VICONPEAK

THE STANDARD

No. 1 2005

BALANCE STUDIES in Movement Function Research

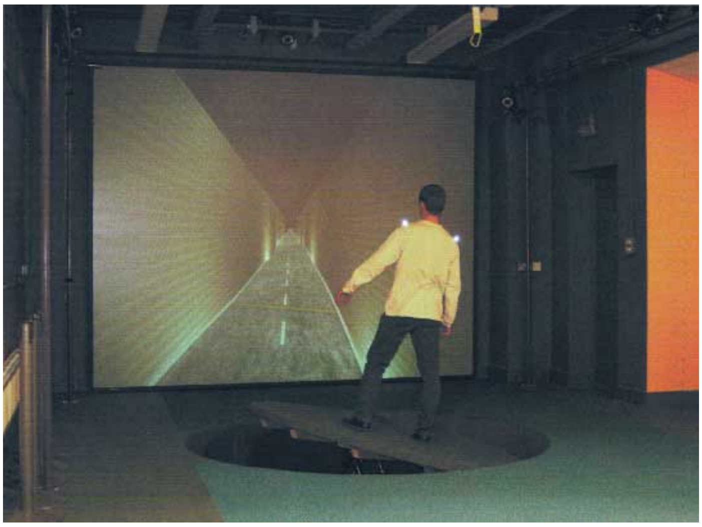

Figure 3: The "Bumpy Road" scene represents a simple feed-forward environment. A pre-determined function drives the platform and the video in synchronism and the subject's balance reactions are measured by the Vicon system.

Figure 4: In the "Boat" environment the underlying logic can be described by real time feedback loops. The subject's movement drives the boat on the 3D video screen and the platform responds at the same time. The feedback is that the movement of the platform has an effect on the subject's balance.

by Dr. Gabor Barton
Senior Lecturer in Biomechanics,
Research Institute for Sport & Exercise Sciences, Liverpool John Moores University, Liverpool, England

A lot of delicate details of human balance and posture have been uncovered following the conventional scientific approach of breaking down the phenomenon of standing balance into its conceptual building blocks (inputs, processing and outputs) and examining the components in great detail. The complexity of the experiments however is still inferior when compared to the challenges of real life situations where balance seamlessly or consciously plays an integral part of coping with our environment. How a figure skater can land after a jump on a narrow blade, how a child learns to ride a bicycle, how a mother can manoeuvre a buggy on a bus braking in a bend, or even how a frail old lady can stand by the kitchen sink with poor vision and painful hips, are all challenges to the experimenter which so far had to be avoided or largely simplified before they could be approached.

Vision, proprioception and the vestibular system are the three main components which determine human balance. The continuously flowing signals are interpreted by the neuro-musculo-skeletal system which is able to maintain an upright position even under highly dynamic conditions. The balancing subject's performance can be measured by standard methods used in biomechanics, including the movement of the center of gravity, center of pressure, video, three-dimensional movement analysis and electromyography. A slightly more complex task is to influence the senses determining balance by controlling what the human sees and feels. Vision can be influenced by projecting an image on a screen or into a head mounted display. Proprioception and the vestibular system can be influenced by placing the human onto a movable platform.

The tool needed to approach balance in its entirety has to have an all encompassing scope. A comprehensive model of a balancing human includes the inputs that influence the neuro-musculo-skeletal system, the processes of the central and peripheral nerve system, and the outputs which are the three-dimensional movements of the body (Figure 1). The CAREN system (MOTEK, Amsterdam, The Netherlands) is the only super-system available commercially at present which combines various tools in an integrated environment in a way that gives control over the standing subject's proprioception, vision and vestibular system, and registers the person's responses by recording quantitative measures of movement. The equipment includes a software driven six degrees of freedom movable platform together with a virtual reality video screen and a complete clinical motion analysis system including a Vicon 612 system with eight M2 cameras, video, force platforms, analogue inputs, and electromyography (Figure 2).

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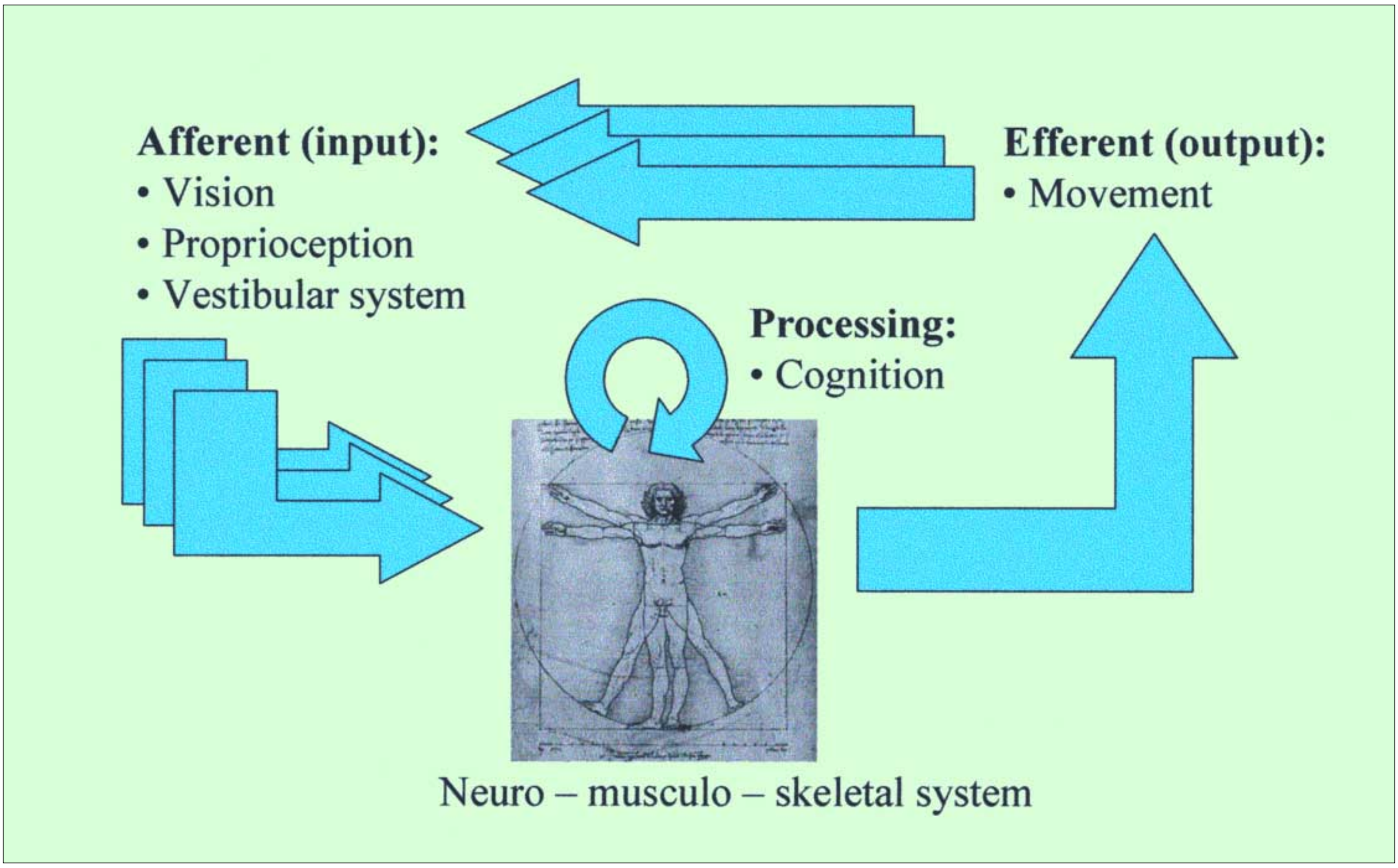

Figure 1: A systems approach to human balance including the inputs determining balance, processing of inputs, and movement of the person as outcome.

The D-Flow software manages all components of the system in a seamless way, thanks to an intuitive user interface which simplifies the building of a virtual environment dragging modules onto a canvas and connecting them with data flow channels. The simplest experiment puts the subject standing on the platform into a "Bumpy Road" environment (Figure 3). The subject's vision is controlled by projecting a 3D moving road scene on the video screen. Proprioception and the vestibular system are controlled by the 3D rotation and translation of the moving platform faithfully matching the road surface. The movement of the subject balancing on the moving platform is measured using the Vicon system, a force platform and surface EMG.

The "Bumpy Road" scene has a feed-forward arrangement as the road's bumps are pre-programmed and are simply driving the OpenGL graphics providing the video, and also driving the platform's movement, while the person's balance responses are recorded. The next level of complexity is based on the additional extra that comes with the CAREN system. All inputs and outputs are handled in real time and so it is possible to create feedback loops by connecting the outputs to the inputs. The Vicon Workstation pumps the marker co-ordinates in real time into a data stream which is processed by the RealTime Engine software running on a dedicated Vicon PC. The D-Flow program (running on yet another PC) receives the data and integrates it into the virtual environment. In case of the "Boat" scene (Figure 4) the subject with Vicon markers attached to his body is standing on a virtual boat (the platform). The boat can be accelerated and decelerated by leaning forward or backward. The subject's tilt sideways turns the boat to right or left and of course the supporting platform rolls at the same time. Visual feedback is provided by a scene which puts the subject in the boat, on the waves, approaching an island with harbours. Even the shark fins are thrown in for reality. The "Boat" scene manipulates the

Figure 2: The layout of the laboratory. A local network of computers controls the Vicon 612 and the virtual reality components including the movable platform and 3D video.

subject in two real-time feedback loops running in parallel, involving vision and proprioception. The movement of the subject drives the 3D video scene and the perceived visual sensation feeds back onto the movement of the subject. Also, the sideways lean tilts the supporting platform which inevitably moves the subject. The platform really behaves like a boat and the visual scene is also breathtakingly responsive.

The Research Institute for Sport and Exercise Sciences (Liverpool John Moores University, United Kingdom) has received funding through the Science Research Investment Fund (SRIF2) scheme from the Higher Education Funding Council for England (HEFCE) to establish a dedicated Movement Function Research Laboratory (MFRL) which houses the only CAREN system in the UK. The mission of this state-of-the-art laboratory is to assess movement function, dysfunction and rehabilitation with a focus on movement re-training (Figure 5). The multidisciplinary team has an exceptional mix of expertise covering biomechanics, gait analysis, musculoskeletal injuries and motor control.

The key individuals involved in the laboratory are Dr Gabor Barton (Lecturer in Biomechanics), Prof Adrian Lees (Professor of Biomechanics), Dr Mark Lake (Reader in Biomechanics), Dr Jos Vanrenterghem (Research Fellow in Biomechanics), Prof Mark Williams (Professor in Motor Behaviour), Dr Mark Scott (Lecturer in Motor Skills) and Dr Raoul Huys (Research Fellow in Motor Control).

One of the workshops of the British Association of Sport and Exercise Sciences (BASES) Annual Conference in 2004 was held in the MFRL. The participants were introduced to the concepts, and the capabilities of the system were demonstrated. The research topics addressed in the MFRL are ranging from fundamental areas to highly specialised topics reflecting the multiple interests and experiences of staff. Since the official opening of the laboratory in October last year, the initial studies aimed at describing the technical characteristics of the CAREN system with an intention to explore its potential in balance research. Several papers and conference presentations related to the first projects are already in the pipeline which will pave the way towards application focused research. The most recent development is the collaboration between the Movement Function Research Laboratory and the Research Unit into Human Ageing and Development, directed by Prof Dave Goldspink within the same Research Institute. The first CAREN User Group Meeting and Workshop is scheduled for June of this year in the MFRL, following the decision by Michiel Westerman (CEO of MOTEK) to declare the MFRL as MOTEK's reference laboratory.

Editor's Note

Check out the STANDARD website: *www.viconstandard.org* for archived articles, a library of clinical paper summaries, news and the Image Library, as well as the current content of THE STANDARD. If you have a colleague who would like to register for THE STANDARD it can be accomplished easily online at *www.viconstandard.org*

We are always pleased to mention the presentation or publication of Vicon Users' papers, accompanied by the appropriate website connection if applicable and/or the publisher's details. Please send title, author and publication information with a short summary by e-mail to *gbishop441@aol.com* or post a copy of the paper itself to Gerald Bishop, Editor, The Standard, Gerald Bishop Associates, Hillview House, New Street, Charfield, Wotton-under-Edge, Gloucestershire GL12 8ES, England.

Incidentally, anyone searching for published papers can not only go to the "Papers" section of *www.viconstandard.org* but, for a wider search, to an extremely comprehensive collection of academic and professional publications at *www.ingenta.com* A recent check showed that over 17 million papers were online there from almost 30,000 publications. A search for "gait analysis" for example, produced a list of 905 and "Vicon" located 105. It is worth checking out.

Finally, check out the NASA website *www.nasa.gov* which is packed with interesting information. If you go to the Home page and type "ABF" into the Search box you will arrive at "Anthropometry and Biomechanics Facility (ABF)". A click on this line takes you to three choices – Equipment, Facilities and Projects. Click on "Projects" to see a list of various interesting aspects of NASA's work. Among these is a project entitled "Evaluation of a full body scanning technique for the purpose of extracting anthropometrical measurements" (numbered 12 in the list). Click on to see the Vicon 612 10-camera system at work. A click on "Equipment" in the three choices includes a description of the Vicon system.

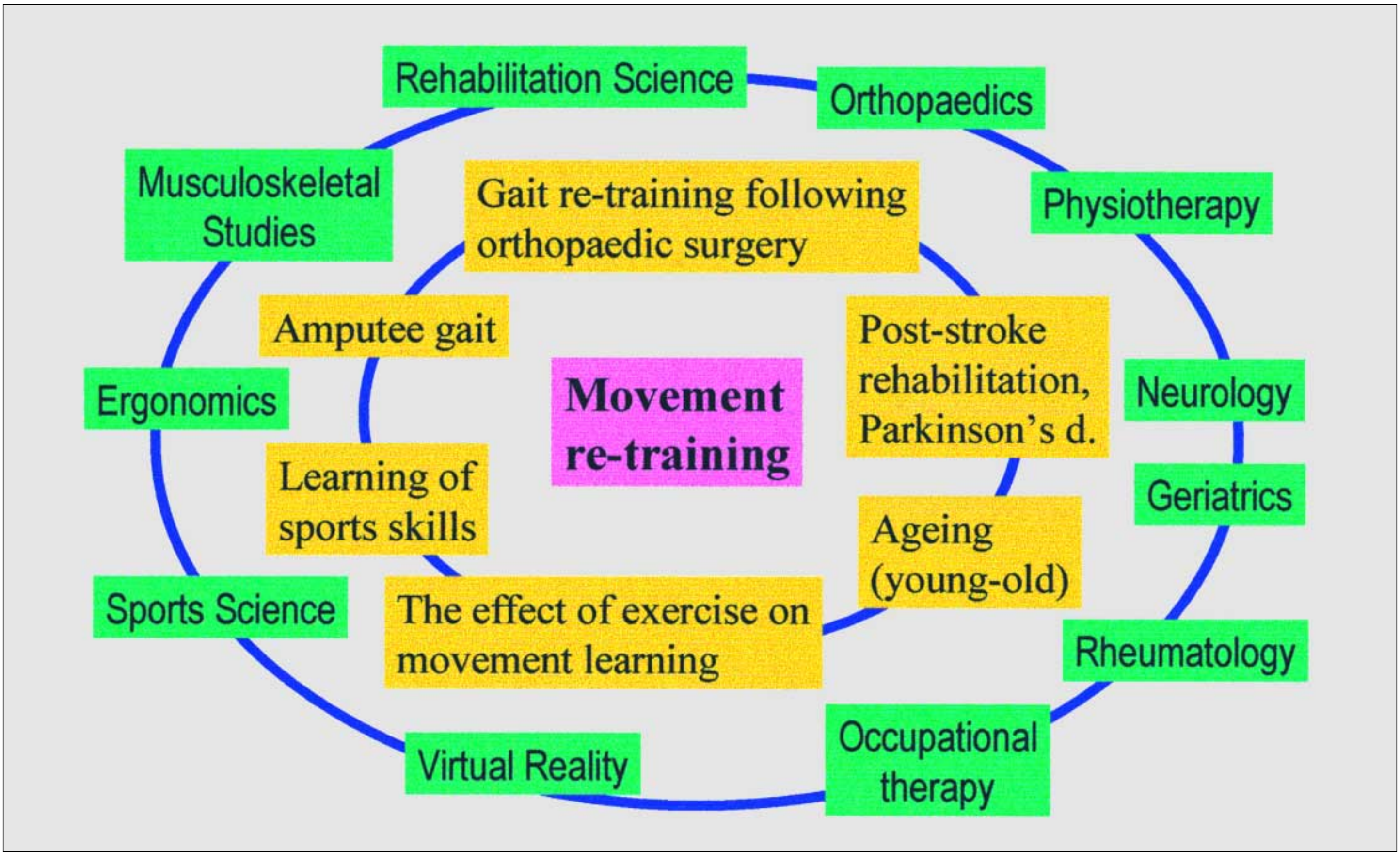

Figure 5: Potential applications which can be targeted with the equipment available at the MFRL.

INTERDISCIPLINARY MOTION CAPTURE

Applications include muscle activation and vibration studies

By Michele Oliver, Ph.D., P.Eng*#.
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and Taylor Murphy, M.Sc.
(Biological Engineering) Candidate*

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Figure 1 Adjustable Vicon permanent camera mounts in small volume capture laboratory.

The School of Engineering at the University of Guelph began offering degrees in Biological Engineering in 1969 and in 1973 became the first fully accredited Biological Engineering program in Canada. Within Biological Engineering, two current foci are Biomechanics and Biomedical Engineering. The school currently has three faculty members who specialize in these areas. When looking across the university campus, even though Guelph is a mid-sized institution, the university is in the enviable position of having a total of eight faculty members who conduct research in Biomechanics. The five other Biomechanics researchers reside in either Human Biology and Nutrition or the Ontario Veterinary College. Given that Guelph has evolved as an extremely interdisciplinary institution, inter-department and external collaboration is encouraged and fostered. As a result, many of the research projects using the Vicon system involve researchers and students from a number of departments and universities.

Motion Capture and EMG Laboratory

The permanent home of the newly installed (July 2004) six camera Vicon 460 motion analysis system is an approximately 16 square meter small volume capture laboratory. The six M2 cameras are attached to the walls along cylindrical bars at varying levels with permanent camera mounts to prevent lab personnel and subjects from tripping on cabling (Figure 1). The Vicon workstation is used to collect signals synchronized using a 64 channel analog to digital conversion board from various analog inputs including: an eight channel Noraxon™ telemetered EMG system, strain gauges, load cells, and Biometrics™ goniometers. The lab also contains a Microscribe™ 3D digitizer which is used for some Vicon validation work as well as other animal and human cadaveric studies.

Funding to purchase the Vicon system was obtained from Canadian Foundation for Innovation New Opportunities and Ontario Innovation Trust grants.

CURRENT RESEARCH PROJECTS

Development of a Dynamically Moveable Armrest for Heavy Equipment Operators

Past research indicates that current lever operators are at risk of repetitive strain injuries as a consequence of exposure to ergonomically inadequate armrest design. It is the goal of the present research to design a more ergonomically sound armrest that will act to decrease muscle activation in the shoulder complex.

The laboratory set-up includes a mock-up of a typical North American excavator cab, including operator chair and hydraulic-actuation joystick (Figure 2). Data acquisition involves six Vicon M2 cameras capturing a customized upper limb marker set, as well as EMG data used to quantify muscle activation levels. Through the application of BodyBuilder software, upper limb kinematics and corresponding joystick angles are quantified in order to assess the movement patterns of the upper limb-joystick linkage (Figure 3). Once an arm movement pattern has been established, an armrest following a similar motion pattern will be designed using computer aided design and then tested using EMG and Vicon to determine the efficacy of the new design. An initial study was conducted to determine the most appropriate EMG normalization technique(s) to use in quantifying muscle activation patterns for joystick motion. During this study both EMG and Vicon data were collected (Murphy and Oliver, 2005).

[Murphy, T. and Oliver, M. A comparison of task and muscle specific isometric submaximal EMG data normalization techniques for the analysis of muscle loads during hydraulic-actuation joystick controller use. Accepted for presentation and publication at the 20th Congress of the International Society of Biomechanics and the 29th Annual Meeting of the American Society of Biomechanics, Cleveland, Ohio, August, 2005.]

Simulated Whole Body Vibration Studies Using Vicon and a 6 DOF Robotic Platform

Current literature regarding human responses to whole-body vibration (WBV) is limited with respect to understanding such areas as: the degree and patterns of muscle activation, effects of posture, effects of vibration exposure levels and types of exposures used, as well as the location and the number of acceleration measurements made on the body. In order to get a better understanding of the

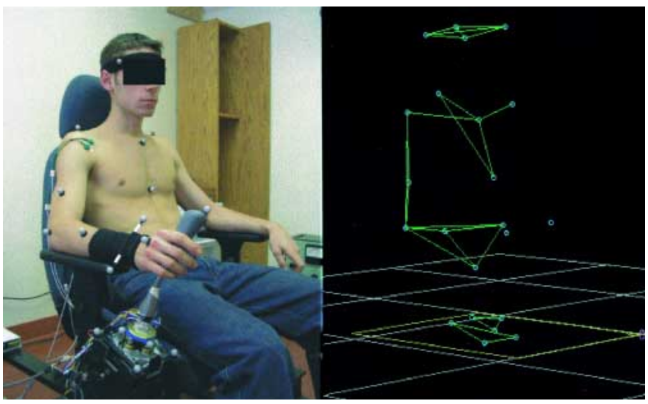
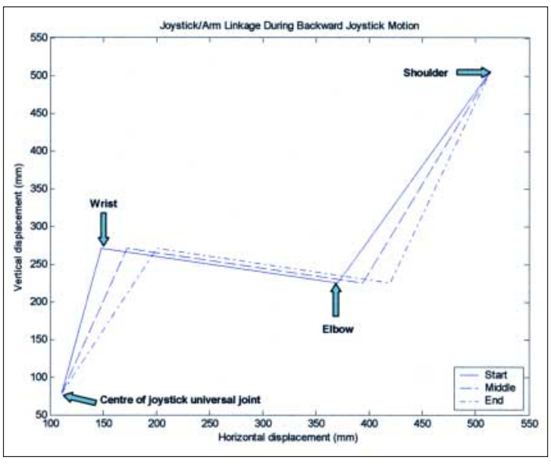


Figure 2 Subject sitting in heavy equipment chair using instrumented joystick

Figure 3 Planar view of wrist, elbow and shoulder motion at the start, middle and end of backward joystick motion (motion is being performed without an armrest) ▶



responses to WBV, more detailed studies need to be conducted, where many levels of the spine are measured for vibration transmission in concert with muscle activation measurements. At the University of Guelph, professors and graduate students from Engineering, Human Biology and Nutritional Science, Biophysics, and Psychology are beginning to conduct studies which aim to fill gaps in the literature.

Field data obtained from operating mobile machines fed into a 6 DOF robotic platform located in a laboratory in Human Biology and Nutritional Science at the University of Guelph will enable the researchers to conduct detailed postural measurements and to monitor the activation patterns of selected muscles. The Vicon system enables these researchers to investigate the effects of WBV exposures for frequencies up to 25Hz which is a very important frequency range for this type of investigation. The capabilities of the Vicon system allow for investigations into the transmission of translational and rotational WBV throughout the human spine, the influence of posture and WBV exposure on vertebral disc herniation, and the influence of WBV on spine stability, all of which are currently being explored at the University of Guelph with the Vicon 460 system.

Initial work which validates the use of the Vicon 460 motion capture system for the prediction of acceleration will be presented this summer at the upcoming combined meetings of the International Society of Biomechanics and the American Society of Biomechanics (Jack *et al.*, 2005).

[Jack, R.J., Oliver, M., and Hayward, G. Validation of the Vicon 460 motion capture system for whole-body vibration acceleration determination. Accepted for presentation and publication at the 20th Congress of the International Society of Biomechanics and the 29th Annual Meeting of the American Society of Biomechanics, Cleveland, Ohio, August, 2005.]

Validation of a Hand and Forearm Marker Set

University of Guelph is one of a very few engineering schools in Canada to have permission to conduct studies on-site using human cadaveric specimens. A group of four, senior biological engineering students is designing a positioning jig for a cadaveric hand and forearm to be used in the validation of a hand/forearm Vicon marker set. Vicon will also be used to assess the positioning capabilities of the jig. The data will be collected using six tripods in a secure Biohazard laboratory located in the School of Engineering. So that the jig can be used in a future study, it will be made from CT compatible materials such that it will allow for the acquisition of CT images to be used in the development of a finite element model of the hand and wrist. Both of the above projects represent a cooperative venture between two researchers and a graduate student from the Guelph School of Engineering and a professor from the Division of Anatomy at the University of Toronto.

Development of Inverse Dynamics Upper Limb Models

Very few models of inverse dynamics exist for the upper limb. Models have been developed which quantify the forces and torques exerted by an operator on a hydraulic-actuation joystick over the full range of joystick motion including the hard endpoint which occurs when the operator has moved the joystick to the end of the range of motion. Using the forces and torque predicted from the joystick models, an inverse dynamics model is in the process of being created which quantifies joint reaction forces and moments in order to quantify loading on the wrist, elbow and shoulder. Vicon and BodyBuilder software are being used to quantify the various arm and joystick angles. Electromyography from selected upper limb muscles is being concomitantly monitored using the Noraxon™ telemetered EMG system.

Future Research

Given that the University of Guelph is renowned for interdisciplinary research, cooperation between departments both inside and outside of the university will continue to generate innovative applications for the Vicon system. As an example, a state-of-the art driving simulator obtained with Canadian Foundation for Innovation and Ontario Innovation Trust Funding is in the process of being commissioned. This represents a cooperative venture between researchers in Computer Information Systems and Psychology and has been installed in the engineering building which may open the door for future collaboration and uses for the Vicon system.

Pete Meddings

17 June 1945 - 4 February 2005

Surprising as it may be to many now working in the field, Pete, a career salesman, was one of the key figures in the creation of clinical gait analysis. He was technically trained and astute (BSc in Physics from Birmingham), but did not design groundbreaking equipment or software. He learned enough biomechanics and physiology to communicate well, but wrote no seminal papers. His special contribution was the insight that only a focused alliance of clinical and manufacturing specialists could create and sustain new medical techniques for the benefit of a small but needy group of patients.

When Pete joined the company in 1990, Oxford Metrics was one of several small private businesses in Europe and US, producing 2D and 3D optical kinematic measurement systems. Most of their customers were engaged in biomechanics research of one sort or another but there was little coherence in the slowly growing community of users. Pete's unique insight was that the only way to move the field forward for the benefit of all concerned was the creation of a coherent market with specialised products tailored to its needs.

With very limited resources and with a conscious decision to forgo other potential commercial opportunities, Oxford Metrics set about analysing the needs of the users and patients and began designing systems to suit. At the same time, Pete began to create channels for this new community of orthopaedic surgeons, engineers, therapists, and particularly the small group of clinical pioneers, to communicate and share their growing range of experiences. This publication, with its circulation far wider than just Vicon users, became a key component of this process.

Pete's plan was pure marketing - not in the sense of pushy inducements to purchase - but the creation of a new market for the benefit of all involved. Part of his legacy is that - 15 years on - the clinical gait analysis community is still close, healthy and growing.

Pete's career had two distinct phases. Directly out of university, he joined one of the world's largest international scientific instrument makers, Beckman Instruments. After training in the UK, he progressed to various international positions within Beckman, spending time in the United States and several other countries. Pete then joined Oxford Metrics as Sales and Marketing Manager/Director and held this key management position for the majority of time until his retirement from OMG. Over 15 years he built up and consolidated the company's growing network of international distributors, basing it very much upon personal relationships rather than tight legal agreements. The majority of Vicon distributors clearly regarded their association with the company and their friendship with Pete as almost one and the same thing.

Pete made many other notable contributions to the general management of the company. Most significant among these was the establishing of an integrated US sales and customer support office. By the mid 1990s it had become clear that Vicon and its customers would benefit from the creation of a strong US presence. The company's diversification into animation applications also suggested that a location close to the heart of this new market would make sense. Pete, from his previous experience and association with a US marketing operation in California had a strong affinity for the US. Consequently he was the obvious choice to set up the new venture and to instil close links between the US and UK operations.

At a cost of considerable disruption to his family, who were not in a position to relocate, in 1997 Pete moved to Orange County, California for 6 months and started building a new business almost from scratch – finding premises, recruiting new staff (many of whom are still with the company), establishing procedures, and building up revenues to support the new organisation. This period also helped cement many of Pete's strong and lasting friendships among Vicon's US customers.

Pete Meddings was, in all things, a man of integrity and drive – a reliable, trustworthy and loyal colleague and a good friend.

Julian Morris, Gerald Bishop

Figure 1c. Measurement of a transtibial amputee's residual limb morphology using magnetic resonance imaging (MRI).

Figure 1a. Patellar-tendon bearing prosthetic socket for a transtibial amputee lined with two 1360 element Tekscan PScan FVR transducers to measure interface stresses during stance and gait.

Editor's introduction:

The author, Vern Houston, worked hard to produce this article despite a heavy workload and imminent deadlines. When asked to provide additional details for the by-line, he wrote the following, which was considered worthy of reproduction in its entirety. I think it is a typical example of collaborative teamwork and humor combining with a rich wealth of experience – a celebrated tradition in movement analysis studies. GB.

PROSTHETICS, ORTHOTICS AN

Experience and Teamwor

By Dr. Vern Houston

Vern writes:

"My job titles are: Associate Professor, Department of Rehabilitation Medicine, NYU School of Medicine; and Senior Research Scientist, Rehabilitation Engineering Research, Department of Veterans Affairs New York Harbor HealthCare System. I have a bachelor's degree in Mechanical Engineering, a doctoral degree in Electrical Engineering, and am ABC Board Certified in Prosthetics and Orthotics, as well as Licensed in P&O in the State of New Jersey. I have worked in clinical care and research and development in Prosthetics, Orthotics, and Pedorthics for 32 years. Our colleague, and recently retired Co-Director of the RERL, Mr. Carl P. Mason, MSBE, worked in the RERL for the Department of Veterans Affairs for 42 years. He was responsible for developing much of the instrumentation and conducting many of the locomotion studies performed in the first gait laboratory established by the Department of Veterans Affairs in the United States, as well as for developing the VAPC myoelectric externally powered hand, elbow, and hook, and the multi-axis SCI manipulator. Our Podiatric Medicine consultant, Martin Mussman, DPM, worked in the VA for 46 years. He started and directed the Podiatric Medicine Service in the Department of Veterans Affairs for over 32 years. Our research therapist, Ms. MaryAnne Garbarini, MA, PT, is a licensed physical therapist with a master's degree in movement disorders. She has worked in Prosthetics, Orthotics, and Pedorthics research for 21 years. Our mechanical engineer, material scientist, computer numerical analyst, Gangming Luo, PhD, is an Assistant Professor in Rehabilitation Medicine at the NYU School of Medicine; and a Research Scientist at the VA NYHHS. He is an internationally recognized expert in soft tissue mechanical modeling and testing, finite element and boundary value analysis, and in computational modeling of prosthesis osseous integration and remodeling. Dr. Luo has worked at the NYUSM and the VA NYHHS in Prosthetics, Orthotics, and Pedorthics research and development for 11 years. Mr. Aaron C. Beattie, BS, is our program analyst, numerical control system integrator and instrumentation specialist. Mr. Beattie has worked in Biomedical and Rehabilitation Engineering research for 21 years. Mr. Chaiya Thongpop, our research assistant and laboratory technician, has been working in Biomedical and Rehabilitation Engineering research for 20 years.

Looking at all of the time we have collectively put in, perhaps the article should be entitled: *"VA NYHHS / NYUSM Rehabilitation Engineering Research Laboratory — Old Researcher Folks Home." Or "RERL Researchers Serve Life Terms".

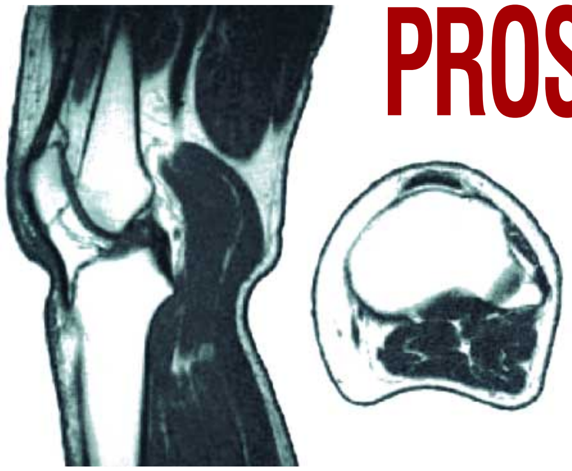


Figure 1d. Mid-sagittal plane and MTP–2.5 cm transverse MRI cross sections of the transtibial amputee in Figure 1c.

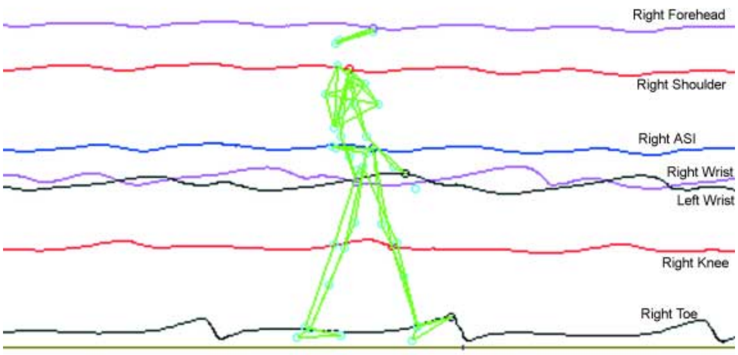


Figure 1f. Trajectories of the transtibial amputee's body segments and prosthetic limb in a comparative gait trial with a TSB prosthetic socket measured with the Vicon Motion Analysis System.

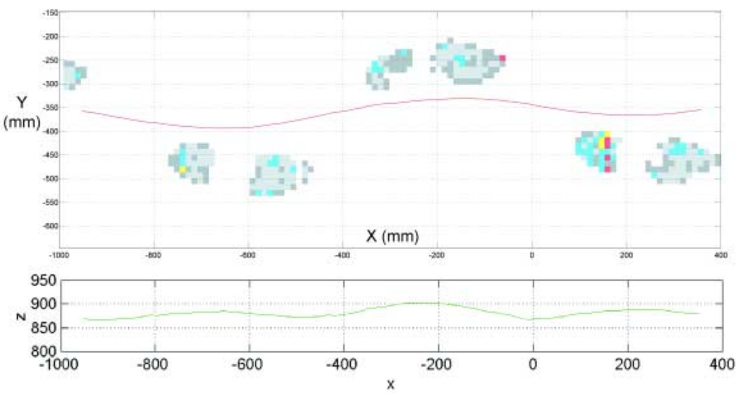
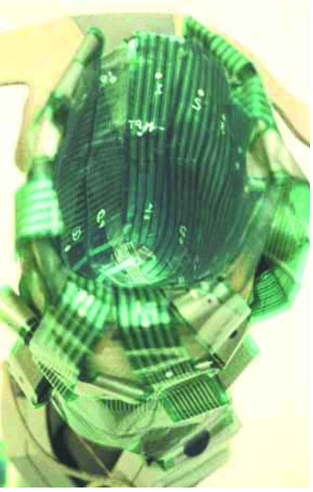


Figure 1g. The resultant center of mass (CoM) trajectory over a typical gait cycle for the transtibial amputee in Figure 1e.



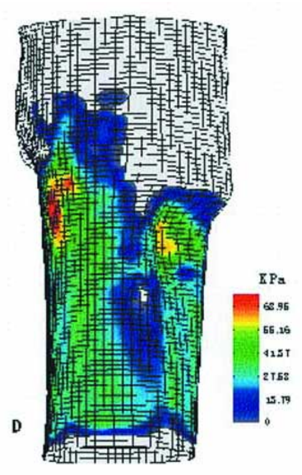
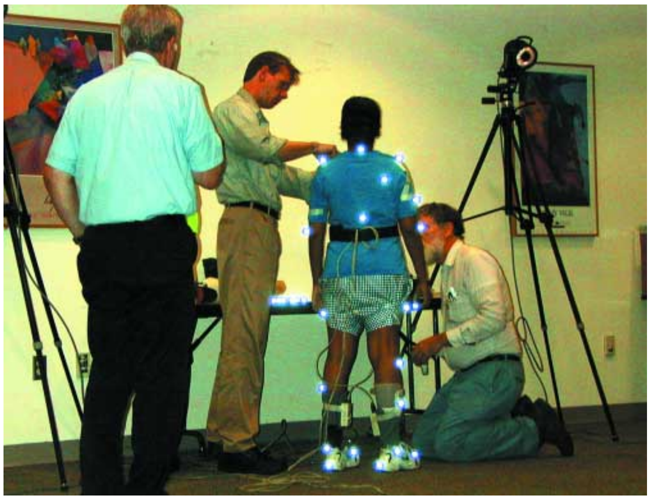


Figure 1b. Resultant interface pressure distribution at midstance in a typical gait cycle for a transtibial amputee in a PTB socket measured with Tekscan PScan transducers.

Figure 2a. Placement of photoreflective markers on an experimental subject in a comparative gait trial evaluating the kinematics of ankle foot orthoses.



D PEDORTHICS R&D

k in Action*

Figure 1e. The transtibial amputee in Figure 1c with photoreflective markers, PScan and FScan transducers, in a comparative gait trial with a TSB prosthetic socket to measure his body and limb segment kinematics.

The Rehabilitation Engineering Research Laboratory (RERL), at the Department of Veterans Affairs New York Harbor HealthCare System (VA NYHHS) and the New York University School of Medicine, Department of Rehabilitation Medicine (NYUSM), is a modern research laboratory established especially for research, development, and testing of Prosthetics, Orthotics, Pedorthics, and Rehabilitation Engineering procedures, systems, devices, and equipment. Historically, the RERL has its roots in the first Prosthetics, Orthotics, Pedorthics, and Biomechanics laboratory founded by the Veterans Administration in 1947 to conduct research and development to improve the rehabilitative treatment and care of US Veterans returning from World War II.

The RERL has offices, a computer laboratory, an electronics laboratory, a machine laboratory, patient fitting and evaluation rooms, a scanning laboratory, and a motion analysis laboratory. RERL instrumentation includes a Vicon eight 1000Hz M2-camera Model 612 Data Station Motion Analysis System with BodyBuilder and Polygon software, VA–Cyberware Lower Limb, Body, and Pedorthics Optical Digitizers, the VA Servo-controlled tissue indenters and integument tester, the VA NYHHS Prosthetics–Orthotics–Pedorthics CAD/CAM Systems, Tekscan PScan, FScan, and IScan stress measurement

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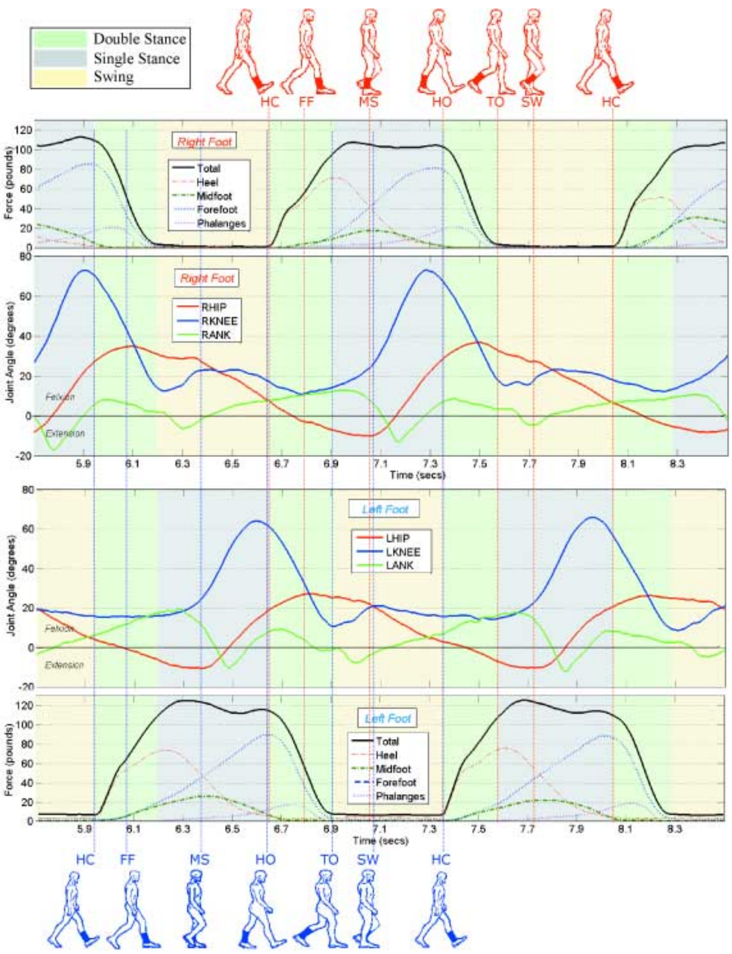


Figure 2d. Resultant pedal total and regional stress measurements and corresponding limb and body segment trajectories over a gait cycle for the subject in Figure 2b wearing the dual-axis AFO on her right leg. Comparative analysis of ipsilateral and contralateral limb measurements reveal advantages and disadvantages of orthosis designs.

Figure 2b. The experiment subject wearing a dual-axis AFO which allows relatively "normal" kinematic function compared to plastic posterior leaf spring design AFOs.

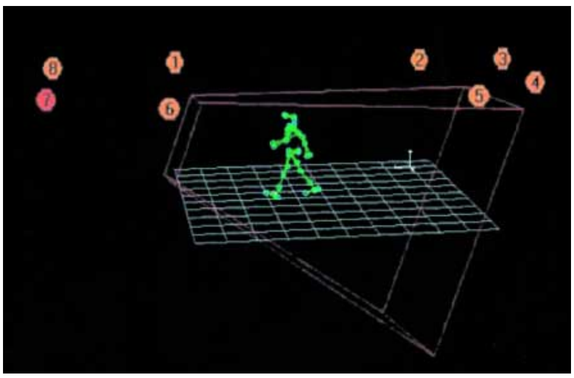


Figure 2c. Vicon BodyBuilder 3-D projected views of the subject in Figure 2b walking in a dual-axis AFO.

Figure 3a. Biomechanical assessment of a pedorthics patient's foot and ankle function. Previous video recordings and subjective assessments can be replaced with quantitative measurements of segmental trajectories, velocities, and accelerations recorded with the Vicon System.

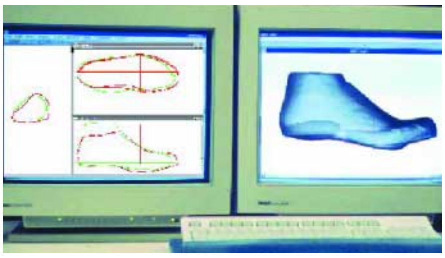
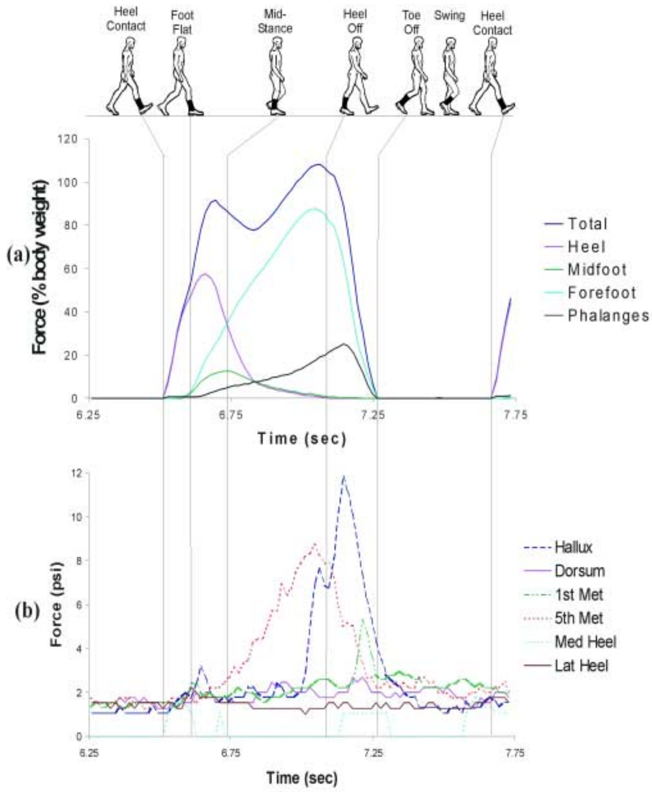


Figure 3c. VA Pedorthics CAD/CAM System design of a custom orthopedic last and shoe patterns for the patient in Figures 3a and 3b.

Figure 3d. Total and regional pedal plantar and dorsal stresses for the subject in Figure 3a and 3b in an orthopedic shoe measured with Tekscan FScan and IScan transducers and Kistler force platform.

Figure 3b. 3-D digitization of an experiment subject's foot and ankle with the VA Pedorthics Optical Digitizer.



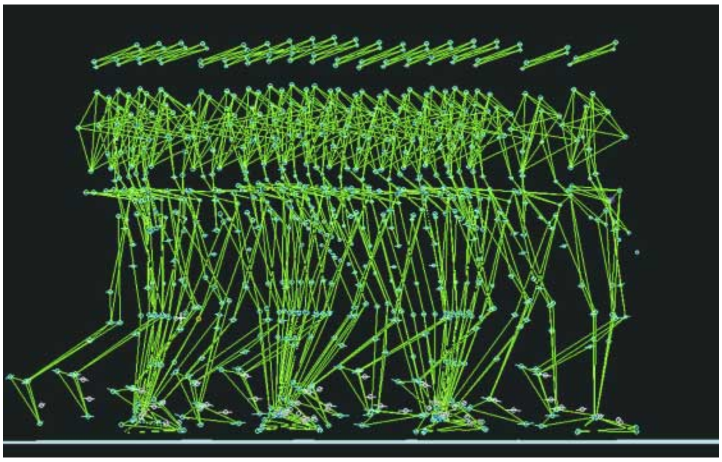


Figure 3e. Body segment model of a diabetic pedorthics patient over a typical gait cycle when wearing a rocker sole shoe.

systems, the CIR Systems GaitRite Electronic Walkway, Kistler Force Platforms, Cosmed K4b2 Respiratory Gas and Metabolic Energy Measurement System, Quark ECG System, and a full complement of electronic and mechanical instrumentation and equipment for design, fabrication, and testing of Prosthetics, Orthotics, and Pedorthics devices, systems, and procedures.

RERL staff are involved in a number of collaborative research projects with researchers at the VA NYHHS, the NYUSM, the NYU Hospital for Joint Diseases, the City University of New York City College Department of Biomedical Engineering, and the State University of New York Downstate Medical Center, in which the Vicon motion analysis system is an essential quantitative measurement and assessment instrument. The "portability" of the Vicon system has enabled RERL researchers to measure and monitor patients' movements in a range of settings while performing activities of daily living, and/or other specified tasks, to evaluate the patients' functional capabilities, to assess the efficacy of new rehabilitative treatments and their respective outcomes, to evaluate prosthetic/orthotic/pedorthic component functional performance, etc.

One of the key areas of research being conducted at the RERL is development, testing, and evaluation of prosthetic socket designs. Data is being collected and comparatively analyzed on the tissue stress–strain magnitude, gradient, and strain energy density distributions that are produced in amputees' residual limb tissues by: (i) traditional patellar tendon bearing socket designs; versus newer (ii) ambient pressure cast total surface bearing (TSB) sockets; versus (iii) positive pressure cast TSB sockets; versus (iv) negative pressure cast TSB sockets, and the consequent circulatory and metabolic impact the resultant stress–strain values have on residual limb tissues. Kinematic data collected with the Vicon system, in concert with information obtained on intra-socket loading and gait timing with Tekscan FScan and PScan transducers and the CIR Systems GaitRite Electronic Walkway, are being used to determine relationships between amputee residual limb geometric, morphological, and mechanical characteristics, and prosthetic socket design geometries and material properties, and prosthetic components' biomechanical characteristics and alignments. Intra-socket pressures are measured with two 1360 element Tekscan PScan FVR transducer arrays, lining the inside of the respective sockets (Figure 1a). As the subject walks, data is synchronously collected by the Vicon, Tekscan, and GaitRite systems, and the Kistler force platforms. The resultant socket/residual limb interface pressure distributions produced by the respective socket designs (as shown in Figure 1b for a PTB socket at midstance) are being comparatively analyzed as a function of the subjects' respective residual limb tissue morphology and mechanical stiffness, as determined from MRI scans and indentation studies (Figures 1c and 1d) of the subjects' residual limbs with and without their sockets donned, with and without external loading applied. Vicon recordings of the subject's gait kinematics (Figure 1f) together with GaitRite, Tekscan FScan, and Kistler force platform measurements of the respective resultant pedal plantar loading reveal the dynamic effects differences in the

Figure 4. Application of the Vicon system in upper limb movement analysis of an arthritic patient tracking hand and wrist movements when opening a tamper-proof container.

respective socket designs can have on the subjects' static and dynamic stability, and their gait, (Figure 1g).

Another key area of research being conducted at the RERL is development, testing, and evaluation of orthosis designs for hemiplegic, multiple sclerosis, and traumatic injury patients. Orthotic cuff/limb tissue and pedal plantar stress spatiotemporal distributions produced by various orthoses are being synchronously measured and comparatively analyzed in conjunction with kinematic data collected with the Vicon system, Tekscan FScan, CIR Systems GaitRite Walkway, and Kistler force platforms, to determine the effects different orthosis designs have on subjects' static and dynamic stability, their gait kinematics, and ambulatory strength and energy requirements. "Near normal" results are shown in Figure 2 for an experimental subject wearing a dual–axis (ankle–subtalar joint) orthosis in a comparative study of ankle–foot orthoses. Intra-subject comparative analyses between right and left limb kinematics for given orthosis designs, as well as between different designs, help reveal trends in performance for categories of subjects that can be used to establish prescription guidelines for the respective orthoses.

A third principal area of RERL research is Pedorthics. As shown in Figure 3a, patients' pedal biomechanical functional capabilities and deficits are assessed with video and Vicon system measurements. Their 3D pedal spatial geometry is measured with the VA Pedorthic Optical Digitizer (Figure 3c), and the resultant digitized data input into the VA Pedorthic CAD/CAM System (Figure 3b), where custom shoe lasts, insoles, and footwear upper patterns are designed and fabricated for subsequent assembly and fitting. Pedorthic research is also being performed measuring static and dynamic plantar and dorsal loading over a range of conditions to establish safe load limits for neuropathic diabetic patients with little to no sensation in their feet, (Figure 3d). The effects of rocker sole designs on pedal plantar loading and gait kinematics and stability in diabetic Charcot patients and rheumatoid and osteoarthritic patients are also being studied, (Figure 3e).

A fourth area of research where RERL investigators have taken advantage of the "portability" of the Vicon system is measurement and analysis of patients' upper limb movement patterns while performing ADLs. RERL investigators have measured upper limb segmental trajectories and velocities of hemiplegic, Parkinson's disease, and rheumatoid arthritic patients when performing tasks such as following a target LED in space to reveal visual field deficits and/or inhibited movement patterns, or opening a tamper-proof medicine container as shown in Figure 4. Such analyses have proven effective in developing alternate movement strategies for hemiplegics, and in assessing treatment efficacies in Parkinson's patients. They also can prove beneficial in design of new types of containers that are not as "painful" to open for arthritic patients.

The Vicon motion analysis system has proven to be a powerful and widely applicable tool for measurement and analysis of movement. RERL researchers are just beginning to tap its capabilities. As technology continues to develop, the RERL researchers look forward to watching the capabilities of the Vicon system grow, so the problems that can be taken on and solved in Rehabilitation Engineering will also expand.

THE BIRTH OF THE VICON MUSEUM

A new museum is about to be established at Vicon HQ in Oxford. "We are gathering the results of 20 years of research and design in motion capture," says Tom Shannon, one of Vicon's founders and the company's Engineering Director.

In the next issue of THE STANDARD, Tom Shannon will take readers on an interesting scientific journey, providing an enlightening review of the many technical milestones represented by the museum's equipment and explaining how much we can still learn from the past.

MEETING POINTS ...

American Academy of Cerebral Palsy & Developmental Medicine (AACPDM) –2005 Meeting – September 14 to 17 is in Orlando, Florida. See *www.aacpdm.org*

American Academy of Orthotists & Prosthetists The 2006 Annual Meeting in Chicago, USA will be held from March 1 to 14 at the Hyatt Regency Riverside Center. Details on *www.oandp.org*

American Academy of Physical Medicine and Rehabilitation (AAPMR) The 66th Annual Assembly will be at the Philadelphia Marriott Hotel, PA, USA from October 27 to 30, 2005 .The 2006 Assembly will be at the Hilton Hawaiian Village Convention Center, Honolulu, from November 9 to 12. Information questions to *info@aapmr.org* The AAPMR website is *www.aapmr.org*

American College of Sports Medicine – The 52nd Annual Meeting in 2005 is at the Gaylord Opryland Hotel in Nashville, Tennessee, USA from June 1 to 5. Abstracts submissions by February 2005; Advance Program available by March; Pre-registration ends May 13, 2005. See *www.acsm.org/meetings*

American Orthopaedic Society for Sports Medicine (AOSSM) The 2005 Meeting is from July 14 to 17 at the Keystone Resort, Keystone, Colorado, USA. Annual Meeting prospectus can be found on *www.sportsmed.org/secure/reveal/admin/uploads/events/Prospectus.pdf*
Information from the Society website: *www.aossm.org*

American Physical Therapy Association (APTA) The APTA Annual Conference 2005 will be held from June 8 to 11 in Boston, Mass. USA. Upcoming meetings on *www.apta.org/Meetings*
Main website *www.apta.org*
The Neurology and Pediatrics Section of the APTA is holding a symposium on "Linking Movement Science and Intervention" from July 15 to 21, 2005 at the University of Utah, Salt Lake City, Utah, USA. Information on *www.iiistep.org*

American Podiatric Medical Association The Annual Scientific Meeting in 2005 will be from August 4 to 7 at Marriott's Orlando World Center, Florida, USA. Meeting details on *www.apma.org/anmeet/meet*
Main site *www.apma.org*

American Spinal Injury Association – the 31st Annual Scientific Meeting is at the Fairmont Dallas Hotel, Dallas, Texas, USA from May 12 to 14, 2005. The 2006 Meeting will be in Boston. More details from *www.asia-spinalinjury.org/annualmeeting*

Australian Physiotherapy Association Conference on Musculoskeletal Physiotherapy is at Brisbane Convention Center, Brisbane, Queensland, Australia from November 24 to 26, 2005. Conference details: *www.mpa2005.com.au* or e-mail *mpa2005@meetingplanners.com.au* The Association website is *www.physiotherapy.asn.au*
The National Paediatric Physiotherapy Conference from September 15 to 18, 2005 is to be at the Alice Springs Convention Center, Alice Springs, Northern Territory, Australia. The special website devoted to this event is *www.apapaeds2005.com.au* and details are available by e-mail from *rose.kraljak@physiotherapy.asn.au*

Bone & Joint Decade (2000-2010) *www.boneandjointdecade.org* The 1st World Congress on Sports Injury Prevention is from June 23 to 25, 2005 in Oslo, Norway. The event is organized by the Oslo Sports Trauma Research Center, and includes "Current Concepts of Rehabilitation of Sports Injuries" The venue is the Holmenkollen Park Hotel. Congress pages: *www.ostrc.no/congress2005/*

Canadian Physiotherapy Association The 2006 Congress will be held from June 30 to July 2 at the Delta St John Hotel & Conference Centre in St John, New Brunswick, Canada. Information from *www.physiotherapy.ca/congress2006*

Centre for Rehabilitation & Human Performance Research* 3rd International Biomechanics Conference at the University of Salford, Manchester, England from September 5 to 7, 2005. Deadline for Abstracts submissions – March 31, 2005. *www.healthcare.salford.ac.uk/crhpr/biomech2005.htm*

Clinical Movement Analysis Society The CMAS 5th Annual Conference will be held during 2006 in Newcastle upon Tyne, England. Information available shortly on *www.cmasuki.org*

European Medical and Biological Engineering Conference (EMBEC) The 3rd Conference is from November 20 to 25, 2005 at the Congress Centre in Prague, Czech Republic. Early registration by August 31, 2005. *www.embec05.org*

European Paediatric Orthopaedic Society is holding the 25th Meeting in Dresden, Germany from April 5 to 8 2006 (year of Dresden's 800th anniversary). The Meeting will take place in the Congress Center, Hotel Westin Bellevue in Dresden *www.westin-bellevue.de* The main Society website is. *www.epos.efort.org* and directly for information on the congress, submission of papers online etc *www.epos.efort.org/Dresden2006/index.asp*

European Society for Movement Analysis in Adults & Children (ESMAC) The 14th Annual Meeting will be in Barcelona at the CCIB International Convention Centre from September 22 to 24, 2005. Early registration date is July 30, 2005. There will be pre-congress (September 19-21) gait analysis courses and seminars. The congress website for more information is *www.esmacmegara2005.com* The main ESMAC website is *www.esmac.org*

Human Factors and Ergonomics Society of Australia The 2005 National Conference is in Canberra from November 21 to 23. Website *www.ergonomics.org/au*
International Ergonomics Association information by email from *info@iea2006.org* including the IEA 2006 16th Congress from July 10 to 14 in Maastricht, Netherlands.

International Federation of Foot & Ankle Societies (IFFAS) 2nd Trienniel Scientific Meeting will be held at the Royal Continental Hotel, Naples, Italy from September 15 to 18, 2005. Information by e-mail *efas@eventplus.it* or telephone
+353 1230 2591; fax +353 1230 2594.
See *www.globalfoot.org*

International Federation of Sports Medicine (FIMS) The 4th European Sports Medicine Congress from October 13 to 15, 2005 will be at the Hawaii Grand Hotel, Lemesos, Cyprus. Contact Pygros Congress Ltd, Nicosia, Cyprus – telephone +357 2277 4157; fax +357 2278 1031. The FIMS World Congress of Sports Medicine in 2006 will be at the International Convention Center, Beijing, China from June 12 to 16. Information from the National Research Institute of Sports Medicine in Beijing – telephone +86 (10) 6719 2750; fax +86 (10) 6719 2755; e-mail *ligp@263.net* The FIMS website is *www.fims.org*

International Society of Biomechanics XXth Congress will be on campus at Cleveland State University, Cleveland, Ohio, USA from August 1 to 5, 2005. Details on *www.isb2005.org* The ISB website is at *www.isbweb.org*

International Society for Biomechanics in Sport The next Symposium will be from August 26 to 30, 2005 in Beijing, China. Paper submissions by April 15, 2005. Secretariat: China Society of Sports Biomechanics, telephone +86 (10) 67194123; fax (8610) 67103176
email *isbs2003@cssb2001.net*
Information from *www.isbs.org*

International Society of Electrophysiology & Kinesiology The XVI Congress will be held in Torino, Italy from June 28 to July 1, 2006. Information from *www.lisin.polito.it* The main website is *www.isek.bu.edu/*

International Society of Physical & Rehabilitation Medicine (ISPRM) The 4th International Congress from June 10 to 14, 2007 is to be in Seoul, Korea and the 5th will be held in Istanbul, Turkey. More information will become available at the Society's website *www.isprm.org*

International Society of Postural & Gait Research The XVIIth Conference will be in the Mercure Eurocenter Hotel, Marseilles, France from May 29 to June 2, 2005. Information by email from *ispgr2005@atout-org.com* The 2007 event is planned for Baltimore, USA.
The Society website is *www.ispgr.org*

International Society for Prosthetics & Orthotics. The 12th ISPO World Congress is to be held from July 29 to August 3, 2007 at the Vancouver Convention Centre in Vancouver, Canada. Information from the ISPO Congress website *www.ispo.ca/congress* or from the president ISPO Canada, Edward Lemaire, PhD, Institute for Rehabilitation Research and Development 505 Smyth Road, Ottawa, ON, Canada KIH 8M2, Telephone (813) 737 7350 Ext 5592.
The UK National Member Society for Prosthetics & Orthotics is holding the next Annual Scientific Meeting in the UK on November 4 and 5, 2005 at the Hilton Swindon, Great Western Way, Swindon, England. Details on *www.ispo.org.uk* or e-mail *info@ispo.org.uk*
Telephone/Fax +44 (0) 141 560 4092

Japanese Orthopaedic Association The 78th Congress will be at the Pacifico Yokohama from May 12 to 15, 2005. Information e-mail *office@joa.or.jp* The 79th Congress is also to be at the Pacifico, Yokohama – from May 18 to 21 in 2006.
The Association's 20th Annual Orthopaedic Research Meeting is from October 20 to 21, 2005 at the Sun Arena, Mie Prefecture (Ise City). See *www.kiso20.umin.ne.jp* The 21st Annual Orthopaedic Research Meeting from October 19 to 20 in 2006 will be at Brick Hall, Nagasaki.
The Association website is *www.joa.or.jp*

National Athletic Trainers Association (USA) The 56th Annual Meeting & Clinical Symposia will be in Indianapolis, Indiana, USA from June 12 to 16, 2005. In 2006 it will be in New Orleans from June 27 to July 1 and in 2007 from June 26 to 30 in Anaheim, California, USA.
www.nata.org

Orthopaedic Research Society (ORS) – The 52nd Annual Meeting will be from March 5 to 8, 2006 in New Orleans, Louisiana, USA. Abstacts online June 20 to August 22, 2005. In 2007 the Meeting will be in San Diego, California, USA. See *www.ors.org* or e-mail *ors@aaos.org*
Scoliosis Research Society (SRS) – The 40th Annual Meeting is from October 28 to 30, 2005 with pre-meeting courses on October 27, at the Loews Miami Beach Hotel, Miami, Florida, USA, and the 41st is planned for September 13 to 16, 2006 in Monterey, California, USA. Information on SRS website *www.srs.org*

Society for Neuroscience "Neuroscience 2005" – the 35th Annual Meeting - will be at the Washington Convention Center, Washington DC, USA, from November 12 to 16, and in New Orleans, USA in 2006 from October 21 to 25. *www.sfn.org*

World Confederation for Physical Therapy The 2007 International Congress will be in Vancouver, Canada in June 2007. Information as it becomes available on *www.wcpt.org*

Additional sites of interest

American Academy of Kinesiology & Physical Education *www.aakpe.org*

American Academy of Pediatrics *www.aap.org*

American Academy of Podiatric Sports Medicine *www.aapsm.org*

American Alliance for Health, Physical Medicine & Rehabilitation *www.aahperd.org*

American Society of Biomechanics *www.asb-biomech.org*

American Society of Exercise Physiologists *www.asep.org*

Association of Academic Physiatrists (AAP) *www.physiatry.org*

Association of Children's Prosthetic and Orthotic Clinics *www.acpoc.org*

Australian Association of Exercise & Sports Science *www.aaess.com.au*

British Association of Prosthetists and Orthotists *www.bapo.com*

Canadian Association of Prosthetists & Orthotists *www.pando.ca*

Canadian Society for Biomechanics *www.health.uottawa.ca/biomech/csb/*

European Orthopedic Research Society *www.eors.net*

Gait & Clinical Movement Analysis Society *www.gcmas.org*

International Federation for Medical & Biological Engineering *www.ifmbe.org* (Click on "Calendar")

International Organization of Physical Therapists in Women's Health *www.ioptwh.org*

North American Society for Pediatric Exercise Medicine *www.naspem.org*

Ontario Kinesiology Association *www.oka.on.ca*

For world wide orthopaedic links *www.freeortho.com/associations*

For other events refer also to *www.gcmas.org/societies.html*

LITERATURE UPDATE

by Dr. Ed Biden,
Institute of Biomedical Engineering,
University of New Brunswick, Canada.

In this column I usually don't review papers from "Gait and Posture", assuming that they are generally on the reading list of Standard subscribers. However, earlier this year a series of four papers which amounts to a text book on movement analysis using stereophotogrammetry was published. These are the sort which will become required reading for students and practitioners in this field.

Cappozzo, A., Croce, U., Leardini, A., Chiari, L., "Human Movement Analysis Using Stereophotogrammetry: Part 1: Theoretical Background", Gait and Posture, Vol 21, pp 186-196, 2005.

Croce, U., Leardini, A., Chiari, L., Cappozzo, A. "Human Movement Analysis Using Stereophotogrammetry: Part 2:Instrumental Errors", Gait and Posture, Vol 21, pp 197-211, 2005.

Leardini, A., Chiari, L., Croce, U., Cappozzo, A. "Human Movement Analysis Using Stereophotogrammetry: Part 3: Soft Tissue Artifact Assessment and Compensation", Gait and Posture, Vol 21, pp 212-225, 2005.

Croce, U., Leardini, A., Chiari, L., Cappozzo, A. "Human Movement Analysis Using Stereophotogrammetry: Part 4: Assessment of Anatomical Landmark Misplacement and its Effects on Joint Kinematics", Gait and Posture, Vol 21, pp 226-237, 2005.

Starting in the first paper with the basic kinematics equations needed to model rigid body movements, the authors move through the concepts of mapping from global to local reference frames, definition of coordinate systems and the derivation of joint kinematics. Their examples tend toward "technical marker arrays" which have been used extensively by their group, but the treatment is thorough and would be an excellent starting point for someone new to the business.

The second paper presents theory around camera calibration, filtering, smoothing, and estimation of errors. The only criticism of the presentation is that the examples tend to be several generations old in terms of the tracking systems tested. They wrap up this paper with a nice description of techniques to estimate segment orientation based on external markers and the challenges of doing so.

The third paper in the sequence focuses on the problems of soft tissue movement. Various methods, from bone pins to x-ray to quantify such movements of the soft tissue relative to bone are presented. The paper then moves into a wide-ranging discussion of means to address the problem. These range from "solidification", where marker positions are fit to "rigid" bodies, through systems which depend on redundant markers and ones which attempt to model the surface of the limb. The authors conclude that a form of global optimization which looks at multiple segments is the best solution.

continued overleaf

The final paper in the series discusses the errors which arise from not having good knowledge of where anatomical landmarks lie. The presentation is focused on the hip and knee. The conclusion drawn is that modern multi camera systems can be used to reduce some of the errors which were common in the past, and that the next step in motion analysis should be improved joint models. Taken together these papers are a very good reference set, and include extensive references for those readers who wish to follow individual discussions to a deeper level.

Virtually concurrently with the above noted papers and their conclusion that improved joint models are needed, **Schwartz, M., and Rozumalski, A., "A New Method of Estimating Joint Parameters From Motion Data" J. Biomech, Vol 38, pp 107-116, 2005**, present just such a model. They track the motion of two arbitrary adjacent segments using a Vicon 512 motion capture system and determine an axis of rotation between every pair of segment configurations. Then they use an iterative method to find the effective axis of rotation. The authors provide results for a hinge where the axis of motion can be known explicitly and also for walking trials with adults. They show results which are subtly different from widely used axis estimation models and argue that their model is very robust. Interestingly enough, earlier work by Capozzo is used as a basis for comparison.

In a somewhat different application of movement assessment techniques the following three papers examine primarily upper limb or whole body movement rather than lower limb motion. This sort of study is becoming more and more common with increased sophistication of movement capture systems.
Park, W., Martin, B., Choe, S., Chaffin D., Reed, M. "Representing and Identifying Alternative Movement Techniques for Goal-Directed Manual Tasks", J. Biomech, Vol 38 pp 519-527, 2005 present a study where participants were asked to perform reaching and lifting tasks. The objective of the study was to determine whether difference in the patterns of the motions could be used to "cluster" the results into particular patterns. This is of interest because, unlike walking, there is a very broad variation in the way that people may choose to perform them. The authors demonstrate that their technique can indeed separate various patterns of motions in the reach and lift tasks they examined. Their methods are applicable to complex three dimensional motions and don't make a large number of assumptions about how the movement is made.

It is interesting to read the above paper followed by **Chang, J., Wu, T., Wu, W., Su, F., "Kinematical Measure for Spastic Reaching in Children With Cerebral Palsy", Clin. Biomech., Vol 20, pp 381-388, 2005** who premise their study on a need to be able to assess reaching tasks as a means of deciding whether treatments are having their desired effect in cerebral palsy. Their experiment used two cohorts each with ten approximately age-matched subjects. One group acted as a normal control and the other had cerebral palsy. This study concluded that the children with CP were slower, less accurate and had less controlled motions. Their primary assessments were based on timing, velocity, and other variables which provide single number descriptions of a motion. Their assessment of motion patterns were observational. It is interesting to speculate whether the techniques of Park *et al* would add an additional dimension to a study such as this.

Besides the challenges in upper limb assessment, due to the complexity of the motions and the differences in techniques and patterns among people, there is the challenge that most studies are done in the laboratory and a useful adjunct would be to be able to monitor activity in daily life. **Vega-Gonzales, A., and Granat, M., "Continuous Monitoring of Upper-Limb Activity in a Free Living Environment", Arch. Phys. Med. And Rehab., Vol 86, pp 541-548, 2005** present results from an activity monitor which essentially measures one coordinate, the difference in elevation between the wrist and shoulder. The device is bilateral and can be worn over an eight hour period. One interesting aspect of the device is that if it was used in a situation where followup experiments were done in a movement lab, the same data could be collected easily and expanded upon with a more complex marker arrangement. The authors compare a group of ten able-bodied adults with ten post-stroke patients. Not unexpectedly the normal group were fairly symmetrical with the dominant limb used only 19% more than the non-dominant side. By contrast the stroke group used their sound arm three to six times more than their involved arm.

This review concludes with two movement assessment papers related to prosthetic gait. The first, **Bateni, H., Olney, S., "Effect of the Weight of Prosthetic Components on the Gait of Transtibial Amputees", J. Prosthetics and Orthotics, Vol 16 #4, pp 113-120, 2004**, used a Peak motion analysis system to study a small group (five) of people with trans-tibial amputations. The study compared their gait when using steel structural components for the prosthesis against their gait when using titanium components. The average difference in weight was just over 180 grams which, the authors hypothesize, would be enough to affect stride length and other measures. Their comparisons were based on kinematic and kinetic gait measures as well as a physiological cost index (PCI) based on heart rate. Contrary to their expectations, there was no consistent change in kinetic or kinematic measures, but the PCI was altered even after five minutes of walking.

Jones, S., Twigg, P., Scally, A., Buckley, J., "The Gait Initiation Process in Unilateral Lower-Limb Amputees When Stepping Up and Stepping Down to a New Level", Clin. Biomech., Vol 20, pp 405-413, 2005, used a Vicon 250 system to study how able bodied and unilateral prosthesis wearers initiated stepping. The focus of the study was on the location of the center of force under the foot and the location of the overall center of mass. The prosthesis wearers included two groups each with five participants. One group had transtibial and the other transfemoral limb loss. It is interesting that there were consistent differences between the normally limbed and prosthesis using populations which suggested that the prosthesis users were being very deliberate about controlling the location of the center of force and the load orientation in order to keep the knee more stable. They also had fewer postural adjustments as they stepped down, which the authors attribute to their being less confident about landing on the prosthesis.
Motion analysis continues to find new applications and the sophistication of analysis methods continues to grow as data capture systems become more and more capable.

VICONPEAK
OMG 3D from the moving image

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