinary rehabilitation teams provide long-term care and support that can improve disabled veterans' abilities, independence and quality of life.

Professionalism Assured at VA

VA facilities and staff are state of the art and improving through certification. Currently, VA has 63 Prosthetics and Orthotics Labs that are staffed by 182 prosthetists and orthotists of whom 127 are certified by the American Board for Certification in Orthotics and Prosthetics (ABC) or by the Board of Orthotist and Prosthetist Certification (BOC). VA prosthetists and orthotists have access to the newest technologies and maintain their expertise by attending conferences, workshops, and manufacturers' training programs. They consult in clinics and provide the P&O devices that physicians prescribe. They custom fabricate, fit and repair artificial limbs and braces or order them from commercial vendors.

More VA prosthetists, orthotists and VA Prosthetics and Orthotics Labs are receiving certification. In December 2003, five (5) Prosthetics and Orthotics Labs were accredited. By June 2005, forty-one (41) of the VA Prosthetics and Orthotics Labs had earned certification by one of the two national accrediting organizations (ABC and/or BOC); and 106 prosthetists/orthotists were board-certified. Several accredited labs also have earned certification from the National Commission on Orthotic and Prosthetic Education (NCOPE), which enables these Labs to participate in residency programs from the nine Prosthetic and Orthotic programs located in universities and colleges throughout the United States. Currently, 58 Prosthetics and Orthotics Laboratories are accredited by ABC or BOC. Additionally, 13 of these labs have received NCOPE accreditation and are approved residency sites.

PSAS and VA Serve Veterans' Needs

Veterans can feel confident that PSAS and VA are working for them. VA-sponsored research, development and testing help deliver effective, new assistive technologies that can improve veterans' mobility and quality of life. VA seeks to restore abilities to disabled veterans through superior rehabilitation care and long-term support. Finally, VA demonstrates its ongoing commitment to U.S. veterans by improving the training and accreditation of VA staff and facilities. PSAS and VA share the common purpose of restoring to the greatest extent possible the abilities of disabled veterans.

Robert M. Baum is Program Manager of Prosthetics and Clinical Logistics at the VA Central Office (10FP) in Washington, D. C. 20420.

Contact Mr. Baum at the above address (Telephone: 202-254-0440 or Fax: 202-254-0470) to ask questions about this article or to suggest future articles.

NURERC Welcomes Traveling Fellows

NURERC hosted the **Traveling Fellows Initiative93 Technische Orthopädie 2007** on March 12-14, 2007. Established in 1993 by Dr. **René Baumgartner**, Dr. **Ernst Marquardt**, Dr. **Georg Neff**, and others, now Dr. **Bernhard Greitemann** coordinates the tour. Approximately every two years, a committee selects German speaking orthopedic surgeons and others who specialize in rehabilitation to visit U.S. hospitals and research institutions.

Traveling Fellow, Felix Tschui, M.D., (Bellikon, Switzerland), spoke at NURERC.

During the 3-day visit, the Fellows toured the Northwestern University Prosthetics Research Laboratory (NUPRL) where they heard presentations by some of NUPRL's researchers. The Fellows also presented their research. **Ludger Linkemeyer**, CPO, (University of Münster, Germany) discussed "A Comparison of Different Artificial Knee Joints for Prostheses." Dr. **Felix Tschui** (Bellikon, Switzerland) presented "Modern Prosthetic Feet Compared by Gait Analysis and Questionnaire (Efficiency and Quality of Gait Were Based on Ground Reaction Forces)." Dr. **Rainer Biedermann** (University of Innsbruck, Austria) discussed "Deformity Correction by External Fixation." Dr. **Nicola Ihme** (University of Aachen, Germany) discussed "Treatment Options in Childhood in Total Aplasia of the Femoral Head."

The exchange of information stimulated new ideas and interesting discussion among NURERC researchers and the Traveling Fellows

Women Seek Careers in Biomedical Engineering

By R. J. Garrick, Ph.D.

Craig Heckathorne, M.S. (Research Engineer at NURERC), **Bolu Ajiboye, M.S.** (doctoral candidate in Biomedical Engineering) and **Sarra McClintock** (graduate of the Northwestern University Prosthetics-Orthotics Center and prosthetist at the Rehabilitation Institute of Chicago) represented Biomedical Engineering (BME) and highlighted career options in prosthetics and orthotics (P&O) and engineering research at **Northwestern University's 36th Annual Career Day for Girls**. Sponsored by the **Robert R. McCormick School of Engineering and Applied Science** and the **Society of Women Engineers** (SWE), nearly three hundred high school girls attended the events.

Mr. Heckathorne and Mr. Ajiboye focused on bioengineering research in upper limb prosthetics while Ms. McClintock focused on lower limb prosthetics and reviewed career opportunities as allied health professionals in the field of P&O. Explaining the objectives and scope of biomedical research in P&O while showing prosthetics components that have been designed and developed in our laboratory, Mr. Ajiboye wore a training arm (TRSP Grip 2 with voluntary closing) that demonstrates to non–amputees how it feels to use a transradial prosthesis.

Demonstrating a training arm, Bolu Ajiboye, M.S. (left), develops an awareness of grasp strength by gripping the hand of Craig Heckathorne, M.S. (right).

Mr. Heckathorne identified different levels of amputation and explained the features of body-powered (mechanical) prostheses as well as myoelectrically-controlled electric-powered prostheses. He showed the audience a partial hand prosthesis that was designed at NUPRL for a research subject whose hand lacks fingers and thumb. Explaining that muscles in the residual limb release electric signals that can operate high-powered prehension devices, he invited members of the audience to use a demonstration myoelectrically-controlled arm designed for non-amputees.

Young women listen attentively to the NUPRL presentation as they consider career options in biomedical engineering.

Ms. McClintock reviewed the importance of custom made sockets and prostheses for the lower limb and explained how people wear them. Noting that hundreds of different knees and feet are available, she described weight activated stance knees. She compared the appearance and function of cosmetically anthropomorphic legs and feet and sports specific prostheses that are optimized for competitive athletics.

In response to audience questions about the education necessary for a career in BME, Ms. McClintock suggested the value of a pre-medical education and advised women in the audience to visit a P&O laboratory where they can speak directly with a professional. Mr. Heckathorne emphasized that math is important for a future in all fields of engineering and that many students select BME as a postgraduate specialty. He identified backgrounds that can lead to careers in prosthetics engineering, including mechanical and electrical engineering, materials science, art and industrial design, anatomy and the ability to work with one's hands.

Mr. Ajiboye described postgraduate BME opportunities in research, academic and commercial sectors and concluded by identifying the field of P&O engineering as an area where one can make a positive difference.

NURERC NEWS

Meetings

Steven A. Gard, Ph.D., participated in the American Academy of Orthotists and Prosthetists (AAOP) Research 101 Meeting, held in Chicago, IL, on December 1-2, 2006.

Dudley S. Childress, Ph.D., participated in a Polytrauma Conference, hosted by Dartmouth College, Thayer School of Engineering, Hanover, NH, on December 3-5, 2006.

Steven A. Gard, Ph.D., attended and participated in the VA Center of Excellence Review Board Meeting, held in Washington, D.C., on December 11-12, 2006.

Steven A. Gard, Ph.D., and **Stefania Fatone**, Ph.D., attended a meeting convened by the American Academy of Orthotists and Prosthetists (AAOP) to discuss "Assessment of Literature Quality for Academy-Sponsored SSCs," held in Seattle, WA, on January 19-20, 2007.

Steven A. Gard, Ph.D., **Dudley S. Childress**, Ph.D., and **Andrew Hansen**, Ph.D., attended the Rehabilitation Engineering Research Center (RERC) Directors' Meeting in Washington, D.C., on March 14-16, 2007. Dr. Childress presented an historical retrospective about the development of rehabilitation engineering research centers.

Invited Lectures and Presentations

Stefania Fatone, Ph.D., was an invited participant at the American Academy of Orthotists and Prosthetists State of the Science Conference on "Biomechanics of Partial Foot Amputation," held in Chicago, IL, on March 3-4, 2007. Dr. Fatone co-authored with Dr. **Michael Dillon** and Ms. **Margaret Hodge** (both of La Trobe University, Australia), the systematic literature that formed the basis for this meeting.

"Effect of Ankle Foot Orthosis (AFO) Foot Plate Length on Plantar Pressures in Adults with Hemiplegia," by **Fatone, S., Gard, S. and Malas, B.** was presented at the 33rd Academy Annual Meeting and Scientific Symposium, San Francisco, on March 21-24, 2007.

Andrew Hansen, Ph.D., was an invited speaker at the Jesse Brown VA Medical Center's weekly research meeting, held in Chicago, IL, on December 1, 2006. Dr. Hansen presented "Roll-over Shape: A Tool for Design, Evaluation, and Alignment of Prosthetic Ankle-Foot Mechanisms."

"Pilot Study Evaluating Ankle Foot Orthoses Using Roll-over Shapes," by **Sorci, E., Fatone, S., Hansen, A. and Gard, S.** was presented at the 33rd Academy Annual Meeting and Scientific Symposium, San Francisco, CA, on March 21-24, 2007.

Publications

Stefania Fatone, Ph.D., and **Andrew Hansen**, Ph.D. "A Model to Predict the Effect of Ankle Joint Misalignment on Calf Band Movement in Ankle-foot Orthoses." *Prosthetics and Orthotics International*, 31(1), March 2007, pp. 76-87.

Hansen, A., Meier, M., Sessoms, P., Childress, D. "The Effects of Prosthetic Foot Roll-over Shape Arc Length on the Gait of Trans-tibial Prosthesis Users." *Prosthetics and Orthotics International*, Vol. 30, No. 3, December 2006, pp. 286-299.

Ohnishi, K., Weir, R. F. *ff*., Kuiken, T. A. "Neural Machine Interfaces for Controlling Multifunctional Powered Upper-Limb Prostheses." *Expert Review of Medical Devices*, Vol. 4, No. 1, 2007, pp. 43-53.

Honors

Stefania Fatone, Ph.D., BPO(Hons), received **Honorary Membership** to the **American Academy of Orthotists and Prosthetists** (AAOP) at the 33rd Academy Annual Meeting and Scientific Symposium, San Francisco, CA, on March 21-24, 2007.

Fellowship and Travel Grant Awarded

Doctoral student, **Angelika (Kiki) Zissimopoulos**, M.S., was awarded the **Dr. John N. Nicholson Fellowship for 2007-2008**. This endowment at Northwestern University supports highly motivated and academically superior graduate students who are enrolled in the sciences or engineering and Ph.D. students in management. Preference is given to applicants who are U.S. citizens of Greek descent.

Ms. Zissimopoulos, who presented "The Biomechanical and Energetic Effects of a Stance-Control Orthotic Knee Joint," (authored by **Zissimopoulos, A., Fatone, S., and Gard, S.A.**) at the 33rd Academy Annual Meeting and Scientific Symposium, San Francisco, CA, on March 21-24, 2007, also was awarded a **Conference Travel Grant** through the Northwestern University Graduate School.

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