2007 Biomechanics Research Symposium

May 11, 2007

The Center for Biomechanical Engineering Research at the University of Delaware is pleased to host the 4th annual CBER research symposium. The motivation for this symposium is to highlight the outstanding and varied biomechanics related research taking place at the University of Delaware.

Poster and podium presentations will be led by young researchers with awards presented for the best poster and podium presentations. Posters will be on display in the morning (2nd floor Spencer Lab) and podium presentations will be held in the afternoon in CCM 106.

Our keynote lecture will be given by Dr. Steven Stanhope, director of the Physical Disabilities Branch at the National Institutes of Health. Dr. Stanhope will discuss findings from a series of research projects related to customization and selective laser sintering construction of passive dynamic ankle-foot orthoses to meet a patient's individual needs and the biomechanical basis for adapted compensatory movement control strategies will be explored.

The keynote lecture will be delivered at 11:00 AM in CCM 106.

CBER is a Research Center of the University of Delaware
Department of Mechanical Engineering, 126 Spencer Lab, Newark, DE. 19716

Schedule of the Day

Time	What	Where
8:15 - 9:00	Poster set-up & Breakfast	2nd floor Spencer Lab
9:00 - 9:45	Poster Session 1 (Even #'s)	2nd floor Spencer Lab
9:45 - 10:30	Poster Session 2 (Odd #'s)	2nd floor Spencer Lab
10:45 - 11:45	Keynote: Dr. Steven Stanhope	CCM 106
12:00 - 12:30	Box Lunch	
12:30 - 1:30	Podium Session 1	CCM 106
1:30 - 1:45	Break	
1:45 - 2:45	Podium Session 2	CCM 106
2:45 - 2:50	Awards	
2:50 - 3:00	Refreshments	
3:00 - 4:00	BIOMS Seminar: Dr. Li Li	CCM 106

Podium Presentations

Time	Presenter	Abstract #
12:30 - 12:45	Daniel Bassett	3
12:45 - 1:00	Qi Shao	23
1:00 - 1:15	Sai Banala	13
1:15 - 1:30	Ji-Chul Ryu	38
	Break	
1:45 - 2:00	Vennila Krishnan	25
2:00 - 2:15	Kristin Briem	5
2:15 - 2:30	Joaquin Barrios	17
2:30 - 2:45	Nicole Chimera	33

Keynote Lecture

A PASSIVE DYNAMIC ANKLE-FOOT ORTHOSIS APPROACH TO ENHANCED GAIT FUNCTION

Steven J. Stanhope, Ph.D.
Physical Disabilities Branch, National Institutes of Health, Bethesda, Maryland, USA*

Ankle-Foot Orthoses are a common form of ankle joint bracing prescribed for patients with impaired joint function. Passive Dynamic Ankle-Foot Orthoses (PD-AFOs) constitute a special class of ankle braces designed to enhance gait function by providing natural support to the lower limb as it progresses over the stance foot. A fundamental design characteristic of all PDAFOs is that they mimic the action of a rotational spring. As a result, PD-AFOs are not capable of replicating all dynamic characteristics of the natural ankle complex. Therefore, the efficient use of PD-AFOs during gait requires the wearer to develop an adapted, lower limb movement control strategy that effectively optimizes assistive PD-AFO characteristics and compensates for characteristics detrimental to gait function.

Studies of the contribution of PD-AFOs to functional tasks such as walking have been limited but revealing. One study of 5 subjects with lower extremity strength impairments showed improved gait performance, demonstrated by increased walking speeds, while wearing a carbon fiber PD-AFO compared to conventional orthoses (Halstead et al., 2003). In addition, preliminary analysis (using state-of-the-art motion capture and biomechanical modeling tools) of two subjects with post-polio syndrome using similar braces revealed two different subject-specific lower extremity movement control compensations (Nelson et al., 2003). In one case, an overall increased walking velocity was obtained through the addition of PD-AFO ankle moments to the wearer's muscular efforts (an example of strength enhancement). In the other case, the PD-AFOs force contribution during the stance phase of gait enabled the wearer to decrease his peak ankle muscle effort while maintaining his functional non-braced walking velocity (an example of strength substitution).

Selective Laser Sintering (SLS) is a powerful solid freeform fabrication technology developed at the University of Texas at Austin and now commercialized by 3D Systems, Inc. It is a manufacturing process that is capable of producing complex-geometry parts directly from computer models without the need for significant human intervention. The SLS process imports data from an object's three-dimensional model that has been mathematically sliced into thin cross-sectional layers. It then builds the object using a high-powered scanning laser beam that selectively fuses sequentially deposited layers of material powder (Beaman et al., 1997), successively fusing and building one cross-sectional layer of the object at a time. SLS has two particular features that make it an extremely beneficial for manufacturing custom PD-AFOs: 1) the process is more automated than current labor-intensive techniques and can produce complex shapes in a fraction of the time and 2) the process meets online customization demands because increased shape or geometric complexity has minimal cost penalty during manufacturing.

The purpose of this presentation is to describe a paradigm for the scientific exploration of adapted movement control strategies associated with PD-AFO use and for the future optimization of customized orthosis prescription. Specifically, findings from a series of research projects related to customization and SLS construction of PD-AFOs to meet a patient's individual needs will be presented and the biomechanical basis for adapted compensatory movement control strategies will be explored.

References

Beaman, JJ, et. al., Solid Freeform Fabrication, Boston: Kluwer Academic Press; 330, 1997.
Halstead, LS, et al., Dynamic Bracing: A Novel Approach. J Spinal Cord Med 26 (1):16, 2003.
Nelson KM, et al., Ankle foot orthosis contribution to net moments. Proceedings of ASB, 2003.

** A collaboration between the National Institute of Child Health and Human Development and the Warren G. Magnuson Clinical Center, National Institutes of Health.*

1 INDIVIDUALS 3 YEARS FOLLOWING TKA SHOW FUNCTIONAL DIFFERENCES COMPARED TO AGE AND GENDER MATCHED CONTROLS

Farquhar SJ, Yoshida Y, Snyder-Mackler L
Department of Physical Therapy, University of Delaware

BACKGROUND: Individuals one year following TKA are known to demonstrate an altered movement pattern during a sit-to-stand task at a year following TKA. Other studies of sit-to-stand (STS) and return-to-sit (RTS) tasks in persons with TKA have tested subjects anywhere from 1 year to 6 years following TKA. It has also been demonstrated that persons following TKA report their best functional performance 3 years following TKA, and functional status declines following 3 years. Little is known of how subjects 3 years following TKA perform RTS. Therefore, the purpose of this investigation was to compare subjects 1 year and 3 years following TKA to assess differences in quadriceps strength and performance of RTS. METHODS: Twelve subjects participated in quadriceps strength testing and motion analysis at 1 year following TKA, and 10 returned for testing 3 years following TKA. These 10 subjects were used in analyses. Differences in quadriceps strength, angles, and extensor moments were compared using repeated measures ANOVA. Post-hoc paired t-tests were used to compare differences found with ANOVA; and to compare the duration of RTS. RESULTS: The operated limb is no different in strength at 1 year and 3 years following TKA ($p=0.31$); meanwhile, the nonoperated limb significantly declines ($p<0.001$). There are no differences in hip flexion angle with time ($p>0.05$); however the hip extensor moment significantly declines by 3 years, on both the operated ($p=0.024$) and nonoperated ($p=0.006$) limbs. There are no differences in knee flexion angle or knee extensor moment with time ($p>0.05$). However, subjects 3 years following TKA perform RTS slower than they did at 1 year ($p=0.001$). CONCLUSIONS: The reduced hip extensor moment may demonstrate a shift toward a more typical movement strategy in this group of subjects. It is not known if declining strength of the nonoperated quadriceps is a result of osteoarthritic changes in the nonoperated knee, or due to ageing. The small sample size limits the conclusions that can be drawn from this data.

2 DEVELOPMENTAL ORIGINS OF HANDEDNESS

Lynch A., Lee, H.M., Bhat, A., Galloway, J.C.

In the general population, there is a bias towards being right handed. Ronnqvist & Domellof (2006) propose this bias may be detected in a right hand preference in 6 month old infants. The purpose of this research was to evaluate spontaneous and object oriented experiences to determine any evidence of a significant right hand bias in the pre-reaching period. We evaluated right and left arm kinematic data of 13 healthy, full term infants seen every 2 weeks from 8 weeks old through week of reach onset using a customized Matlab program. A three factor ANOVA evaluated data for differences in movement length, speed, smoothness, movement frequency, and hand toy distance. A reach success ratio, how many movements were “successful contacts” with a toy, was calculated. In the *toy condition*, there is a trend towards the right arm and hand movements being smoother ($F(1, 12)=3.57$, $p<.1$) but ending at points further away from the toy ($F(1,12)=6.65$, $p<.05$) than the left arm. We also found that, regardless hand, in the *toy condition*, a trend is found of increased speed between mid and late phase ($F(2, 11)=3.05$, $p<.1$). The *no toy condition* illustrates the same trend: right arm and hand movements as smoother ($F(1, 12)=3.57$, $p<.1$) and movements ending further away from the toy ($F(1, 12) =257.56$, $p<.01$). The right hand also moves faster in the *no toy condition* across all phases ($F(2, 11)= 3.05$, $P<.1$) and has more movements ($F(1, 12)=6.16$, $p<.05$) in the late phase of development. As well, regardless toy condition, the left hand movements are progressively longer over each developmental phase ($F(2,11)=16.37$, $p<.01$) while the right hand movement distances remain stable. Both hands achieve similar reach success ratio in toy contact (R=16%, L=14%) suggesting that, regardless trends of differences in speed, smoothness, and movement frequency, there is no resultant behavioral right hand.bias. This study provides evidence that early arm differences leading to later handedness are not readily apparent as “left only” or “right only” in the pre-reaching period. Therefore, we propose that infants emerge with rapid asymmetry in the period between reach onset and the hand preference phasesuggested by prior research. We suggest limb asymmetry leading to later hand dominance results from influences of non-linear, multi-factorial extrinsic and intrinsic variables experienced by the infant after reach onset.

3 SINGLE AND MULTI-JOINT EMG-DRIVEN MODELLING OF THE ANKLE AND KNEE

Bassett, D.N., Shao, Q., Manal, K.T., Buchanan, T.S.

INTRODUCTION: Single-joint models may be adequate for some applications; however, it may be more appropriate to use a multi-joint model when studying complex motions. The present study investigates biarticular muscles in EMG-driven models accounting for their contributions to both joints they span.
METHODS: Six subjects performed normal walking, hopping, and hop-and-stop tasks while EMG, ground reaction forces, and motion data were collected. Three hybrid EMG-driven models were developed: single ankle, single knee, and multi-joint of the ankle and knee. An optimization algorithm was used to calibrate the forward dynamic Hill-type models by using the inverse dynamic joint moment as a benchmark.
RESULTS AND DISCUSSION: Normal walking comparison between forward dynamics and inverse dynamics joint moments at the ankle gave R^2 values of 0.97 and 0.96 and RMS-error of 18.6% and 19.8%; whereas at the knee the R^2 values were 0.80 and 0.79 and RMS-error of 20.9% and 23.1% for single-joint and multi-joint models respectively. New task predictions displayed the versatility of the calibrations for hopping ankle and hop-and-stop knee predictions which performed very similarly to walking, and compared to normal walking have similar kinematics and muscle activations. Muscle force predictions showed small variations between single and multi-joint models for the quadriceps, hamstrings, or the dorsiflexor. However, as expected, the gastrocnemii muscle forces varied significantly between the two types of models. Furthermore, a correlation was noted between the magnitude of the late stance knee flexion moment and relative magnitude of the gastrocnemii forces.
CONCLUSION: The three models perfomed very similarly for all subjects and all tasks; however, significant differences were found in the gastrocnemii force predictions. Implying single-joint models of the ankle should account for kinetics of the knee to replicate the presumably more realistic multi-joint force predictions.

4 CONSECUTIVE FOOTSTRIKES MAY NOT BE NECESSARY TO QUANTIFY GAIT SYMMETRY DURING RUNNING

Becky Avrin Zifchock[1] and Irene Davis[1,2]
[1]Motion Analysis Laboratory, University of Delaware
[2]Drayer Physical Therapy Institute

Quantification of gait symmetry is useful for the detection of pathology, as well as the efficacy of treatment. It is often calculated using non-consecutive footstrikes due to equipment limitations (ie, one forceplate). Yet, studies assessing symmetry in this way may be criticized as gait is continuous in nature and each step is affected by those prior. To date, the effect of non-consecutive steps on gait symmetry calculation is unknown. **PURPOSE:** To determine whether there is a difference in symmetry values calculated using consecutive versus non-consecutive footstrikes. **METHODS:** Kinetic and kinematic variables were measured in 52 injury-free runners. Knee stiffness (KSTF), peak ground reaction force along the long axis of the shank (SHfz), peak instantaneous loading rate along the shank (SHlr), peak acceleration along the shank (PPA), peak hip adduction angle (HAD), peak hip internal rotation angle (HIR), peak knee adduction angle (KAD), and peak rearfoot eversion angle (REV) were calculated. Data were collected for five trials of two consecutive footstrikes. Symmetry was quantified using the Symmetry Angle (SA). For each variable, the SA was calculated between the values for each set of consecutive footstrikes and between the average right and left-side values: $SA_{consec} = (SA_1, \ldots SA_5)_{avg}$ and $SA_{non\text{-}consec} = SA_{Ravg,\ Lavg}$, respectively. Paired t-tests were used to compare between methods ($\alpha = 0.05$). No differences were expected between methods. **RESULTS:** Of the eight variables, only KAD exhibited a significant difference between methods, where the SA calculated from non-consecutive footstrikes was greater ($p = 0.02$). The remaining variables were less than 7.5% different between methods. **CONCLUSIONS:** In general, quantification of gait symmetry is unaffected by the use of non-consecutive footstrikes. This suggests that the patterns of movement are sufficiently consistent, such that differences between sides can be reliably detected using either method.
Supported by ISB Matching Dissertation Grant and ASB Student Grant-In-Aid

5 EFFECTIVENESS OF INTRA-ARTICULAR HYALURONIC ACID INJECTIONS ON FUNCTION AND PAIN IN KNEE OSTEOARTHRITIS

Briem K[1], Axe M,[1,2] Snyder-Mackler L[1]
1.Department of Physical Therapy, University of Delaware
2.First State Orthopaedics.

Background and Objective: Intra-articular (IA) injections of Hyaluronic Acid (HA) are currently indicated to palliate symptoms and improve function in patients with knee osteoarthritis (OA). The effects on kinetics and kinematics during gait and other functional outcomes is limited. This study investigated the effectiveness of HA injections on pain, knee function and movement patterns in patients with knee OA and determined characteristics that discriminated people who respond well to this treatment vs. those who do not. Methods: 16 subjects (50.6± 8.4yrs, BMI 30.8 ± 4.0 kg/m^2) with symptomatic knee OA and scheduled for 5, weekly, HA injections were recruited. Each was tested prior to treatment and no later than 3 weeks following the last injection. Gait analysis was performed to analyze kinematic and kinetic patterns during the stance phase of gait. Knee function was assessed with questionnaires, range of motion (ROM) measures, a six minute walk (6MW) and a timed stair climbing task (SCT). T-tests and linear regression were used. Alpha was set at 0.05. Results: Overall the group improved in self reported scores and in the SMW and STC measures after treatment. Eight subjects (non-responders=NR) showed minimal or no improvements in self reported scores (mean change in KOS -3.02) whereas eight (responders=R) felt marked improvement (mean change in KOS +23.50). There was no between group difference in mean 6MW and STC performance pre- or post-HA. No changes in joint kinematics were observed after treatment; interlimb differences remaining grossly unchanged. Kinetics remained unchanged in R, whereas the knee adduction moment increased in NR during weight acceptance (p=.013). We found a relationship between pre-treatment knee flexion ROM and changes in self-reported scores after HA treatment (p=.005; r=.669). Knee ROM also predicted gait kinematics such as joint excursions during gait. Discussion and Conclusion: Symptoms and/or functional performance improved in the majority of patients. Although pain relief has been proposed to lead to increased knee joint loading, this was not supported by the result of this study. Knee flexibility prior to IA injections of HA may predict which patients will experience greater symptomatic and functional gains following treatment.

6 VARIATION IN ARTICULAR CARTILAGE MATERIAL PROPERTIES AND TRABECULAR BONE STRUCTURE IN THE RABBIT KNEE

Christine Turka (MSME), Jason Kreidler (grad), Phillip Holcombe (undergrad), John E. Novotny Ph.D

Osteoarthritis is a degenerative joint disease that causes pain and loss of function. It is characterized by the degeneration of articular cartilage, the smooth thin tissue that covers the ends of articulating bones. Articular cartilage provides wear resistance, maintains joint lubrication, and distributes loads through the joint. Increased understanding of the mechanical environment of the tissue may provide insight into the mechanisms involved in the progression of osteoarthritis.
Mechanical loading was conducted on 16 healthy New Zealand White rabbits to simulate osteoarthritis. Material properties of the cartilage and trabecular bone structure were then analyzed. MicroCT scans were conducted on the knee joints followed by analysis using a 3-D viewer software package, to determine trabecular bone structure. Creep indention tests using and Instron machine were then preformed in order to determine cartilage material properties. Analysis of the creep indention tests was conducted using a FEM model utilizing ABACUS and MATLAB.

7 STRAINS IN THE BICEPS BRACHII DURING DYNAMIC ELBOW FLEXION SHOW CONCENTRIC, ECCENTRIC AND ISOMETRIC BEHAVIOR SIMULTANEOUSLY

John E. Novotny, Brian A. Knarr, and Hehe Zhou, Dept. of Mechanical Engineering

Methods have been developed to quantify internal muscle mechanics using cine-phase constrast and post processing algorithms (Zhou and Novotny, 2006) and have described Lagrangian finite strains during cyclic motion in the supraspinatus and biceps brachii. The purpose of this paper is to define the overall uniformity of deformation within the normal biceps brachii during elbow flexion by observing frequency distributions of the finite Lagrangian and principal strain magnitudes. MRI images through the mid-plane of the biceps brachii were collected during cyclic motion from full extension to ~120° flexion at 24 equally spaced time frames. The first frame at full extension was used as the zero strain reference. Longitudinal and transverse strain (SY/SX), shear strain (SXY), maximum/minimum principal strain (PS1/PS2), and maximum in-plane shear strain (PSXY) were calculated for 0.2×0.2 pixel triangular meshes at each frame for the distal half of the muscle. Percent areas of each muscle at various incremental ranges of strain magnitude were calculated, and frequency distributions across the 24 time frames were created and averaged across subjects. At the highest contraction velocity, 150°, PS2 showed generally shortening, with a peak around -15% and a negative maximum near -40%. Portions of the muscle showed positive PS2, or pure elongation, up to 25%. Results indicate the possibility of compartimentalization of muscle function within the biceps brachii, even during this simple motion and relatively low loads and velocities. Non-uniformity could be a function of non-uniform activation, material properties or fiber type and contractibility. Future work should focus on how these distributions change with fatigue, pathology or ageing, and aim to describe mechanisms. Results will aid in building models of internal muscle mechanics.

8 HABITUATION AND FATIGUE IN THE STRETCH REFLEX OF THE ANKLE

Gregory M. Gutierrez, Nicole D. Jackson, Thomas W. Kaminski

Many studies have investigated the role of inversion stretch on the reflex response of the ankle musculature during quiet stance, however none have considered the effect of habituation of the reflex over time. Furthermore, the influence of fatigue on the habituation of the stretch reflex at the ankle has yet to be evaluated. The purpose of this work was to investigate the effect of habituation and fatigue on the stretch reflex of the ankle musculature in response to an inversion perturbation. A total of 40 subjects, recruited from the university community, participated and were divided into a treatment group (10 M/10 F) and a control group (10 M/10 F). All subjects performed 10 pre-test trials for the reflex response to a sudden ankle inversion with electrodes placed on the Tibialis Anterior (TA), Peroneus Longus (PL), and Peroneus Brevis (PB) on their dominant leg. The treatment group was then fatigued on an isokinetic dynamometer to 50% of their max eccentric eversion force, while the control group sat quietly for 5 min. Subsequently, all subjects performed 10 post-test trials. The peak EMG value was calculated for each trial and all data were normalized to the peak value from the 1st pre-test trial. A (2 x 6) Group x Trial mixed MANOVA was performed with the alpha level set at 0.05, *a-priori*. There was a significant group x trial interaction ($p = 0.017$) for the PL ($p < 0.001$) & PB ($p < 0.001$) muscles, indicating a fatigue effect on habituation of the reflex. A significant decrease over trials ($p < 0.001$) was noted for all three muscles. The linear decrease in reaction intensity over time indicates that habituation of the stretch reflex must be accounted for in future research. A high anxiety level present at the onset of testing, followed by increased familiarization throughout a testing protocol, may help to explain this habituation. The effect of fatigue on habituation of the stretch reflex is evident in the PL and PB muscles, in which a decrease was noted in the response intensity following the fatigue protocol, while the control group demonstrated dishabituation in those muscles following the rest period. Furthermore, in all subjects, the TA muscle was not fatigued and they all demonstrated dishabituation following the “rest period”. Therefore, the effects of fatigue must also be considered during reflex testing.

9 SKELETAL PHENOTYPE OF MICE LACKING HIP/RPL29

Daniel S. Oristian[1], Liyun Wang[2], Mary C. Farach-Carson[1], Catherine B. Kirn-Safran[1]
1. Dept. of Biological Science, University of Delaware
2. Dept. of Mechanical Engineering, University of Delaware

Ribosomal proteins (RPs) play important regulatory functions in the ribosome and modulate protein synthetic rates in response to external cues. Disruption of the *heparan sulfate interacting protein/ Rpl29* (*Hip/Rpl29*) gene caused a global growth defect in homozygous null mutants, resulting in a short stature phenotype that is apparent from prenatal life through adulthood. In primary mouse embryonic fibroblasts, the absence of HIP/RPL29 is accompanied by a reduction in proliferation and protein synthesis, and a decrease in the steady state levels of core ribosomal components. Interestingly, the proliferation index of HIP/RPL29 null chondrocytes remains unaffected in developing growth plates suggesting that the skeletal growth defect might rather be a consequence of a deficiency in bone matrix synthesis. To investigate the postnatal effects of HIP/RPL29 absence on adult bone structure, we compared the wet weight of individual long bones (femur and tibia) in null mutants and control mice. We found that the average bone weight is approximately 30% lower in null animals when compared to corresponding bones in controls. We also evaluated the cortical and trabecular bone morphology differences between HIP/RPL29 null and control animals using standard histology and micro-computed tomography (micro-CT). We found that HIP/RPL29 null femoral diaphysis exhibit a significant decrease in bone marrow (40%) and cortical area (15%), in addition, we report a significant 30% decrease in the polar moment of inertia in HIP/RPL29-deficient bones. On the other hand, no significant differences were detected in the trabecular microstructure of the distal femur in null mice when compared to controls. Altogether, our data show that the amount of total bone tissue is decreased in mice lacking a regulatory component of the ribosome, supporting the idea that high volume protein synthesis is essential for bone matrix production during periods of rapid bone growth, predominantly during development. Stimulation of this pathway might provide a novel means of accelerating bone and connective tissue regrowth during wound healing. (Supported by NIH COBRE 2 P20 RR016458-06 to MCFC & LW)

10 BIMANUAL MANIPULATION: EFFECT OF TASK DIRECTION ON FORCE COORDINATION

Paulo B. de Freitas, Vennila Krishnan and Slobodan Jaric
Motor Control Lab, Department of Health, Nutrition and Exercise Sciences, University of Delaware

When manipulating an object the grip force (normal to the object's surface; GF) has to be adjusted to load force (tangential to the object's surface; LF) that tends to cause a slippage. Although the elaborate GF-LF coordination is generally a well known phenomenon, important aspects have not been studied yet. For example, it remains unknown whether the recently showed low level of force coordination associated with consecutive changes of LF direction (i.e., 'bidirectional tasks') represents a distinctive force control pattern, as well as whether the hand dominance plays a role in GF-LF coordination. To explore these aspects fourteen participants were instructed to bimanually hold fixed handles applying a precision grip and exert the prescribed sinusoidal pattern (2 Hz) of LF in vertical direction. The changes in LF maxima and minima were set in a way to produce a gradual shift from unidirectional (entire profile required pulling up) to purely bidirectional LF exertion (same force applied in consecutive pulling up and pushing down). The results revealed higher GF-LF coordination (i.e. lower GF/LF ratio, higher correlation between GF and LF, higher gain and lower offset of GF with respect to LF) in unidirectional than in all bidirectional trials independently of how much 'bidirectional' they were. The non-dominant hand demonstrated both a higher gain of GF and directionally more accurate exertion of LF. Regarding the change of LF direction, the results generally suggest the existence of two partly distinctive neural control mechanisms for the GF-LF coordination. Specifically, whenever LF switches from the 'main force direction', even when the magnitude of that switch is minimal, the elaborate GF and LF shows marked deterioration. The neural basis of this phenomenon, such as a potential role of muscle synergies or afferent sensory feedback, requires further studies. Regarding the effect of handedness, certain aspects of task performance and force coordination revealed the advantage of the non-dominant hand. We speculated that this advantage in controlling forces could represent an addition to the current views of the non-dominant arm/hemisphere advantage in controlling limb position.

11 AN INDUCED ACCELERATION ANALYSIS OF THE EFFECT OF HIP FLEXION ANGLE PERTURBATIONS ON THE ROLE OF HIP ABDUCTOR MUSCLES DURING THE SWING PHASE OF GAIT

Debra George-Reichley and Jill S. Higginson
Department of Mechanical Engineering, University of Delaware

The body's configuration at any point during gait can impact the ability of each muscle to contribute to the movement of the limbs. To investigate the effect of the swing leg's position on the function of six hip abductors as the leg moves through its trajectory from toe-off to heel strike, we calculated the flexion, adduction, and rotation accelerations induced at the hip by those muscles. For our study we used a 3D model of a healthy male subject walking at his self-selected speed. Kinematic data was obtained experimentally and subsequently the right hip flexion angle was set ten degrees higher or lower throughout the gait cycle, creating two additional cases. We found that in the normal case, all six muscles always generated an abducting moment, but varied in flexion (positive) or extension (negative) flexion moments and inward or outward rotation moments. When hip flexion was lowered ten degrees, abduction acceleration increased, flexion acceleration decreased, and outward rotation acceleration increased, while the opposite was true when hip flexion was increased. These results suggest that taking longer strides increases the ability of hip abductors to circumduct the leg in early swing, whereas a shorter stride increases circumduction ability in late swing. In both cases, an increase in abduction acceleration is accompanied by larger hip extension accelerations, especially in the gluteus medius muscles. Greater extension accelerations would oppose the leg's forward motion during swing and potentially reduce gait speed, possibly implying a connection between the need to circumduct the swing leg and slow gait, as seen in stroke subjects.

12 IMAGING SOLUTE TRANSPORT IN MECHANICALLY LOADED BONE IN LIVING MICE

Wen Li, John Novotny, Liyun Wang. Center for Biomedical Engineering, Department of Mechanical Engineering Research, University of Delaware

Osteocytes are the most numerous cells in bone and play a critical role in maintaining bone quality and health. Since the surrounding of osteocytes is impermeable mineralized matrix, transport of molecules involved in osteocyte metabolism and cell-cell signal communication occurs through tiny pores termed lacunar-canalicular system (LCS). This transport has not been quantitatively measured in real-time and in living animals due to technical difficulties. To test the hypothesis that the primary mechanism for moving large molecules in bone is mechanical loading-induced convection, we began to measure solute diffusion and convection in loaded bone of living animals utilizing a customized mechanical loading system and confocal microscopy. We performed preliminary experiments to validate the loading system and an intermittent loading protocol for reliable imaging the loaded bones. Adult C57B6 mice were anesthetized and injected with a fluorescent tracer. The left tibia was exposed 30 minutes post injection and observed under a confocal microscope with a water dipping lens while the lower body of the animal was immersed in an imaging chamber filled with PBS. A rigid fixture was used to securely hold the tibia at the knee and the ankle joints to minimize motion. To apply controlled mechanical loading, a custom-made mechanical loader was used to compress the mice knee. The motion of the loader was driven by a personal computer through a motion control/data acquisition system. To avoid loading-induced motion artifacts, intermittent cyclical compression was used where a rest period was inserted between two adjunct cycles and a triggering signal was sent to the microscope to capture an image. To simulate slow locomotion, we used 0.5 Hz cyclical sinusoidal loading inserted with a 4-seconds rest period. We were able to maintain the animals alive for up to 2 hours under the confocal microscope, and to obtain well-focus-images during mechanical loading using a peak loading force less than 3 N that induced 800 microstrain at the tibial mid-shaft. We are currently using this refined protocol to measure transport of various sized molecules among osteocytes as a function of loading parameters. This study will provide new insights into in vivo osteocyte responses to mechanical loading and the distribution and delivery patterns of pharmaceutical agents in bone.

13 ACTIVE LEG EXOSKELETON (ALEX) FOR GAIT REHABILITATION OF MOTOR-IMPAIRED PATIENTS

Sai K. Banala, Graduate Student, Suni K. Agrawal, Professor
Mechanical Systems Laboratory, Department of Mechanical Engineering
John P. Scholz, Professor
Department of Physical Therapy

Active Leg EXoskeleton (ALEX) has been designed for gait rehabilitation of patients with walking disabilities. We propose force-field controller which can apply suitable forces on the leg to help it move on a desired trajectory. The interaction forces between the subject and the orthosis were designed to be 'assist-as-needed' for safe and effective gait training. The controller was first tested in simulations and later experiments were conducted. Experiments were performed with healthy subjects walking on a treadmill. It was shown that a healthy subject could be retrained in about 45 minutes with ALEX to walk on a treadmill with a significantly altered gait. In the coming months, this powered orthosis will be used for gait training of stroke patients.

14 3-D KINEMATIC LOWER LIMB COMPARISON OF OVERGROUND AND TREADMILL RUNNING

Rebecca E. Fellin[1] and Irene S. Davis[1,2]
[1]University of Delaware, Newark, DE,
[2]Drayer Physical Therapy Institute, Hummelstown, PA

Introduction: Gait analyses are performed using both treadmill and overground modes of running. This led researchers to question whether mechanics are similar between the two modes. Studies examining 2D motion of the knee and rearfoot suggest that the mechanics are similar. However, no studies have examined 3D hip, knee and rearfoot motion between the two modes of running. Therefore, the purpose of this study was to compare 3D kinematics of hip, knee and rearfoot between overground and treadmill running.
Methods: This study is ongoing, and we have collected five trials each of overground and treadmill running at 3.35 m/s utilizing a VICON motion analysis system for five recreational runners. These include two females and three males, 31.8 ± 7.1 years, who run at least 10 miles/week. Right limb peak stance kinematic variables were determined using customized LabVIEW software. Heel strike was identified at the distal heel marker velocity change from negative to positive. Toe off was identified at peak knee extension. These methods were validated with forceplate data for overground running.
Results: Preliminary data suggested the motion patterns were very similar between the two modes of running. Additionally, peak variables were similar with the differences ranging between 0.1 and 2.3 degrees and the mean difference being 1.3 ± 0.8 degrees.
Conclusion: Based on these preliminary results it appears that treadmill running is a good representation of overground running.

15 PASSIVE SWING ASSISTIVE EXOSKELETONS FOR MOTOR-INCOMPLETE SPINAL CORD INJURY PATIENTS

Kalyan K Mankala, PostDoc, Sai K Banala, Graduate Student and Sunil K Agrawal, Professor
Department of Mechanical Engineering

We present a passive device for swing assistance of motor-incomplete spinal cord injury patients. This device is aimed at reducing the physical demands on the therapists during treadmill training. We model the human leg as two links and a point foot mass, with a moving trunk. We employ passive elements in the design which get charged by the treadmill. Using the system dynamics, we optimize the design parameters to obtain a feasible swing motion of the leg. An exoskeleton was constructed based on these design parameters and tests were performed on a healthy subject at different treadmill speeds.

16 ADAPATATION DURING DISTURBED WALKING IN MEDIAL KNEE OSTEOARTRITIS AND HEALTHY: A CASE COMPARISON

Katherine Rudolph, Dept of Physical Therapy, Deepak Kumar, PhD Student, BIOMS,UD

Background and Significance :Medial Knee Osteoarthritis(MKOA) patients use higher levels of knee muscle activity and cocontractions as compared to controls during level walking as well as during a valgus perturbation that challenges knee stability during walking. This study analyzes the neuromuscular responces over repeated valgus perturbations in people with MKOA as compared to healthy adults.
Methods: A subject with MKOA (50,Male,BMI 22) and a Healthy young adult without knee pain (23,Male.BMI 21) walked overground for 10 trials followed by 50 consecutive trials in which a perturbation plate moved laterally for a distance of 5.4 cm at a speed of 40cm/sec trigerred by a switchmat. Force plate and EMG data were collected at 1080 Hz and kinematics were captured by a Vicon System, at 120Hz. Bilateral EMG from VL,VM,LH,MH,LG,MG were recorded using preamplified surface electrodes(20mm interelectrode distance) @ 1080 Hz. Kinematic and EMG data were processed using Visual3D software.
Results and Discussion**:** The subject with OA responded to the perturbation with altered knee kinematics and higher muscle activity during the first few perturbed trials, followed by a gradual decline in EMG and increase in joint motion in subsequent trials whereas the control subject's EMG and kinematic data remained essentially unchanged across trials. The higher EMG when knee stability was challenged is consistent with our hypotheses that subjects with knee OA use a knee stiffening strategy that involves high levels of muscle activity and limited knee motion. This strategy may help to stabilize the knee that has excessive mediolateral knee laxity with is common in people with OA. The decline in muscle responses to successive exposures to the perturbation may indicate that subjects with OA are able to learn to cope with the destabilizing events without stiffening the knee. The unchanging level of EMG activity and knee motion in the control indicates that either the perturbation was not destabilizing, or that the subject used the same stabilization strategy without learning.

17 DIFFERENCES IN FRONTAL PLANE MECHANICS BETWEEN ASYMPTOMATIC CONTROLS AND PATIENTS WITH MEDIAL OR LATERAL COMPARTMENT TIBIOFEMORAL OSTEOARTHRITIS

Joaquin Barrios, Irene Davis, FACSM, Chandra Lloyd, Todd Royer
University of Delaware, Newark, DE

Purpose: Differences in frontal plane knee mechanics between medial and lateral compartment tibiofemoral (TF) osteoarthritis (OA) have not been well defined. Further, investigation of asymptomatic controls can provide a normal reference for comparison of frontal mechanics. We hypothesized that the peak knee external adduction moment, peak knee adduction angle, and knee frontal plane angular impulse would be greatest in the medial TF OA subjects, lower in the controls, and lowest in the lateral TF OA subjects. Methods: To date, fifteen subjects with symptomatic medial TF OA (mean age 66.2 mean BMI 32.2, mean K-L grade 3.1), 15 subjects with symptomatic lateral TF OA (mean age 65.7, mean BMI 30.4, mean K-L grade 3.3) and 15 asymptomatic control subjects (mean age 56.3, mean BMI 27.8) have been recruited from the community. Three-dimensional motion analysis was conducted on each subject in a standard shoe. Homogeneity of group means for each variable was tested using a single classification ANOVA. Results: Significant heterogeneity of means were found for peak knee external adduction moment ($p<.001$), peak knee adduction angle ($p<.001$), and knee adduction excursion ($p<.001$). Post-hoc t-tests were conducted for each variable to ascertain group differences. For each of the variables, the three groups demonstrated significant differences from each other. Conclusion: These results suggest that differences in frontal plane mechanics exist between asymptomatic control subjects and subjects with medial or lateral TF OA. Interventions to address abnormal mechanics in subjects with TF OA may differ according to the compartment that is most affected.
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18 SURGICAL RECESSION OF THE GASTROCNEMIUS FOR ISOLATED CONTRACTURE: A CASE STUDY

Nicole Chimera[1], Michael Castro[2] & Kurt Manal[1]

[1]Department of Mechanical Engineering, Center for Biomedical Engineering Research
[2]Pennsylvania Orthopaedic Foot & Ankle Surgeons, Philadelphia PA

The inability to achieve normal ankle dorsiflexion is known as equinus. Isolated gastrocnemius contracture (IGC) is an equinus in which there is normal ankle dorsiflexion with the knee flexed however there is less then 5° or 10° of dorsiflexion with the knee fully extended. The inability to achieve normal dorsiflexion during the stance phase of gait can result in early heel-rise and may be associated with elevated fore-foot pressure; which may provide insight into why decreased ankle dorsiflexion range of motion is associated with numerous foot injuries. Surgical intervention may be indicated if conservative treatment fails to resolve gastrocnemius tightness and symptoms persist. One surgical option is the Strayer procedure (gastrocnemius recession) which involves division of the gastrocnemius tendon distal to the muscle bellies. The purpose of this case study is to report kinematic and foot pressure measurements pre and post-operatively for a healthy, active 62 year old female subject clinically diagnosed with bi-lateral ICG. The subject participated in two data collections. The first collection took place one week prior to surgery and the second approximately 3 months following right gastrocnemius recession. Motion analysis data were collected pre and post operatively and foot pressure recordings for the right and left feet were sampled post-op. The patient had a 15 degree increase in dorsiflexion range of motion upon clinical examination following surgery that was also evident in ankle joint motion during gait analysis. Recall the subject had left gastrocnemius tightness at the time of testing. The left heel rose earlier in stance than the right foot following gastrocnemius recession. Subjects with IGC lift the heel off the ground early to compensate for loss of ankle dorsiflexion. Early heel rise will cause the forefoot to be loaded for a greater proportion of stance resulting in elevated plantar pressures. Gastrocnemius recession improves patient function, normalizes joint kinematics and reduces forefoot pressure.

19 HYDROSTATIC PRESSURE INDUCES OSTEOGENIC RESPONSES IN MC3T3 OSTEOBLASTS

Joseph D. Gardinier[1], Greg Madden[1], Elizabeth Adams[2], Randall Duncan[1]
[1]Department of Biological Sciences, [2]Delaware Biotechnology Institute

Gross mechanical loading generates various mechanical forces on bone that are essential for the maintenance of bone mass. While fluid shear has been shown to produce anabolic responses in osteoblasts [1], we postulate that hydrostatic pressure incurred during loads produces similar osteoblast responses as fluid shear. Hydrostatic pressure gradients of 0-5psi and 0-10psi at 0.25, 0.5, and 1Hz were applied to MC3T3 cells seeded on type-1 collagen coated glass slides in a custom-built chamber, similar to a parallel fluid flow chamber used to apply 12 dynes/cm^2 of shear stress. Like sheared MC3T3 cells, pressure induced a rapid, 5-fold increase in ATP release within 5 minutes of the onset of hydrostatic pressure compared to static controls. This response was dependent on the frequency and change in magnitude of the pressure gradient. Using an atomic force microscopy, we found that cellular stiffness increased 3-fold within 15 minutes of the onset of hydrostatic pressure and continued to increase up to 10-fold depending on the applied pressure gradient. This increase in stiffness was similar to that measured in osteoblasts in response to fluid shear. These data would indicate that hydrostatic pressure gradients induce a similar response in MC3T3 cells as fluid shear. Future studies include simultaneous application of pressure and fluid shear in which each mechanical load will be varied independently to provide further insight into the control of osteogenesis through mechanical loads.

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20 THE SIMULATION OF NORMAL AND PATHOLOGICAL GAIT USING OPENSIM

Ming Xiao, Chris Richards and Jill Higginson

Muscle-driven forward simulation is a powerful tool to understand muscle function during human walking. However, it also incurs great computational expense(1). OpenSim is a new forward simulation tool based on Computed Muscle Control (CMC)(2). The objective of this study was to determine the feasibility of building normal and pathological (stroke and OA) gait simulations using OpenSim. Demonstrations will be provided and the advantages and limitations of this approach will be discussed.

3D musculoskeletal model was generated by OpenSim. The model was first scaled to subject dimensions. Inverse dynamics and residual reduction algorithms were then used to find the joint angles that best reproduce the experimental kinematics. CMC was applied to compute the set of muscle excitations that drives the model to track the desired kinematics. Finally, the computed excitations were used to drive a forward dynamics simulation. Each simulation was completed within 30 minutes on a personal computer with a 3.0GHz Pentium 4 processor. Simulation joint angles were within ± 2º of the experimental data. Ground reaction forces were within ±1 standard deviation of experimental data.

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21 FRONTAL AND TRANSVERSE PLANE REARFOOT, HIP AND KNEE PATTERNS IN FEMALE RUNNERS WITH A HISTORY OF PATELLOFEMORAL PAIN

Brian Noehren M.S. PT, Irene Davis Ph.D. PT

INTRODUCTION: Patellofemoral Pain (PFP) in runners is often associated with abnormal lower extremity motion in the frontal and transverse planes. Due to the variability in these patterns, the timing of peak values varies widely, making it difficult to compare across subjects and groups. In addition, peak values provide information about one discrete point in time. Thus, analysis of the general trend of the patterns may be a more robust method of examining these mechanics. Purpose: To compare the average curves in the secondary planes of motion of the hip, knee and rearfoot between runners with a history of PFP compared to healthy, age-matched controls.. METHODS: This is an ongoing study in which 19 female runners, ages 18-45 years old, with a history of PFP have been recruited. 19 uninjured, age and mileage-match females, served as the controls. 3D kinematic data were collected as subjects ran along a 25m runway at a speed of 3.7 m/s. Each trial was time-normalized, averaged across the stance phase, and then averaged across groups. Effect sizes (ES) were then calculated for each group. All ES greater than 0.5 were considered clinically significant. RESULTS: The PFP subjects had a 0.11 ES for hip adduction (7.9 deg vs 7.2 deg) and a 0.40 ES for hip internal rotation (0.3 deg vs 2.5 deg) At the knee the PFP subjects had a ES of 0.51 for knee adduction (-1.2 deg vs -0.6 deg) and a ES of 0.71 for knee internal rotation(-5.8 deg vs -1.5 deg). Lastly the PFP group had a 0.33 ES for rearfoot eversion (4.4 deg vs 5.4 deg). CONCLUSIONS: The average value of an entire stance trajectory curve is less sensitive to local changes and may be a better discriminator of secondary plane mechanics between PFP subjects and healthy controls. The PFP subjects had lower knee adduction and greater internal rotation curves. The combination of knee abduction and internal rotation in the PFP group may increase stress and contact area on the lateral patella.

22 PREDICTING RETROSPECTIVE TIBIAL STRESS FRACTURES IN FEMALE RUNNERS USING KINEMATIC AND KINETIC VARIABLES

Michael B. Pohl, Irene S. Davis FACSM, University of Delaware, Newark, DE

INTRODUCTION: Both kinematics and kinetics of the lower limb have been shown separately to be related to the incidence of tibial stress fractures (TSF) in female runners. Increased hip adduction (HADD) and knee internal rotation (KIR), along with decreased knee adduction (KADD) have been reported in subjects exhibiting tibial stress fractures. In addition, peak tibial shock (PPA), vertical impact load rate (ILR) and peak absolute free moment (FM) have been shown to be higher in these subjects. However, it is currently unknown which kinematic and kinetic variables are the most important in terms of predicting the occurrence of a TSF.
PURPOSE: To determine which kinematic and kinetic factors are the best predictors of tibial stress fractures in female distance runners.
METHODS: Twenty-eight female runners who had previously sustained a TSF along with an age and mileage matched control group (n=28) participated in the study. Subjects ran along a 25m runway at 3.7m/s while kinematic and kinetic data were recorded at 120 and 1080Hz respectively. Five trials from each subject were used for data analysis and ensemble means were calculated for both the injured and control groups. The variables HADD, KIR, KADD, PPA, ILR and FM were entered into a binary logistic regression.
RESULTS: HADD was able to correctly predict whether a subject would fall into the injured or non-injured category 67.3% of the time. Adding FM to the regression equation improved the confidence to identify injured subjects to 78.2%. The inclusion of PPA raised the predictive ability even further to 83.6%. The addition of ILR, KADD and KIR did not further improve the ability to predict injury.
CONCLUSIONS: Based on these results, HADD, FM and PPA appear to be the most important of the variables of interest in terms of predicting TSF in female runners.

23 ESTIMATION OF CORRECTIVE CHANGES IN MUSCLE ACTIVATION PATTERNS FOR STROKE PATIENTS DURING FES INTERVENTION

Qi Shao, Daniel N. Bassett, Kurt Manal, Thomas S. Buchanan
Center for Biomedical Engineering Research, University of Delaware

Functional electrical stimulation (FES) has been used in the rehabilitation of post-stroke patients. It is important to know how to stimulate the muscles when using FES. Many control methods have been used to derive the required electrical stimulation patterns. However, these models were not developed based on biomechanical model of human neuromuscular system, thus can not account for sophisticated neurological control strategies during human movements. Based on our developed electromyography (EMG) driven model, we have created a biomechanical model to estimate the corrective increases in muscle activation patterns needed for a person following stroke to walk with an improved normal gait. Firstly, the EMG-driven model was tuned using the subject's gait trial, which could then be used to predict joint moments for new muscle activation patterns. Using the tuned model, we constructed an optimization model to calculate the corrective EMG patterns to achieve a healthy joint moment profile. We included 2 stroke subjects in our study and determined the changes in muscle activation patterns that would correct their gait patterns. Different stimulation protocols were implemented and generated different ΔEMG patterns, which may be selected based on clinical judgment and practical condition. After the corrective muscle activation changes are estimated through our model, the appropriate electrical stimulation patterns may be determined through other developed models. These stimulation patterns could be implemented as baseline in open-loop control or hybrid control during FES intervention.

24 FLUID AND PARTICLE TRANSPORT IN AN IN-VITRO MODEL OF AN EXPANDING/ CONTRACTING HUMAN ALVEOLUS

Sudhaker Chhabra and Ajay K. Prasad
Department of Mechanical Engineering, University of Delaware, Newark, DE 19716.

Inhaled particulate matter from the environment can produce adverse health effects on the human respiratory system. Conversely, inhalable therapeutics can be delivered to the respiratory tract to treat local and systemic ailments. Both of these fields of study require the accurate prediction of particle transport and deposition in the lung, particularly in the acinar region. A necessary first step to predict particle trajectories is to characterize the airflow in which the particles are suspended. The current work focuses on the fluid mechanics of the acinar region of the lung to infer particle transport and deposition. We have developed an in-vitro model of a single human alveolus mounted on a rigid tube for our study. The alveolus is capable of expanding and contracting in synchronization with the oscillating flow in the bronchiole. Advanced diagnostic tools have been used to measure the complex flow patterns and mixing between bronchiole and alveolar fluids.

The key outcome of our study is that maximum fluid transport to the alveolar wall occurs when bronchiole flow is combined with alveolar oscillation. Consequently, particle deposition at the alveolar walls is possible when alveolar walls oscillate. To date, we have fully explored synchronous flow where the alveolus oscillates in phase with the bronchiole flow. Ongoing studies are focused on out-of-phase (asynchronous) flows typically seen in diseased lungs. Our goal is to examine if a phase lag between the bronchiole flow and alveolar motion affects mixing and dispersion.

25 HAND FORCE CONTROL DURING OBJECT MANIPULATION IN MULTIPLE SCLEROSIS

Vennila Krishnan, Paulo Barbosa de Freitas Jr, Slobodan Jaric,
Motor Control Lab, Department of Health, Nutrition, and Exercise Sciences, University of Delaware

Background and Objectives: Hand force coordination is essential for everyday manipulation tasks. The aim of this study was to evaluate a method for assessment of hand function in mildly affected MS patients. Methods and Materials: Sixteen MS patients (EDSS 1-4.5) and sixteen age and gender matched healthy controls were examined on simple manipulation tasks using an instrumented rod-like device. The device consisted of two handles that could be either fixed or detached from the base. Two transducers measured grip force (G; component acting normally upon the contact area) applied against the handle, while two additional transducers measured the load force (L; tangential component) that was exerted along the handle. In the dynamic manipulation task, subjects lifted and held the handles, using either one or both hands. In the static manipulation tasks subjects traced a depicted ramp pattern under both visual and non-visual feedback condition. Results: When compared with healthy individuals, MS patients revealed a deteriorated task performance regarding the accuracy of exertion of the prescribed L pattern. Excessive G/L ratio (i.e. 'over-gripping') was also observed in MS patients under all task conditions. The force coupling observed through the cross correlations between G and L revealed similar results in two groups. Switching from visual feedback to no feedback conditions and switching from bimanual to unimanual conditions revealed similar effect in both groups. Conclusion: The results suggest that the applied methodological approach is sensitive enough to distinguish between the mildly involved MS patients and healthy individuals. Taking also into account a lack of objective quantitative test of hand function in neurological patients, as well as the importance of hand function *per se*, one could conclude that the applied method could be developed into a standard protocol for testing hand function in MS and, possibly, other neurological diseases.

26 MODELING MECHANICAL ENHANCED SOLUTE TRANSPORT IN THE BONE LACUNAR-CANALICULAR SYSTEM

Xiaozhou Zhou and Liyun Wang
Center for Biomedical Engineering, Department of Mechanical Engineering Research

Osteocytes rely on solute transport through canaliculi for nutrient supply, metabolic waste removal, and for exchanging molecular signals among themselves and with other cells. We have recently developed an imaging approach based on Fluorescence recovery after photobleaching (FRAP) for measuring solute transport around osteocytes in the presence of applied mechanical loading. The goal of the present study was to model solute transport during FRAP experiments in loaded bone, which could be used to fit with the experimental data and to obtain the transport characteristics (such as Peclet number) for various solutes and loading conditions. We developed a two-leveled model to describe the interstitial flow at the entire bone level and the tracer diffusion and convection at the lacunar-canalicular level in a mouse tibia subjected to an intermittent cyclic loading. At the entire bone level, interstitial flow velocity was obtained analytically using poroelasticity and Darcy's law from the off-center compression applied to an intact mouse tibia (0.5 Hz sinusoidal loading with an inserted 4-sec rest period). The flow velocity served as an input for the lacunar-canalicular level model. At this microscopic level, a lacuna 30 micron below the medial periosteum was assumed to be photobleached where solute concentration was reduced to half of its original value as performed in our FRAP experiments. The time course of the solute concentration recovery due to both diffusion and convection from the surrounding lacunae was numerically calculated using a modified diffusion-convection equation and a finite difference scheme. To mimic the transport of biological molecules of different sizes, we tested three solutes with diffusion coefficients varying from 3, 30, to 300 $\mu m^2/s$. Our results showed that the recovery rate of the solute concentration in the photobleached lacuna is more than 10 times higher during the loading period than that during the rest period for all the three solutes. This finding suggested a significant enhancement of transport due to convection. The overall time-averaged transport of solute into the photobleached lacuna behaved as an exponential damping process, and the recovery rate generally increased with the solute diffusion coefficient and the loading magnitude. However, for high loading magnitudes (> 6N), the overall recovery rate becomes almost identical for the relatively large solutes with a diffusion coefficient of 30 and 300$\mu m^2/s$. In summary, we have developed a mathematical model that can be used to fit experimental data and to obtain the characteristics of solute transport among osteocytes. Understanding osteocyte metabolism and cell-cell signaling is critical for studying bone mechanotransduction, adaptation as well as drug delivery.

27 EXPERIMENTAL MEASUREMENT OF THE THREE-DIMENSIONAL STRAIN FIELD AND MOLECULE DIFFUSION COEFFICIENT IN ARTICULAR CARTILAGE UNDER STATIC COMPRESSION LOADING

Greg Wolos, Claudia Kim*, John Novotny[†], Jennifer Docimo**
**Graduate students and [†]Assistant Professor, University of Delaware*

A novel method was developed to mechanically load a murine humeral head while imaging the loaded cartilage using a multi-photon/confocal microscope. The method required development of a portable, high-resolution mechanical testing device and a unique microscope stage design that allowed the cartilage to be imaged without sacrificing its structural integrity. Coupled measurements of molecule diffusion and strain were collected at the same location in the tissue. Diffusivity of inert molecules was calculated using the fluorescence recovery after photobleaching (FRAP) method. Nuclei displacement was calculated using a three-dimensional, cross-correlation technique by tracking chondrocyte cell nuclei between three static loads. The Lagrangian finite strain was then calculated from the displacement field and principal strains were determined. Changing diffusivity in the superficial tangential zone as a function of static compressive strain was found to fit well to a second order polynomial. The diffusivity first decreased with compressive strain before increasing. The increase in diffusivity was not expected and is thought to be attributed to collagen fiber realignment.

28 A HYBRID METHODOLOGY USING ULTRASONOGRAPHY AND MOTION ANALYSIS FOR ESTIMATION OF ACHILLES TENDON MOMENT ARMS *IN VIVO*

Justin D. Cowder, Nicole Chimera, Thomas S. Buchanan and Kurt Manal
University of Delaware, Department of Mechanical Engineering

Current techniques for computing musculotendon moment arms (MA) include the center of rotation and tendon excursion methods (Maganaris 2004; Ito et al., 2000). Both methods require an angular change in joint position and a change in musculotendon length or its line of action and thus require 4 measurements to compute the MA at a given joint angle. Errors associated with these measurements are difficult to ascertain when data is collected *in vivo*, of which the effect of such errors on MA accuracy cannot be determined. Accordingly, reducing measurements can improve MA estimation. Thus, we present a hybrid methodology using ultrasonography (US) and video-based motion analysis to estimate Achilles tendon moment arms for the ankle joint in the sagittal plane in which two values at each joint angle are needed to compute the MA. One is the spatial location of the joint center and the second is the distance from the transducer to the midline of the tendon.
This method was validated using an animal model and also used to estimate the Achilles tendon MA of a single human subject *in* vivo. The Achilles tendon MA is the perpendicular distance from the ankle joint center (midpoint between lateral and medial malleoli) to the midline of tendon. The technique for data collection involved acquiring US images of the Achilles tendon in the saggital plane while recording the position of reflective markers on the US probe and both malleoli. Based on motion analysis and US image synchronization data, the Achilles tendon midline was determined, which was then used to compute the MA via the hybrid method. In addition, a digitizing wand was used digitize the midline of the tendon in the animal model to compute the MA for validation of hybrid method results. *In vivo*, the hybrid method was used to estimate Achilles tendon MA at rest and MVC with the ankle in maximum dorsiflexion and at a neutral angle, both with the knee in 115^{o} of flexion. Results for the hybrid method in the animal model resulted in a MA measurement of 37.5mm compared to 38.8mm using the digitized wand; a 3.3% difference. *In vivo*, MA measurements from rest to maximum voluntary contraction were similar with a decrease when in dorsiflexion. In summary, the hybrid method reduced errors involved in MA estimations and offers itself as an accurate estimate of Achilles tendon MA *in vivo*.

29 ESTIMATION OF KNEE JOINT COMPRESSION FORCE IN SUBJECTS WITH MEDIAL COMPARTMENT KNEE OSTEOARTHRITIS

Joseph A. Zeni, Jr and Jill S Higginson, University of Delaware

INTRODUCTION: Determination of individual muscle force contributions during walking is limited by the problem of redundancy in the motor system. We have developed a static optimization technique that can be applied to pathological gait in order to determine individual muscle forces as well as overall knee joint forces. The purpose of this investigation was to determine whether this optimization technique produces results that are physiologically meaningful for individuals with knee osteoarthritis (OA) as well as provide a foundation for which future optimization parameters can be established in this subject population.
METHODS: Ten subjects with radiographic evidence of medial compartment knee OA took part in the investigation. EMG, 3D motion analysis and kinetic force plate data were obtained during 30 second walking trials on an instrumented treadmill. Static optimization was then performed to determine uni- and bi-articular muscle forces for sagittal plane ankle, hip and knee muscles. Muscle forces to minimize net muscle stress were determined.
RESULTS & DISCUSSION: Average knee joint force was determined to be 2.15 times body weight (BW). This value is similar to previous work that used a telemetered knee prostheses to determine actual knee compression force at 2.1 BW (Taylor et al., *J Biomech*, 2001). Estimated force production from individual muscles closely matched the EMG patterns aquired experimentally, suggesting that the static optimization criteria provides accurate onset and offset times of muscles contributing to knee joint compression. Future research will include frontal and coronal plane moments as well as evaluation of alternate cost functions.

30 MEDIALLY WEDGED INSOLES REDUCE KNEE PAIN DURING FUNCTIONAL ACTIVITIES IN SUBJECTS WITH LATERAL KNEE OSTEOARTHRITIS.

Chandra H. Lloyd[1], Todd D. Royer[1], Joaquin Barrios[2], and Irene M. Davis, FACSM[2]
[1]Health, Nutrition and Exercise Sciences, and [2]Physical Therapy, University of Delaware

We have previously demonstrated that laterally wedged orthotics can alleviate knee pain in subjects with medial compartment knee osteoarthritis. However, this effect has not yet been demonstrated in subjects with lateral knee osteoarthritis (LKOA) using a medially wedged orthotic. PURPOSE: To determine the effect of medially wedged orthotics on knee pain and function in subjects with LKOA. METHODS: As part of a larger study, ten subjects aged 65± 7 years with LKOA (K-L grades II-IV) were chosen for evaluation. Subjects were given an orthotic with an individually determined amount of wedging (range 5-15 degrees, average 9 ± 3 degrees) based on maximum pain reduction during a lateral step-down test. Subjects returned for testing following two weeks of accommodation to the orthotic. Two functional tests were performed: a 6-minute walk test, followed by a timed stair ascent and descent test. Subjects rated their knee pain before and after each test on a 100mm visual analog scale. Dependent t-tests ($p \leq 0.05$) were used to assess changes in walking distance, stair test time, and knee pain between the no-wedge (NW) and wedge (W) conditions. RESULTS: There were no differences between the NW and W conditions for six minute walk distance ($p=0.57$) or stair test time ($p=0.12$). For the stair test, knee pain significantly increased in the NW condition (pre-test pain 14.9±18.7mm, post-test pain 22.6±21.3mm; $p=0.02$) while there was no change in pain for the W condition (pre pain 11±12.3mm, post pain 13.8±15.5mm; $p=0.16$). Similar results were found for the six minute walk, with pain increasing significantly in the NW condition (pre pain 13.4±15.5mm, post pain 22.9±17.8mm; $p=0.005$) but not in the W condition (pre pain 11±15.6mm, post pain 17±18.7mm; $p=0.25$). CONCLUSION: Short term accommodation to medially wedged orthotics appear to prevent increases in knee pain associated with walking and stair climbing in patients with lateral knee OA. ACKNOWLEDGEMENTS: Support from NIH-RR16548 (Thomas Buchanan, PI) is acknowledged.

31 ASSESSMENT OF LATERAL HAND FUNCTION DEFICITS IN CHILDREN WITH HEMIPLEGIC CEREBRAL PALSY BY WAY OF GRIP AND LOAD FORCE COUPLING AND THE JEBSEN-TAYLOR TEST

Sam Mackenzie, Nancy Getchell, Slobodan Jaric, Freeman Miller, and Chris Modlesky

Introduction: Children with hemiplegic cerebral palsy (CP) often have impaired motor function wherein one side of the body is more prominently affected. While lateral involvement is typically recognized in a qualitative sense, quantifying force coordination would improve our understanding of CP and may aid in the development of new interventions. Purpose: The purpose of this study was to compare the hand force coordination of children with hemiplegic CP and typically developing (TD) children while lifting a light object. Methods: Five children with mild to moderate hemiplegic CP (2 boys, 3 girls, age =11.7 ± 2.0 years) all with left side involvement and 5 TD children (2 boys, 3 girls, 2 left-handed, 3 right-handed, age = 11.3 ± 1.6 years) performed simple lifting of a light object that measured grip force (*G*) and load force (*L*). The extent of lateral involvement was evaluated by comparing *G*/*L* ratios and Pearson cross correlation coefficients of *G* and *L* within limbs. Subjects also completed the Jebsen-Taylor Test of Hand Function, a standardized timed test that mandates rapid completion of several occupational tasks. Results: The CP group showed higher average involved limb (I) *G*/*L* ratios compared to non-involved limb (NI) ratios and those *G*/*L* ratios of the TD group over lift, hold, and release phases. Pearson cross correlation coefficients for the CP group during lift and release were also lower than for the TD group [CP: 0.94 (I lift), 0.90 (NI lift), 0.89 (I release), 0.84 (NI release); TD: 0.96 (NDom lift), 0.97 (Dom lift), 0.92 (NDom release), 0.92 (Dom release)]**.** Time to complete the Jebsen-Taylor test was higher for the CP group (I = 202 ± 56 sec and NI = 58 ± 29 sec) than for the TD children (NDom = 33 ± 3 s and Dom = 30 ± 5 s). Discussion: Lateral involvement was demonstrated in the CP group by higher *G*/*L* ratios, lower Pearson cross correlation coefficients, and results of the timed Jebsen-Taylor test. Investigation into the mechanism(s) of these findings is ongoing. Future research will determine whether bimanual activity reduces pathological performance by way of improved grip and load force coupling. This research was supported by NIH grant HD050530.

32 ESTIMATING THE MAXIMUM FORCE GENERATING ABILITY IN POST-STROKE MUSCLES

Trisha Kesar(1), Ramu Perumal (2), Stuart A. Binder-Macleod (1,2)
(1) Inter-disciplinary Program in Biomechanics and Movement Sciences
(2) Department of Physical Therapy

Muscle weakness is a common sequel of stroke. It is challenging, if not impossible, to accurately measure the force generating ability of post-stroke muscles. We can, however, estimate the maximum force generating ability of post-stroke muscles. Previous studies on healthy human muscles showed a nonlinear relationship between volitional contraction intensity and degree of central activation, with an underestimation of the degree of central activation during submaximal contractions. It is not known if central activation can be reliably measured in post-stroke muscles. The goal of the current study was to compare 2 methods of estimating the maximum force generating ability of post-stroke quadriceps femoris muscles. In the 1st method, a supramaximal twitch was superimposed over a maximum voluntary isometric contraction (MVIC) (twitch interpolation technique) to asses the extent of volitional activation (VA), which was then used to obtain the estimated maximum force generating ability (Max_{VA}). In the 2nd method, twitch to tetanus ratios (TTR) were used to obtain a novel estimate of the maximum force generating ability, i.e., the estimated maximum tetanic force (Max_{TTR}). We compared the estimated maximum forces to the measured MVIC force. Our results showed that the measured MVIC forces (366.1± 54.4 N) were much lower than the estimated maximum forces (Max_{VA}=698.4±210.5 N and Max_{TTR}=806±216.2 N). Thus, the MVIC may underestimate the maximum force generating ability of the quadriceps muscle by 48-54%. The degree of volitional activation measured by the twitch interpolation technique was 56.8±28.7%, implying marked impairments in muscle activation. The estimated Max_{TTR} was 13.4% greater than the estimated Max_{VA}, suggesting that the twitch interpolation technique may underestimate the degree of volitional activation in post-stroke muscle. A better understanding of the causes of post-stroke muscle weakness can help improve rehabilitation interventions for restoring muscle function in individuals with hemiparesis following stroke.

33 HOPPING TASKS: COMPARISON OF SURFACE VS. FINE-WIRE ACTIVATION PATTERNS

Nicole Chimera[1], Daniel Benoit[2], and Kurt Manal[1]
[1]Department of Mechanical Engineering, Center for Biomedical Engineering Research
[2]School of Rehabilitation Sciences, University of Ottawa, Ottawa, ON

When recording muscle activation patterns, surface electrodes are used more often than fine-wire; most likely due to the simplicity of use, little discomfort to patients, and fairly good reproducibility. There are characteristics of surface electrodes however that should be considered. For example, they sample from a larger tissue volume than fine-wire electrodes. Additionally, muscle fibers may shift with respect to the skin/surface electrode with changes in joint angles. Thus, choice of electrode type may influence the timing and shape of the activation profile, especially during dynamic activities. EMG is used during functional tasks to determine muscle onset and time to peak activation; two variables which may contribute to dynamic stability. Muscle onset and time to peak may be influenced by choice of electrode and therefore it is important to understand the influence electrode type has on these timing variables. Previous studies have shown that muscle activation patterns during manual muscle testing, walking and running are similar, and that timing measures are not different when using surface and wire electrodes. However hopping tasks, reported to decrease the incidence of knee ligament injuries, have yet to be considered. The purpose of this investigation was to compare surface and fine-wire neuromuscular activation patterns during hopping.
Seven male subjects participated in hopping and walking tasks while surface and fine wire EMG were recorded simultaneously. For walking, hopping, and hop and stop trials the surface and fine-wire electrodes exhibited no differences in average muscular activation profiles and timing variables. During dynamic hopping tasks onset of muscle activation, time to peak muscle activation, and muscle activation patterns recorded using surface and fine-wire electrodes were similar. Thus, the use of non-invasive surface electrodes provides an adequate representation of timing variables for the muscles tested and the dynamic hopping tasks examined in this study.

34 MODELING REMOVAL OF CHOLESTEROL FROM MULTI-PHASED MEMBRANE

Brian A. Rosen, Department of Chemical Engineering, University of Delaware

Seratonin, one of the five major neurotransmitters in the brain, plays a wide range of roles in the regulation of physiological functions, and malfunctions in seratonin pathway can lead to neurological disorders such as Alzheimer's and Neiman Pick C. One of the major moderators of Seratonin signaling in the hippocampus is the plasma membrane, more specifically, its cholesterol composition. The plasma membrane is a combination of liquid disordered (l_d) phases and liquid ordered (l_o) lipid rafts, which contain a higher content of cholesterol and higher affinity to the seratonin$_{1A}$ receptors. The cholesterol within the lipid raft plays an important role in the signal propagation through the seratonin pathway. The dependence of Seratonin-binding on cholesterol is generally measured by depleting the plasma membrane of cholesterol using methyl-β-cyclodextrin (MβCD), a liquid extracting agent with a binding pocket for cholesterol. A precious study (Pucadyil et al., 2004, *Biochimica et Biophysica Acta*, 1663, pp 188-200) shows that depleting the membrane of 75% of its cholesterol inhibits seratonin-binding by 50%, implying a strong dependence of seratonin-binding on cholesterol, based on the assumption of uniform cholesterol depletion from the membrane. To evaluate this assumption, we conduct a parametric study on the cholesterol removal from the two phases of the membrane, where mass transport properties of both the multi-phase plasma membrane and the liquid extracting agent are varied and partition of cholesterol among the multi-phases of membrane is examined. The results from this model will be used to validate the conclusion from Pucadyil et al. (2004).

35 AN IMPAIRMENT DURING GAIT FOR INDIVIDUALS THREE YEARS AFTER TOTAL KNEE ARTHROPLASTY.

Yoshida Y, Farquhar SJ, Snyder-Mackler L.

INTRODUCTION: Altered gait patterns after total knee arthroplasty (TKA) have been reported as asymmetrical due to quadriceps weakness in the early post-operative phase. There is also a compensatory mechanism using greater hip extension moment and lower knee extension moment to obtain symmetric acceptance of external force1 year after surgery. However, there is no information about how the compensatory mechanism is altered beyond 1 year. Nor are there explanations as to why individuals after TKA show slower gait speed for years after TKA, though they improve their functional performance. METHODS: Seven individuals 3 years after TKA and 12 age and weight matched healthy individuals were participated in gait analysis and quadriceps strength testing. RESULTS: Individuals 3 year after TKA were bilaterally weaker, and walked significantly slower, with prolonged double support time compared to age and weight matched group. The patterns of joint moments contributing to total support loading of the lower extremity was not different between two groups; however, vertical ground reaction force was significantly lower in the both limbs compared to the healthy group. DISCUSSION: Although individuals 3 years after TKA no longer have different joint moment contribution patterns to total support moment during loading from controls, the overall loading of the lower extremity was significantly lower compared to age and weight matched healthy individuals. Quadriceps weakness continues to result in a decreased ability to accept the external force during loading, and may prevent individuals from improving gait speed. Individuals with TKA need to improve overall quadriceps strength to improve their ability to accept the external force, allowing them to walk more efficiently.

36 GLENOHUMERAL ROTATION AND SCAPULAR POSITION CHANGE FOLLOWING COMPETITIVE HIGH SCHOOL BASEBALL

Thomas SJ, Swanik KA**, Swanik CB*, Huxel KC***, Kelly JD****:*
**Department of Health, Nutrition, and Exercise Science, Human Performance Laboratory*
***Department of Nursing and Heath Sciences, Neumann College, Aston, PA.*
****Department of Athletic Training, Indiana State University, Terre Haute, IN.*
*****Department of Orthopedic Surgery, Temple University Hospital, Philadelphia, PA*

Pathologies such as anterior instability and impingement are common in baseball and have been linked to decreases in internal rotation (IR) and concurrent increases in external rotation (ER) motion. Additionally, alterations to scapular position have been identified in this population. Objective: To measure glenohumeral (GH) IR and ER rotation, total ROM and scapular position (upward rotation, protraction) throughout the course of a high school competitive baseball season. Methods: Nineteen high school baseball players (age = 16.58± 0.77 years, mass = 78.56± 11.98 kg, and height = 180.34± 6.22 cm) with no history of shoulder or elbow surgery completed this study. Participants were assessed pre and post season with the non-dominant arm serving as a control. GH IR and ER were measured supine with the scapula stabilized. Total GH ROM was calculated as the sum of IR and ER measures. Scapular upward rotation was tested at rest, 60°, 90°, and 120° of GH abduction in the scapular plane; scapular protraction at 0°, hands on hips, and 90° of GH abduction in the scapular plane with maximum IR; A Saunders Digital Inclinometer (The Saunders Group Inc. Chaska, MN) was used for scapular upward rotation and GH ROM; A Vernier Caliper (Mitutoyo Measurement Technology. UK) was used for scapular protraction. Results: Separate 2-way MANOVA's with repeated measures were performed for scapular upward rotation and protraction. Separate 2-way ANOVA's with repeated measures were performed for IR, ER, and total GH motion. Overall the dominant arm had significantly less GH IR (11.35°, p=.005) and significantly more ER (4.69°, p=001) than the non-dominant arm. However, the total motion on the dominant arm was significantly less when compared to the non-dominant arm (6.66°, p=0.001). No significant differences were observed from pre to post season for IR (p=0.473) or ER (p=0.223). Overall, scapular upward rotation significantly decreased at 60° (1.4°, p=.014), 90° (2.3°, p=.001), and 120° (2.9°, p=.001) of abduction, as well as scapular protraction, which significantly decreased at 90° (0.5cm, p=0.001) from preseason to postseason. Scapular upward rotation at the 0° position significantly increased on the dominant arm from pre to post season (1.4°, p=0.018). Conclusion: Competitive high school baseball players presented with significant glenohumeral motion differences (decrease in IR and increase in ER) when comparing their dominant to non-dominant arm. For this reason there was also a significant decrease in total motion in the dominant arm. Previous literature suggests that these changes have been thought to predispose the shoulder to injury. Secondly, after 12 weeks of competitive baseball there were scapular position changes (upward rotation and protraction). This data suggests that scapular changes are acquired over the course of 12 weeks of baseball.

37 A COMPARISON OF HIP EXTERNAL ROTATION STRENGTH: SEATED VS. PRONE

Kevin McCoy and Irene Davis

Hip external rotation strength has been linked to running related injuries. This strength can either be measured in sitting or with the subject prone. Sitting may provide better stabilization of the pelvis. However, the hip is extended in the prone position, which more closely simulates hip positioning during running. The resulting values between these two methods have not been compared. PURPOSE: The purposes of this study were (1) to compare the values of hip external rotation torque in prone and sitting, (2) to compare the reliability of each of the methods, both within and between testing sessions, and (3) to determine whether the values obtained from these two methods are correlated. METHODS: 20 subjects (10 male, 10 female) were collected. Subjects were 18 – 25 years old, were injury free at the time of collection, and had never suffered a serious hip injury. Subjects' right legs were measured in the prone and seated positions in a random fashion to eliminate an order effect. A handheld dynamometer was positioned on the medial side of the leg just proximal to the ankle. The device was secured by a strap which was attached to a wall. The subject was instructed to slowly ramp up their effort over 5 seconds to reach a maximum at the end of the count. After a warm-up trial, four maximum effort trials were recorded. The last three were used for analysis. Following a 10 minute rest, the

measures were repeated for the other position to determine reliability. 5 subjects returned for a second collection. The procedure from the first collection was repeated. The force was multiplied by segment length and normalized to body weight. A dependent t-test was used to assess normalized torque differences between the measurements of the methods. Intraclass Correlation Coefficients, (3,k) and (3,1), were used to examine the between and within day reliability, respectively. A Pearson correlation was calculated. RESULTS: The prone measurement was found to be significantly greater ($p<.001$) than the seated (3.27 % body mass*m vs. 2.20 % body mass*m). Reliability was higher in prone for both between day (.961 vs. .855) and within day (.929 vs. .856) testing. The methods were found to be significantly correlated ($r =0.70$, $p= 0.03$). CONCLUSIONS: The prone strength measurements were significantly greater, and more reliable than the seated measurements. The two methods were significantly correlated, and thus related.

38 FIRST GENERATION OF MOBILITY DEVICES IN SPECIAL NEEDS INFANTS

Galloway, J.C., Ryu, J. , Agrawal, S.K.

Self generated mobility via locomotion is a key for the cognitive, social and motor development of young infants. For certain children with special needs, self generated mobility is only attained via assistive technology such as a power wheelchair. Up until recently, infants under 24 months of age were not considered candidates for training in power mobility. Recent work in our labs and others suggest that younger infants can utilize their reaching and grasping ability to learn power mobility.

This interdisciplinary project combines our previous work in motor development and learning in infants with special needs, and the application of robot technology for rehabilitation to determine whether young infants without structured training, would drive a mobile robot, and if so, to determine how their driving would change over multiple sessions.

We recently completed a longitudinal study of the driving performance of two infants, one typically developing 7 month old, and a 14 month old with mobility impairments. Both infants increased their total session time, percentage of session time spent driving, and total path length. These results suggest that, without training, young infants will independently move themselves using a mobile robot. These results provide the foundation for training studies to advance the self generated mobility in young infants with special needs.

Future studies will be discussed that explore the multiple training and technology combinations to reduce the barriers to exploration via self generated mobility. We will present our ideas for the first generation of mobility devices to advance the general development of infants with special needs.

Abstract #	***Presenter***
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