2008 Biomechanics Research Symposium

May 23, 2008

The Center for Biomechanical Engineering Research at the University of Delaware is pleased to host the 5th 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). Podium presentations will take place in the morning and afternoon in CCM 106.

Our keynote lecture will be given by Dr. Hugh Herr from MIT. Dr. Herr is Associate Professor within MIT's Program of Media Arts and Sciences, and The Harvard-MIT Division of Health Sciences and Technology. He is the director of the Biomechatronics group where his research program seeks to advance technologies that promise to accelerate the merging of body and machine. His methods encompass a diverse set of scientific and technological disciplines, from the science of biomechanics and biological movement control to the design of biomedical devices for the treatment of human physical disability. Professor Herr's group has developed powered orthotic and prosthetic mechanisms for use as assistive interventions in the treatment of leg disabilities caused by amputation, stroke, cerebral palsy, and multiple sclerosis.

The keynote lecture will be at 2:15 PM 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 & coffee	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 - 12:00	Podium session 1	CCM 106
12:00 - 1:00	Box Lunch	
1:00 - 2:00	Podium session 2	CCM 106
2:00 - 2:15	Refreshments	
2:15 - 3:15	Keynote: Dr. Hugh Herr	CCM 106
3:15 - 3:25	Awards	

Podium Presentations

Time	Presenter	Abstract #
10:45 - 11:00	Rebecca Fellin	1
11:00 - 11:15	Erin Hartigan	2
11:15 - 11:30	Matthew Hinsey	3
11:30 - 11:45	Deepak Kumar	4
11:45 - 12:00	Joseph Zeni	5
	Lunch	
1:00 - 1:15	Shridhar Shah	6
1:15 - 1:30	Qi Shao	7
1:30 - 1:45	Ann Tokay	8
1:45 - 2:00	Wen Li	9

Keynote Lecture

The Importance of Neuromechanical Limb Models in the Design of Leg Prostheses and Orthoses

Professor Hugh Herr, Massachusetts Institute of Technology

A long-standing goal in rehabilitation science is to apply neuromechanical principles of human movement to the development of highly functional prostheses and orthoses. Critical to this effort is the development of actuator technologies that behave like muscle, device architectures that resemble the body's own musculoskeletal design, and control methodologies that exploit principles of biological movement. In this lecture, I discuss how agonist-antagonist actuation, polyarticular limb architecture, and reflex behaviors can result in quiet, stable, and economical legged mechanisms for walking and running. Neuromechanical models are presented to examine the importance of limb morphology and neural control on locomotory performance. These models are then used to motivate design strategies for prosthetic and orthotic mechanisms.

Location: 106 Center for Composite Materials
Time: 2:15 - 3:15
Refreshments immediately prior

1 PATTERN COMPARISON OF 3D LOWER LIMB KINEMATICS DURING OVERGROUND AND TREADMILL RUNNING

Rebecca E. Fellin, Irene S. Davis, Dept of Physical Therapy, University of Delaware, Newark, DE.

Running gait analyses are performed utilizing both treadmill (TM) and overground (OG) running modes. Previous studies, which examined 2D knee and rearfoot motion suggest similar mechanics between OG and TM. However, no studies have compared 3D kinematic patterns of the hip, knee and rearfoot between both modes of running. PURPOSE: To compare 3D kinematic patterns of the hip, knee and rearfoot between overground and treadmill running. METHODS: We utilized a VICON motion analysis system to collect five trials each of OG and TM running at 3.35 m/s for twenty recreational runners. The subjects (aged 25.2 ± 6.2 years) ran at least 10 miles/week. Kinematic patterns of the right lower limb were compared utilizing the methods of Trend Symmetry yielding three, separate symmetry values. Trend similarity, a measure of the waveform similarity, ranges from 0-1.0, with 1.0 indicating the patterns are identical. Range offset is a measure of the mean difference between curves. It is calculated by subtracting the average OG value from the average TM value, with zero indicating similar curves. Range amplitude, a measure of relative excursions, is the ratio of TM excursion to OG excursion. A value of one indicates identical excursions. RESULTS: Trend Symmetry values ranged from 0.86 to 099 (Table 1). Range offsets varied from -1.0 to +0.7 degrees. Range amplitude varied from 0.82 to1.06. The sagittal plane motions exhibited the most similarity. The greatest differences occurred in the transverse plane for all three measures. CONCLUSION: These results indicate that, on average, kinematic patterns in treadmill and overground running are very similar.

2 KNEE FUNCTION BEFORE AND AFTER ACL RUPTURE AND THE RESPONSE TO INTERVENTIONS

Erin Hartigan PT, DPT, ATC, Andrew Lynch, sPT, Lynn Snyder-Mackler PT, ScD, SCS
Department of Physical Therapy, Biomechanics and Movement Science, University of Delaware.

An athlete ruptured his right ACL and subsequently ruptured his left ACL almost 2 years later. We obtained prospective gait and functional data on the left limb allowing us to identify whether greater muscle co-contraction values precede ACL injury or if changes occur in response to the injury. We hypothesized that EMG muscle co-contraction values would increase during gait and functional scores would decline in response to ACL injury. The subject received progressive strength training prior to the right ACL reconstruction and progressive strength training in conjunction with perturbation training prior to the left ACL reconstruction. Therefore we were able to determine whether two different interventions affect co-contractions and functional outcomes similarly. We hypothesized that perturbation training would improve functional scores and decrease co-contraction better than strength training alone. We concluded that this subject appeared to have adopted a generalized increased co-contraction strategy to control dynamic knee stability across the stance phase of the gait cycle in the absence of ACL. Perturbation training in conjunction with strength training more strongly affected functional criteria that have been shown to be linked to dynamic knee stability. This may be due to the fact that the subject utilized earlier hamstring acticity to prepare for the foot contacting the ground. Furthermore, the large increase in lateral gastroc activity during the preparatory phase, when this muscle is typically inactive, was only evident after strength training. An increase in lateral gastroc activity during weight acceptance was a neuromuscular control strategy present after both interventions. This may be responsible for the improvements seen in functional hop and KOS scores.

3 KNEE JOINT STIFFNESS BETWEEN HEALTHY AND OSTEOARTHRITIC SUBJECTS

Matthew Hinsey ATC, Buz Swanik PhD, ATC, Katy Rudolph PhD, PT, Deepak Kumar PT
University of Delaware

Osteoarthritis (OA) involves chronic inflammation, joint effusion, and altered muscle activation which also accompany complaints of pain, stiffness and instability. Coordinated muscle activation increases knee joint stiffness and stability, but it is unclear how optimal stiffness regulation is achieved in OA and healthy subjects. Seven healthy and 3 OA subjects were instructed to either relax or activate their quadriceps at 30% of their maximum voluntary isometric contraction, while a custom-built device applied a knee perturbation move from 30^o to 50^o of flexion at 100^o/s (accel. & decel. = 3000^o/s^2). Three trials were collected for each condition and stiffness was calculated as the change in force (Newton·meters) divided by the change in position (Degrees). These values included short-range stiffness (first 3^o); muscle stiffness (3^o to peak torque); average total stiffness (entire 20^o move). The passive stiffness values of the healthy group are 4.64±1.16, 7.27±1.75, and .57±.15Nm/^{o}, respectively. The passive stiffness values for the OA group are 5.64±1.63, 8.31±4.01, and .89±.51Nm/^{o}, respectively. Active stiffness of the healthy group are 5.71±1.11, 8.93±2.34, and 2.07±.61Nm/^{o}, respectively. The active stiffness values for the OA group are 6.77±1.28, 9.11±5.99, and 2.37±1.12Nm/^{o}, respectively. Knee stiffness is 3-4 times higher when the quadraceps contract at 30%MVC. The OA group had greater passive and active stiffness than the control group. The chronic inflammatory cycle and noxious stimuli may modify resting muscle tone via the pain-spasm cycle while joint malalignment, effusion and capsular adhesions mechanically restrict motion. Increased stiffness in the OA group during active trials may originate from heightened stiffness observed during passive tests, which serve as a foundation whereby active contractions are superimpose for improved stability. Greater active stiffness may also reflect attempts to stress-shield articular tissue through tenomuscular structures.

4 ADAPTATION TO PERTURBED WALKING IN PEOPLE WITH MEDIAL KNEE OSTEOARTHRITIS

Kumar,Deepak [1]; Reisman,Darcy [1,2]; Rudolph, Katherine.S [1,2]
[1]Biomechanics and Movement Science, [2]Department of Physical Therapy

BACKGROUND and SIGNIFICANCE: People with knee osteoarthritis (OA) use higher muscle activation when exposed to an unexpected perturbation during walking. High muscle co-contraction, decreased knee excursions and increased adduction moments can increase knee loading, potentially leading to more rapid OA progression. The aim of this study is to investigate if people with knee OA fail to adapt their muscle activation patterns during perturbed walking in ways that would worsen joint loads. METHODS: 6 subjects with knee OA and 5 controls walked for 10 trials (locked) and over a platform that translated laterally (lateral) at initial contact (IC). Kinematic (120 Hz) and kinetic (1080 Hz) were captured for 50 trials. Surface EMG was collected at 1080Hz from quadriceps, hamstrings and gastocnemeii . Data were analyzed over 3 intervals - Preparation, loading response (LR) and midstance (MSt). Differences between locked and lateral data over the first 5 trials were compared. RESULTS: Prep phase: Controls used similar knee flexion and EMG as in locked trials; OA subjects flexed more at IC and adapted by flexing less over 5 trials; OA subjects' EMG was higher in all muscles and 2 of 3 muscles' EMG fell progressively over the 5 trials. Loading Response: Controls showed no change in knee flexion or EMG from locked trials whereas the OA subjects flexed their knees less across all trials and increased knee flexion from Trial 2 thru 5. OA subjects had greater EMG for 2 of the 3 muscles across all trials and showed no adaptation. Midstance: Both groups limited knee extension in trial 1. Controls adapted within 1 trial whereas the OA subjects showed a more gradual adaptation over all 5 trials. OA subjects had higher EMG all 3 muscles throughout the 5 trials and both groups appeared to adapt over 5 trials. DISCUSSION: Differences appeared in preparation for IC where the OA subjects used a stiffening strategy involving higher muscle activity and greater knee flexion. During MSt OA subjects continued to use higher EMG and less motion but adapted similar to controls. Greater knee flexion with higher muscle activity can be a compensation for knee instability but can also increase joint loads. The minimal adaptation seen by both groups in prep and LR may be due to inadequate time for tuning the long loop reflexes or because adaptation does not occur under conditions where joint loads are high. In MSt the higher EMG and slower adaptation in OA indicates that joint loads may remain higher than normal which might influence the integrity of the cartilage in the joint. The mechanisms and effect of these neuromuscular responses warrants further investigation.

5 DYNAMIC KNEE JOINT STIFFNESS IN SUBJECTS WITH KNEE OSTEOARTHRITIS

Joseph Zeni, Jr., PT, BIOMS program, University of Delaware
Jill Higginson, Ph.D., Mechanical Engineering, University of Delaware

INTRODUCTION: Joint stiffness is an important consideration in pathologies in which biomechanical alterations may affect disease progression. In persons with knee osteoarthritis (OA), factors underlying dynamic joint stiffness, such as higher antagonistic muscle activity, may expedite the progression of cartilage deterioration through higher sustained joint compression forces. The purpose of this investigation was to determine how the severity in knee OA affects the dynamic joint stiffness of the knee joint. METHODS: 15 control subjects, 15 subjects with moderate OA and 8 subjects with severe OA participated in a walking assessment that included acquisition of 3D kinematic and kinetic data at control (1.0 m/s), self-selected and fast speeds. Knee flexion angles and moments were through inverse dynamic techniques. Dynamic joint stiffness was calculated as the slope of a linear regression line when the joint moment was plotted against joint angle. The linear region of the dynamic joint stiffness curve during loading response (2-15% gait cycle) was assessed for differences between groups. RESULTS/DISCUSSION: Significant differences in dynamic knee joint stiffness were seen between groups at the self-selected ($p=0.011$) and fast walking speeds ($p=0.005$). Differences were nearly significant at the control walking speed ($p=0.061$). For all of the speeds, the severe group had the highest level of joint stiffness, while the control group had the lowest level of knee joint stiffness. Because joint stiffness may result in higher joint compression forces and higher rate of joint loading, these results suggest that persons with more severe OA adopt movement patterns that may potentially lead to further progression of the disease.

6 THE EFFECT OF SELECTIVE MUSCLE WEAKNESS ON SHOULDER FUNCTION

Shridhar Shah, John Novotny and Jill Higginson,
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INTRODUCTION: Different studies have found that there is a profound loss of shoulder strength with aging. The decreased strength of shoulder muscles results in an overall loss of function during activities of daily living. The purpose of this study is to identify roles of specific muscles in range of motion, strength, function and stability of the shoulder during abduction using forward dynamic simulation of an upper extremity musculoskeletal model. METHOD: We generated a forward dynamic simulation of the upper extremity in SIMM, using excitation patterns as inputs, with muscle onset, offset and magnitude expressed as a function of time. To study the effect of selective weakness, for each muscle, we reduced the maximum isometric force by 50%, keeping remaining muscle excitations intact. For each perturbation, the trajectory of the elbow was recorded during the one second simulation. Results were compared with the normal simulation. RESULTS: In the normal simulation, negligible flexion and rotation occurred, and nearly 120° abduction was achieved at the end of one second. With 50% strength in the middle deltoid, only 85° of abduction could be attained. The weakness in infraspinatus and subscapularis resulted in more than 50° of external rotation. DISCUSSION: The weakness in middle deltoid, infraspinatus and subscapularis resulted in the most pronounced deviation from normal. Weakness in the other muscles resulted in final angles close to normal suggesting that these muscles are primarily used for balancing out-of-plane motions of the limb.

7

AN EMG-DRIVEN FORWARD SIMULATION OF SINGLE SUPPORT PHASE DURING GAIT

Qi Shao and Thomas S. Buchanan
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In this report we describe for the first time a forward dynamics model that incorporates an EMG-driven model, and we apply this approach in a pilot study to estimate joint moments, muscle forces and measured kinematics during single support phase of gait. EMGs, joint positions and force plate data were collected from 4 walking trials of two young healthy subjects. An inverse dynamics model was developed using SD/FAST and SIMM. We implemented an optimization algorithm to calibrate the kinematics of the pelvis and back, reducing the residual forces and torques there. An EMG-driven model was used to estimate the muscle forces of the right leg to match the calculated inverse dynamic joint moments. The forward dynamics model was developed using the same musculoskeletal model described above. Muscle forces calculated from our EMG-driven model were used to drive the model spanning the right ankle and knee joint. For the other joints, the model was driven by the joint torques calculated using inverse dynamics. The forward dynamic knee and ankle joint moments calculated from the EMG-driven model matched the inverse dynamic joint moments. The calculated right hip, knee and ankle joint kinematics matched the measured kinematics. Our forward dynamics model used EMGs as input and successfully tracked measured kinematics during single support phase of gait. It demonstrated for the first time that muscle forces calculated from an EMG-driven model can be used to drive forward modeling of kinematics. This technique has great potential in study of the inter relationships between muscles and the resulting movements in healthy and impaired subjects.

8

THE FEASIBILITY OF USING FUNCTIONAL ELECTRICAL STIMULATION ASSISTED CYCLING IN CHILDREN WITH CEREBRAL PALSY

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Cerebral palsy (CP) is a non-progressive disorder of the brain that results in decreased strength, abnormal muscle tone and difficulty with gradation of movement in the affected muscle groups. These impairments result in decreased independence with functional mobility and decreased physical activity. Stationary cycling has been proposed as an effective exercise intervention in this population as it does not require standing balance. However, many children with CP lack the coordination and muscle strength to cycle at threshold target levels to improve cardiovascular function. Functional Electrical Stimulation (FES) assisted cycling is proposed as a method of supplementing the individual's volitional effort and improving the coordination of the task. The purpose of this investigation was to assess the feasibility of applying FES to children with CP, as these children have intact sensation in their lower extremities. Two subjects participated in this demonstration and results showed that FES applied to the quadriceps can result in increased average cycling cadence and torque and increased average and peak power. FES also decreased the variance in cycling performance. Further investigation is necessary to determine the optimal stimulation settings and intervention frequency and to investigate the strength, motor control and functional effects of FES assisted cycling intervention.

9 SOLUTE TRANSPORT IN THE BONE LACUNAR-CANALICULAR SYSTEM IS SIZE AND SHAPE DEPENDENT

Wen Li, Liyun Wang
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Recent studies show that osteocytes, the most abundant bone cells, play a more active role in bone adaptation and metabolism than previously thought. In response to external mechanical loading, osteocytes release signal molecules to modulate functions of other bone cells, such as bone resorption by osteoclasts and bone formation by osteoblasts. Since osteocytes are embeded in impermeable mineral matrix, transport of the signaling molecules and metabolites occurs mainly though tiny pores around osteocyte cell bodies and cell processes termed lacunar-canalicular system (LCS). However, quantitative data of transport rates of various sized molecules are scarce in bone. To test our hypothesis that solute transport in bone LCS is size and shape dependent, we used an in situ fluorescence recovery after photobleaching (FRAP) technology to directly measured the diffusion coefficients of molecules in bone LCS. Fluorescent conjugated molecules varying from 376 to 43,000 Da in molecular weight and of either linear (Dextran 3k, 10k) or globular shape (Parvalbumin, Ovalbumin) were used. After the fluorescent molecules were injected into mice via the tail veins, the animals were sacrificed after a period of time (30min-7hr), and the tracer distribution in exposed tibia were examined using a confocal microscope. It was found that linear molecules penetrate into bone and equilibrium at a slow rate compared with globular molecules of comparable molecular weight. Furthermore, FRAP experiments were performed and tracer diffusion coefficients were calculated using a custom MatLab program and a two-compartment model. We found that larger molecular weight molecules diffusion slower than the smaller ones in LCS, and linear molecules move slower than globular ones of comparable size. The data shows that solute transport was not simply based on the fiber matrix theory. The partial fluorescence recovery after photobleaching indicated that part of the tracer molecules might bounded to the extracellular matrix and cannot move freely. Further study will be addressed on this issue.

10 ANALYSIS OF RPL29-DEFICIENT BONE MICROSTRUCTURE BY MICROCT AND FT-IR

Laura Sloofman[1], Daniel S. Oristian[1], Xiaozhou Zhou[2], Liyun Wang[2], Lyudmila Spevak[3], Adele Boskey[3] and Catherine B. Kirn-Safran[1]
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Ribosomal proteins (RPs) play an important function in the maintenance of a normal protein synthetic rate. Our group generated the first viable mouse mutant model lacking an individual ribosomal protein. In these mutants, the absence of RPL29 results in global skeletal growth deficiencies that persist during adulthood. Previously, we found that a decrease in protein biosynthesis affecting matrix production in RPL29 knockout mice reduces bone mass and increases bone fragility. The bone microstructure of femoral mid-shafts from both null (n=13) and control (n=15) mice was first assessed using micro-computed tomography (microCT). Both male and female RPL29-deficient femoral diaphyses exhibited significant structural changes. Notably, the cortical area in the male femurs was preserved in null mice while the bone mineral density increased. To gain further insight into the chemical changes induced by this mutation, we examined the Fourier transform infrared (FT-IR) spectroscopic profiles of three month-old hard resin-embedded tibiae. Consistent with the six month-old microCT data, we found increased mineral-to-matrix ratios in the growth plate of male null mice. This increase was not observed in the female tibiae. However female samples exhibited a decreased carbonate-to-mineral ratio in the growth plate cartilage along with a reduction in collagen cross-linking in the trabecular bone, indicating a lack of maturity of null bones when compared to wild type controls. In contrast, significant differences were not observed in crystal growth between null and WT in male or female tibiae. This data along with our previous studies support the idea that the phenotypes resulting from RPL29 deficiency are gender specific.

This project is supported by NIH-COBRE P20 RR016458-06.

11 FLUID FLOW AND PARTICLE DISPERSION IN ACINI DURING ASYNCHRONOUS VENTILATION

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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 human lung can be divided into (1) the conducting airways, and (2) the acini. The acini are responsible for gas exchange and consist of alveoli and bronchioles. The acini are useful delivery sites for inhaled therapeutic aerosols. In normal lung function the alveolus expands and contracts in phase with the bronchiole airflow oscillation. Lung diseases such as emphysema compromise the elasticity of the lung. Consequently, the alveolus may not oscillate in-phase with the oscillating bronchiole airflow. We have previously studied flow and particle transport in an alveolus for in-phase flow. The current work focuses on measuring out-of-phase airflow patterns and particle transport in an in-vitro model of a single expanding/contracting human alveolus. The model consists of a transparent, elastic, oscillating alveolus (represented by a $5/6^{th}$ hemisphere) attached to a rigid circular tube. Realistic tidal breathing conditions were achieved by matching Reynolds and Womersley numbers. Flow patterns were measured using PIV; these velocity maps were subsequently used to calculate particle transport and deposition on the alveolar wall. Our results suggest that fluid mixing decreases and the fluid interaction between the alveolar and the bronchiole fluid increases as the phase-lag is increased from 0 to $\pi/2$. Subsequently, the particle deposition is highest for $\pm\pi/2$ phase-lags.

12 MOTOR UNIT DISCHARGE BEHAVIOR WITHIN PHASIC BURSTS FROM HIGHER THRESHOLD MOTOR UNITS

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Dept. of Health, Nutrition & Exercise Sciences

Our recent experiments on motor unit rate coding during sinusoidal force modulation tasks have focused on motor units demonstrating sustained discharge without periods of de-recruitment. As these experiments continue, we are accumulating recordings of higher threshold motor units (~20 %MVC) that contribute brief bursts of action potentials during peaks in these isometric force-matching conditions. The purpose was to improve our understanding of contributions from such motor units because they offer greater twitch forces as compared to very low threshold units that dominate motor unit literature. METHODS: Using custom electrodes, motor unit action potentials were recorded from the first dorsal interosseous muscle of 13 subjects as they performed 6 sinusoidal isometric force matching tasks. .3, .6 and .9-Hz force oscillations were centered at 20% of maximum voluntary contraction (MVC) force and had amplitude of +/-3 and 6% MVC. Multiple measures of motor unit discharge behavior were computed for each burst of action potentials. RESULTS: We obtained a sample including 80 motor unit recordings distributed evenly across conditions. Among multiple measures of motorunit discharge behavior, minimum discharge rates per burst and the first inter-spike interval (ISI1) exhibited the greatest differences across task frequencies. The minimum discharge rate within a burst increased significantly with increases in task frequency ($p<.05$: 5.9, 7.7, 9.7 pps at .3, .6 and .9-Hz, respectively). ISI1 decreased linearly across the increases in task frequency from 145 to 80 ms ($F=7.9$, $p<.01$). CONCLUSION: Consecutive motor unit action potentials with atypically brief inter-pulse intervals are known to enhance muscular force output and ISI1 is advanced as the primary neural factor that drives increases in force oscillation frequency. The greater firing rate minima at higher task frequencies matches the reduced time available for downward rate modulation at greater task frequencies.

13 COMPENSATIONS TO A WEIGHTED WALKING CHALLENGE AMONG VARYING OSTEOARTHRITIS SEVERITIES

Andrew Kubinski, Joe Zeni, PT, Jill Higginson, Ph.D
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As knee osteoarthritis (OA) plagues the population, there is a need to find out how the disease progresses over time and what compensation strategies people use in their daily life to maintain “normal” function. Our study sought to find what strategies people with increasing severity of OA use to compensate to a weighted walking challenge. We analyzed 5 healthy control subjects, 5 moderate OA subjects (radiographic K/L grade of 2 or 3), and 2 severe OA subjects (radiographic K/L grade of 4). Kinematic and kinetic data were collected on a split-belt treadmill at a walking speed of 1.0 m/s without weight and also collected at 1.0 m/s while the subject wore a weighted vest with approximately 1/6 body weight. We analyzed the differences in knee flexion angle, knee flexion moment, knee power, hip flexion moment, and anterior/posterior ground reaction force between conditions and subject groups. A reduced peak knee flexion moment was accompanied by an increased peak hip flexion moment for the moderate and severe OA groups during the weighted and unweighted trials. The difference was more pronouced as the OA severity increased. From these results, we found no major compensation to the challenge of weighted walking compared to strategies already used by individuals with OA. Throughout the day, many people challenge their bodies with an increased walking speed (to hurry across the street) or by carrying a load (like a child, groceries, or a backpack). These preliminary results suggest that no additional compensation is observed when OA subjects are asked to carry a load, but future studies will include more patients and the less impaired limb.

14 EFFECTS OF WALKING SPEED ON MECHANICAL RECOVERY IN HEALTHY AND STROKE POPULATION.

Ben Roewer, Chris Henderson, Jill Higginson, PhD.
Department of Mechanical Engineering

INTRODUCTION: The Recovery Index is a quantification of the exchange of mechanical energy that occurs in pendulum-like motion. For perfect recovery, vertical components of energy (potential and kinetic) are completely transferred to the horizontal component of energy (kinetic). In the sagittal plane, gait can be modeled as an inverted pendulum, with energy being exchanged in order to alternatively raise the center of mass and propel it forward. In healthy ambulators, optimal recovery (~65%) occurs at the self-selected walking speed (SSWS). In hemi-paretic ambulators, SSWS decreases, but it is unknown how decreased walking speed affects recovery. This study investigates the effect of walking speed on the recovery index in healthy and stroke subjects. METHODS: An over ground walking trial was conducted in order to determine SSWS for seven healthy subjects and seven stroke subjects. Each healthy subject was tested on a treadmill at six different speeds ranging from 25% to 200% of their SSWS. Each stroke subject was tested on a treadmill at six different speeds ranging from 20% slower than their SSWS to the fastest speed at which they could safely walk. Kinematic data was collected on all subjects. The resulting trajectory of each subject’s whole-body center of mass was processed in custom Matlab code in order to calculate the percent recovery. RESULTS: For six healthy subjects, recovery reached a maximum (60% - 75%) when walking speed was between 75% and 100% of SSWS. For five healthy subjects, recovery values consistently decreased at speeds above 125% of SSWS and below 75% of SSWS. For five stroke subjects, recovery increased by as much as 40% when walking speed was increased above the SSWS. DISCUSSION: Maximum recovery is expected to occur near the SSWS in healthy subjects. Since most stroke subjects improve their recovery with increased walking speed above SSWS, it suggests that gait retraining targeted at increasing SSWS may also improve recovery of mechanical energy and may reflect more efficient movement patterns. While recovery may improve for most stroke subjects, it remains undetermined what gait characteristics, if any, might suggest how recovery will change due to increased walking speed in that population.

15 A COMPARISON OF SPLIT-BELT AND SINGLE BELT TREADMILL WALKING OVER TIME

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Instrumented split treadmills are becoming common in gait labs. The split nature of the belts may alter normal walking mechanics. However, these changes may resolve as one accommodates to the split treadmill. PURPOSE: To compare base of gait, foot progression angle, and hip adduction angle between split and single belt treadmill, walking initially and after 10 minutes. METHODS: To date, we have collected 8 healthy subjects walking on the split and single belt treadmill. The subjects included 3 males and 5 females between 18 and 50 years of age. An AMTI split-belt treadmill was used. The treadmill has a wide (0.66 m) and a narrow belt (0.33 m) side by side. Each subject walked first on the wide belt for 10 minutes and then with one foot on each belt for 10 minutes. Data were collected at 0 and 10 minutes for both conditions. RESULTS: Hip adduction angle (ADD) was initially 1º lower on the split-belt treadmill, indicating a wider stance. This angle was consistently lower in all but two subjects. At 10 minutes, the same six subjects increased their hip ADD. The hip ADD remained the same over time on the single belt condition. Similar changes were found for the base of gait (BOG). On the split-belt, the BOG was initially about 0.05 m wider than from the single belt. All subjects initially demonstrated a wider BOG, and exhibited a mean reduction of 0.02 m. Finally, the foot progression angle (FPA) was similar between conditions and across time. CONCLUSION: The difference in hip ADD and BOG in split-belt and single belt treadmill walking were small initially. These differences were reduced, but not resolved, at 10 minutes. This may suggest that a longer accommodation period is necessary. The FPA was not affected in the split-belt condition.

16 A POWERED LEG ORTHOSIS FOR GAIT REHABILITATION OF MOTOR-IMPAIRED PATIENTS

Sai Banala, Elizabeth Brackbill, Sunil Agrawal, Mechanical Systems Laboratory
Seok Hun Kim, John Scholz, Physical Therapy, University of Delaware

This poster describes the design and human machine interface of a powered leg orthosis for gait rehabilitation of patients with walking disabilities. The leg orthosis uses controllers 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 are designed to be 'assist-as-needed' for safe and effective gait training. The description of the controllers, simulations and experimental results with the powered orthosis are presented. Experiments have been performed with a dummy leg in the orthosis as well as with healthy subjects walking on a treadmill. In addition, this powered orthosis has been used for gait learning of stroke patients, and we hope to apply it to a larger patient pool.

17 ASSESSING THE QUALITY OF NEUROMUSCULAR FUNCTION USING BRIEF FORCE PULSES

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The peak rate of force development (RFD) is an indicator of the ability to rapidly generate muscular forces and can be measured as the slope of the force-time curve during rapid isometric contractions. RFD has almost entirely been studied within isometric contractions to maximal force levels and results are not always highly correlated with functional performance. The objective of this work is to expand the study of RFD to submaximal force tasks in which the peak RFD achieved may determine success in common daily tasks that can be described as quick but requiring low force. The aims of this study were to develop a protocol for quantifying the peak force-RFD (PF-RFD) relationship from rapid isometric contractions across a full range of forces and to compare the resulting measures between powerful and dexterous muscle groups. It was hypothesized that a strong linear relationship would be observed between the PF achieved and the corresponding peak RFD and that regression parameters taken from these relationships obtained during isometric knee extension (KE) and index finger abduction (FA) would be similar. For both muscle groups, subjects completed five trials, each consisting of five brief contractions (as quickly as possible) at each force level of approximately 20, 40, 60, 80 and 100% of their pre-recorded maximal voluntary contraction. Linear regression was used to determine the PF-RFD relationship. Preliminary data include 6 healthy volunteers, aged 22±4 years. Based on data from all subjects and both muscle groups, a significant relationship exists between PF and peak RFD (R^2=.924, p<.01). Taken from individuals, mean slopes of the PF-RFD relationship for KE and FA were 8.23 (R^2=.949, p<.01) and 7.98 (R^2=.944, p<.01), respectively. Within subjects, there was no significant difference between slopes of muscle groups (p>.05). In conclusion, strong linear relationships were obvious in both muscle groups and the similarity of regression parameters between muscle groups suggests that the PF-RFD relationship is a general characteristic. The significance of these results is that they support further development of this protocol as a source of neuromuscular evaluation and outcome measures. Note that because these data are normalized to maximal voluntary force, the resulting parameters describe the quality of neuromuscular function independently from strength.

18 MONITORING PARAFFIN EMBEDDED TISSUE SAMPLE CUTTING WITH AN INSTRUMENTED HISTOLOGICAL MICROTOME AND NEAR REAL TIME IMAGE PROCESSING

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A prototype system for direct measurement of the cutting characteristics of histological microtomes, and for subsequent image processing of cut samples has been developed and tested. This new technique, used to monitor the quality and durability of microtome knives, proper microtome set-up parameters, and cutting of tissue embedded in paraffin, consists of i) several sensors integrated onto a modified microtome and ii) an image acquistion and processing sub-system that monitors cut slice quality. The sensors are used to quantify several microtome blade performance metrics including cutting force, vibration and sound emission. The imaging system examines the paraffin embedded tissue slices after cutting and automatically determines several quality metrics including compression in the cutting direction and knife line defects. Results thus far indicate that the system will enhance the histologist’s ability to rapidly evaluate cutting blade quality and optimize overall mictrotome performance resulting in consistent, high quality histological specimens.

19 DIFFERENTIAL RESPONSE TO INTRA-ARTICULAR HYALURONAN INJECTION FOR KNEE OSTEOARTHRITIS.

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INTRODUCTION: Knee osteoarthritis (OA) is a common cause of decline in function and restricted joint mobility has been associated with disability. Intra-articular (IA) injection of hyaluronic acid (HA) is often prescribed to improve symptoms and function in patients with knee OA. Effects on functional outcome measures are not well-known and clinical experience leads us to believe that not everyone benefits. Therefore, the purpose of this study was to ascertain the effects of HA injection on self-report and functional measures in patients with knee OA and to identify clinical and/or radiographic characteristics of those likely to respond. METHODS: Forty-eight subjects scheduled for HA injection were recruited and tested before and following treatment, with questionnaires and functional tests. A treatment response was defined ‘a priori’ to identify responders (R) and non-responders (NR). RESULTS: Mean scores improved for self-report and functional test scores for the sample as a whole. Twenty-eight patients improved markedly and showed consistent functional improvement, whereas 20 NR achieved smaller functional gains. Patients with moderate OA in the medial compartment experienced greater benefits from injections of HA than those with more severe OA. In general, greater knee joint ROM at baseline was associated with greater improvements with treatment. CONCLUSION: Despite mean group improvements nearly half the patients did not rate their function better and demonstrated inconsistent changes in functional performance. Responders demonstrated considerable improvement in all measures. Patients with greater knee joint ROM and less severe OA were more likely to demonstrate significant and consistent improvement across self-report scores and functional tests.

20 FINITE ELEMENT MODELING OF THE BICEPS BRACHII

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Previous investigations of the internal mechanics of the biceps brachii have shown non-uniform behavior throughout the muscle (Pappas 2002, Novotny and Zhou 2006). Variations in the mechanics were shown to exist anteriorly versus posteriorly. Additionally, the minimum principal strain direction was shown to differ statistically from the pennation angle in the muscle. This suggests that the deformation of the muscle is influenced by more than just the fiber direction. Finite element models have been used to examine muscle mechanics, defining separate elements to represent the intracelluar and extracellular components of muscle (Yucesoy 2002). The FE model created in this study is composed of two elements, representative of the muscle fibers and extracellular passive component of the muscle. The model is driven by the in vivo deformation data obtained from previous studies (Novotny and Zhou 2006) as internal boundary conditions. By driving the model with actual deformation patterns, better insight to the behavior and stress formation within the biceps brachii can be obtained. Preliminary data in the model show behavior differences in the anterior and posterior portions of the muscle, with stress levels reaching 250 and 600 kPa, respectively. Results also indicate that higher stress in the extracellular matrix occurs mainly when the matrix is resisting localized bulging and expansion. Future work will explore the effects of applying normal distributions to various properties of the elements, such as activation level, force-length properties, and stiffness properties. Further adaptations of this model can be useful in exploring effects of fatigue, aging, training, and injury on internal stress and strain.

21 FUNCTIONAL OUTCOME MEASURES IN ACL-DEFICIENT ATHLETES AFTER PERTURBATION TRAINING

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Introduction: The University of Delaware's anterior cruciate ligament (ACL) functional screening classifies patients with ACL-deficiency into two groups.[1] One of these groups, non-copers, demonstrate functional limitations that may not be resolved completely with conservative intervention.[2] Specialized perturbation training, designed to enhance the neuromuscular control of the knee, is hypothesized to produce superior functional outcomes compared to strength training alone.[3] Methodology: Six outcome measures were selected based on clinical importance when identifying functional impairments in the ACL-deficient population. Paired t-tests were performed to determine outcome differences from pre- to post-intervention on both the strength only and strength augmented with perturbation treatment groups. A priori significance level was set at $p = 0.05$. Results: Significant differences in the Knee Outcome Survey – Activities of Daily Living (KOS-ADL) and Global Rating Score (GRS) were found in both groups. Only the group receiving perturbation and progressive strengthening demonstrated significant improvements in maximum voluntary isometric contraction (MVIC) and central activation ratio (CAR). Differences in the timed hop (THP) test approached significance ($p = 0.07$) in the strength and perturbation group. Discussion: Significant differences in strength and CAR in the perturbation group imply a neuromuscular adaptation that enhances strength gains more than strengthening alone. The perturbation group demonstrated normal activation of the quadriceps while the strength group continued to demonstrate muscle inhibition, with less than 95% activation.[4] Greater power may yield a significant difference in timed-hop scores of the perturbation group.

1. Fitzgerald et al., *Knee Surg Sports Traumatol Arthrosc.* 2000;8:76-82. 2. Fitzgerald et al., *J Orthop Sports Phys Ther.* 2000;30:194-203. 3. Fitzgerald et al., *Phys Ther.* 2000;80:128-140. 4.Lewek et al., *J Orthop Res.* 2004;22:110-115.

22 USE OF FORCE FIELD CONTRAINTS IN ROBOT-ASSISTED GAIT TRAINING AFTER STROKE

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Robot-assisted training has been developed as a potential method of gait rehabilitation after stroke. Most of current robotic devices for gait training, however, guide the patient's leg through a fixed gait pattern. This training strategy may decrease the efficacy of gait training due to a habituated response to sensory input. An active leg exoskeleton (ALEX) device developed in our lab is designed to apply various force fields to gently resist excessive deviation of the foot from a desired swing-phase trajectory and to provide active-assisted motion along the foot path during gait training. Our preliminary study showed that training with ALEX can produce adaptation of even the relatively stereotypical gait pattern of healthy subjects, which was retained for a short time after training. The purpose of this study was to determine whether robot-assisted gait training with ALEX could improve the gait pattern of chronic stroke survivors. One 72 (S1) year-old and one 47 (S2) year-old have participated to date, both males with right hemiparesis acquired, respectively, 3.5 and 3.2 years previously. Both participants underwent three blocks of 5-day training which involved visual feedback and force field constraints. Treadmill walking evaluation showed that the swing-phase foot paths of both subjects were close to that of a normal control after the third training block. Joint excursion during treadmill walking increased at the hip, ankle and especially the knee. Noticeable carryover effects of gait training were found on over ground walking after 15 days of training. Over ground walking evaluation revealed that walking speed in S1 increased from 0.51±0.04 to 0.69±0.04 m/s after three training blocks; his Timed Up and Go (TUG) score decreased from 14.71 sec to 12.99 sec. S2 showed only minimal change in walking speed and TUG over training. The patients' Dynamic Gait Index scores increased from 13 to 17 (S1) and from 20 to 24 (S2) after the third training block. In addition, joint excursions during over ground walking increased for both the subjects. Results of these case studies suggest that gait training with ALEX involving visual feedback and force field constraints can improve the gait pattern in chronic stroke subjects. Future studies are planned to investigate the effect of gait training with ALEX in a larger set of chronic stroke survivors.

23 WALKING KINEMATICS DUE TO INDUCED LIMP ON A SPLIT-BELT TREADMILL

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Neurological pathologies such as cerebral palsy and stroke can result in asymmetric gait. Split-belt treadmills offer a promising research tool for investigating both the causes and potential treatments for decreasing asymmetry in gait. The goal of this study is to better understand the kinematic changes in gait when asymmetry is introduced. Five healthy subjects with no history of musculoskeletal disorders walked on a split-belt treadmill at different variations of their self selected speeds (SS): 50%, 100%, 125%, 150%, and 200%. Once this was completed, in a random order one of the treadmill belts was maintained at 100% SS and the other set to one of the four speed conditions. The process was repeated for the other belt. Comparisons of hip flexion and knee flexion were made between opposite legs as a function of speed and symmetry. Early results suggest that the leg which maintains 100% SS exhibits kinematic compensation for the increasing speed on the contralateral limb. We observed an increase in peak hip and knee flexion at initial contact and earlier peak hip and knee extension in swing phase. These results may be related to changes in AP GRF at heel strike which may require the joints to flex further to accommodate faster speeds. The time shift in the peak hip extension and knee flexion suggests that the subjects attempt to extend the stance time on the slower of the belts for increased stability. These results are similar to what has been found by previous studies examining stroke kinematics and spatio-temporal parameters, and suggests that both limbs need to accommodate to unilateral perturbations.

24 FORCE GENERATION DURING SUPERIMPOSED SUBMAXIMAL VOLITIONAL AND ELECTRICALLY-ELICITED CONTRACTIONS

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Functional electrical stimulation (FES) is often used to augment the volitional forces generated by weak muscles during functional movements such as walking and standing. The relationship between stimulation intensity and the forces generated by relaxed healthy or paralyzed muscles has been documented. However, there is inadequate information regarding force generation when electrical stimulation is superimposed on submaximal volitional contractions. The aim of this study was to establish a relationship between the augmentation in isometric forces produced by electrical stimulation trains of varying intensities and the level of submaximal contraction over which the electrical stimulation was superimposed. Quadriceps muscles of 6 able-bodied subjects were tested. Levels of stimulation intensity and volitional contraction were set to generate different percentages of the subjects' maximal voluntary isometric contraction (MVIC). Force augmentation was defined as the additional force generated by the electrical stimulation over the force being produced by the subject's volitional contraction. Results showed that the relationship between force augmentation (F), the level of volitional contraction (V), and the level of electrical stimulation (S) could be modeled by the equation: $F=S(M-V)^N$, where M is the maximum force generating ability of the muscle and N is a parameter that we posit is determined by the differences in recruitment order between electrical stimulation and voluntary activation for each subject. Future work will involve validating the above equation in additional able-bodied subjects and in individuals with muscle weakness due to hemiparesis following stroke.

25 EFFECT OF FORCE FIELD JOYSTICK TO ENHANCE EARLY MOBILITY IN INFANTS

Xi Chen, Ji-Chul Ryu, Amy Lynch, Sunil Agrawal, and James Galloway

In typically developing infants, the emergence of independent locomotion is associated with advances in perception, cognition, motor, and social skills. In contrast, children with moderate to severe motor impairments often have delayed or absent locomotion. Such chronic immobility is thought to place them at risk for further impairments across developmental domains. Independent locomotion arises with a navigational ability, such that the child is able to move directionally towards desired objects. Recent findings from a pilot study establish that typically developing infants as young as 5 -6 months can be trained to operate a joystick to achieve goal oriented robot motion. One infant with chronic immobility also demonstrated goal oriented driving. However, neither infant group was able to achieve left or right goal directed motion. Training thus far appears to be effective only for volitional guidance of straight driving paths. While the mechanisms in typical development to promote navigational ablity are unclear, they seem to be linked with a perceptual awareness of obstacles, a physical navigational skill, and a caregiver to physically "over-ride" unsafe movement efforts. This research extends to explore the application of a caregiver guided force feedback joysitck to train navigational skills: right and left directionality. Force field input has been shown in other areas to impact motor control and promote learning of movements. This presentation depicts the hardware components for a force field joystick, as well as the software programming designed to enable design of various clinical training options. This poster will present the engineering and clinical rational for the three modes: ramble, guide, and follow. Navigational results from 6 adults with typical development and 1 infant with chronic immobility will be presented. Future directions will be discussed.

26 GASTROCNEMIUS RECESSION: TREATMENT FOR FOOT PATHOLOGY ASSOCIATED WITH ISOLATED CONTRACTURE

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Isolated gastrocnemius contracture (IGC) is a type of ankle equinus in which there is normal ankle dorsiflexion with the knee flexed however there is less than 5° of dorsiflexion with the knee fully extended. The ankle must reach at least 10° of dorsiflexion during the stance phase of gait just prior to heel lift off when the knee is at or near full extension if normal walking mechanics are to be achieved. Because knee extension and ankle dorsiflexion are coupled motions during mid-stance, IGC may result in kinematic and kinetic alterations at the ankle and knee during the stance phase of gait. IGC is associated with various painful foot pathologies that left untreated or treated unsuccessfully can severely affect quality of life. While conservative management is the current standard of care, gastrocnemius recession surgery can be a last resort treatment for painful foot pathologies in patients with IGC. Although excellent clinical outcomes have been reported following recession of the gastrocnemii, the surgery is not a common treatment option for patients. To date there is a lack of quantitative biomechanical data reported in the literature. Motion analysis data was collected on two female subjects with painful foot pathologies and associated IGC pre-operatively and at 3 months post-op during gait. Ankle dorsiflexion angle during the stance phase of gait increased post-operatively. Subjects demonstrated a reduction in peak ankle plantarflexion moment post-operatively. Pre- and post-operatively subjects exhibited a normal knee flexion angle during weight acceptance, however they did not extend the knee during mid-stance. Subjects exhibited normal extension moments pre- and post-surgery, however subjects never moved into a relative knee flexion moment during mid-stance. Gastrocnemius recession surgery resolved subjects' painful foot conditions with minimal changes to pre-operative kinematics and kinetics. Therefore gastrocnemius recession surgery may be a beneficial treatment option for patients with foot pathology and associated IGC.

27 GRAVITY-BALANCING LEG ORTHOSIS AND ITS PERFORMANCE EVALUATION

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John Scholz, Department of Physical Therapy

In this poster, we propose a device to assist persons with hemiparesis to walk by reducing or eliminating the effects of gravity. The design of the device includes the following features: 1) it is passive, i.e., it does not include motors or actuators, but is only composed of links and springs; 2) it is safe and has a simple patient–machine interface to accommodate variability in geometry and inertia of the subjects. We use a hybrid method to achieve gravity balancing of a human leg over its range of motion, in which a mechanism is used to first locate the center of mass of the human limb and the orthosis. Springs are then added so that the system is gravity-balanced in every configuration. For a quantitative evaluation of the performance of the device, electromyographic (EMG) data of the key muscles, involved in the motion of the leg, were collected and analyzed. Further experiments involving leg-raising and walking tasks were performed, where data from encoders and force-torque sensors were used to compute joint torques. These experiments were performed on five healthy subjects and a stroke patient. The results showed an overall decrease in the required joint torques produced by the subject. In the walking experiment, there was a positive impact on the range of movement at the hip and knee joints, especially for the stroke patient: the range of movement increased by 45% at the hip joint and by 85% at the knee joint. We believe that this orthosis can be potentially used to design rehabilitation protocols for patients with stroke.

28 THE RELATIONSHIP BETWEEN BODY COMPOSITION AND MOTOR SKILL PROFICIENCY IN CHILDREN AGED 4–6 YEARS

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Obesity amongst children is a serious national health issue. If specific gross motor skill deficits could be identified in children who are overweight and/or obese, a more complete curriculum could be established to help these children increase their gross motor skill proficiency and thus increase participation in physical activity leading to a healthier lifestyle. Approximately 42 children between the ages of 4 and 6 years old were tested on the Movement Assessment Battery for Children (Movement ABC). Body Mass Index for each child calculated using their height and weight measurements and the Centers for Disease Control and Prevention website. All children were recruited from the Early Learning Center at the University of Delaware. Parental consent forms were obtained according to University of Delaware guidelines before any data collection began. It is hypothesized children whom are overweight and/or obese will score significantly lower on the Movement ABC than their normal weight peers. Also, it is hypothesized children identified as “at risk” for DCD will be more likely to be overweight and/or obese in part due to their lack of gross motor skill proficiency which may lead to less participation in physical activity.

29 TESTING AND APPLICATION OF A NOVEL HYBRID COMBINATION OF ULTRASOUND AND MOTION ANALYSIS FOR ESTIMATION OF ACHILLES TENDON MOMENT ARMS IN VIVO

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Muscle-tendon parameters, including the moment arm (MA), are of importance in biomechanical studies for use in determining muscle forces and in musculoskeletal modeling and treatment of muscle pathologies. Prior methods (such as center of rotation and tendon excursion) for determining the Achilles tendon MA have not addressed the effect of muscle contraction level on MA length and utilize protocols that have functional limitations which require numerous measurements for a single MA. Hence, a novel method for estimating the MA of the Achilles tendon was designed to overcome the limitations of currently used methods. The hybrid method combines motion capture and ultrasound to require only two simple measurements for MA estimation. In this study, a hybrid method was developed and validated for Achilles tendon MA estimation using an ovine model. It was then applied *in vivo* to ten subjects. On average, Achilles tendon MA lengths increased from dorsiflexion to plantar flexion, as seen in previous studies. Small increases in MA length were seen from rest to MVC, averaging 3.4%. This result directly addressed the effect of muscle contraction on Achilles tendon MA length and shows that there is relatively no change in MA from rest to MVC, which was not distinctly answered in previous studies. Also, hybrid MA estimates were markedly smaller in magnitude than those previously published in literature and the magnitude difference between studies lies mainly in the methodologies used. In summary, the hybrid method was successfully developed on an ovine model in which it was able to reduce necessary measurements, characterize human Achilles tendon MAs at rest and MVC and at range of motion limits showing lower overall magnitudes and relatively no differences in MA length with muscle contraction. Implications of the MA magnitudes observed in this study can have research and clinical applications in terms muscle force estimates as well as in planning of surgical procedures of patients with muscle pathologies.

30 SELF-REPORT OUTCOME COMPARISONS AFTER PERTURBATION TRAINING

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Department of Physical Therapy

BACKGROUND The screening process established by the University of Delaware has allowed the rehabilitation specialist to classify a patient with an acute ACL rupture as a good rehabilitation candidate (potential coper, PC) or as someone who is recommended for early surgery (non-coper, NC). This classification is based on a testing sequence involving a single leg hop for distance, a timed 6-meter hop, a global self rating and a functional outcome self-report measure (KOS-ADLS). Perturbation training has been shown to maximize the functional outcomes of potential copers, but has not been investigated with non-copers. The purpose of this study is to compare improvements in functional outcomes between potential copers and non-copers. METHODS After being classified by the UD ACL Screening Protocol, 49 subjects have been enrolled, including 36 PC and 13 NC. A PC is identified by achieving > 80% on the timed 6-meter hop compared to the uninvolved leg, a KOS-ADL score of >80%, a self report global rating of >60% and no more than 1 incident of giving way during activities of daily living or as an NC by failing any one of those criteria. They have undergone an average of 9 perturbation training sessions consisting of strategic manipulation of support surfaces with appropriate feedback aimed at decreasing co-contraction and normalizing muscular response. Strengthening was also provided with progressive resistive exercise and neuromuscular re-education if the patient has a quadriceps index of less than 90%. Follow-up testing has also been administered. RESULTS After perturbation training, the noncopers still scored significantly worse than the potential copers on the KOS-ADLS and GR. The NC group improved the KOS-ADL (from 80% to 90%; p=.002) and GR (from 64% to 81%; p=.007). The improvements were not as great for the PC group, KOS-ADL (from 90% to 96%; p=.000) and GR (from 83% to 90%; p=.002) as they were by definition better at baseline. CONCLUSIONS These preliminary data suggests that perturbation training has potential to increase self-report scores in those classified as NC as well as PC. These individuals, who are frequently recommended to immediate surgical management, appear to respond well to perturbation training as evidenced in their self-reported level of function.

31 MODELS AND EXPERIMENTAL PARAMETERS FOR PRECISE DIFFUSION MEASUREMENT IN ARTICULAR CARTILAGE USING FRAP

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Diffusion is an important mechanism within articular cartilage and its measurement may be useful in understanding changes during degeneration or osteoarthritis. The fluorescence recovery after photobleaching (FRAP) technique has been used in previous studies. However, performance of FRAP in articular cartilage can be difficult compared to other tissues due to the tissue's relative opaqueness. There may be an increased bleach time and photobleaching may occur during the recovery. As a result, the data does not necessarily follow the commonly used simple logarithmic curve, and highly variable half-recovery times and diffusion constants may be found. To more completely link results collected during FRAP in articular cartilage to theory, two models are proposed. Developed during the University of Delaware's Mathematical Problems in Industry Workshop (June 2007), the first includes neutral solute diffusion and a bleaching term to account for loss of fluorescence during post-bleach observation of recovery. The second further incorporates molecular kinetics where fluorescent solute may bind and unbind within cartilage. To determine the robustness and sensitivities of these models, their results were compared as important parameters of the FRAP experiment were varied. These included pre-bleach acquisition time, bleach time, percent laser power during bleach, ROI size, normal versus high speed acquisition during recovery, recovery duration, and the effects of location. Results show that the data fits well using both models and that sensitivities to parameter variations exist. Understanding the effects of these experimental parameters on the results of the two models will aid in their appropriate selection for use in articular cartilage. It also highlights the necessity of a more complex theoretical basis for the analysis of FRAP results in quantifying diffusion in articular cartilage.

32 CALCULATION OF VERTICAL LOAD RATES IN THE ABSENCE OF VERTICAL IMPACT PEAKS

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In running, vertical load rate (VLR) is calculated as the slope of the force-time curve between foot strike and clear vertical impact peak (VIP). Without a well-defined impact peak, it is difficult to discern the period over which the VLR is calculated. If so, the time to these events might serve as a surrogate for the timing of an attenuated or missing VIP. These variables could provide a time period over which to calculate a vertical load rate. The purpose of this study was to examine the timing of a number of impact-related variables with the timing of the VIP in a group of rearfoot strike runners. Twenty male and female recreational rearfoot strike runners (age 25.2, ±8.32), currently running at least six miles per week were tested. Data were collected via a triaxial accelerometer (PCB Piezotronics, Depew, NY) a forceplate (Bertec, Worthington, OH). Five running trials were collected for each subject. Time to VIP were correlated with time to peak: positive acceleration (PPA), braking force (BF), vertical force (VF) and lateral force (LF). Next, we correlated these times with the time to VIP. We then used these variables to estimate the time to VIP in a separate set of 30 recreational runners whose force and accelerometry data had been collected in a similar manner previously. We calculated the time of VIP relative to the time of BF to create a correction factor for BF, which was 0.55 BF, or 13% stance. Based on the non-significant correlations of VF and LF, these variables were removed from the data set, leaving times to PPA and BF along with VIP to be validated on the separate set of runners The rms values of VIP, PPA and the corrected BF (CBF) between the estimated and actual time of VIP in a new data set were 0.03, 0.03, and 0.04 respectively. When applied to the new data set, the rms values for all three variables were small. Based on the results of these data, it appears that either time to PPA, time to CBF or a set value of 13% stance could be used as a surrogate for time to VIP when vertical impact peaks are missing.

33 CONTROL OF A PASSIVE MOBILITY ASSIST ROBOT

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In this paper, a control methodology for a mobility assist robot is presented. There are various types of robots that can help persons with disabilities. Among these, mobile robots can help to guide a subject from one place to the other. Broadly, the mobile guidance robots can be classified into active and passive types. From a user's safety point of view, passive mobility assist robots are more desirable than the active robots. In this paper, a two-wheeled differentially driven mobile robot with a castor wheel is considered as the assistive robot. The robot is made to have passive mobility characteristics by a specific choice of control law which creates damper-like resistive forces on the wheels. The paper describes the dynamic model, the suggested control laws to achieve the passive behavior, and proof of concept experiments on a mobile robot at the University of Delaware. From a starting position, the assistive device guides the user to the goal in two phases. In the first phase, the user is guided to reach a goal position while pushing the robot through a handle attached to it. At the end of this first phase, the robot may not have the desired orientation. In the second phase, it is assumed that the user does not apply any further pushing force while the robot corrects the heading angle. A control algorithm is suggested for each phase. In the second phase, the desired heading angle is achieved at the cost of deviations from the final position. This excursion from the goal position is minimized by the controller. This control scheme is first verified in computer simulation. Then, it is implemented on a laboratory system that simulates a person pushing the robot and the experimental results are presented.

34 THE EFFECT OF GAIT RETRAINING ON MEDIAL KNEE LOADING

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PURPOSE: Gait retraining to reduce knee loading in patients with knee OA has received recent attention. Individuals with genu varum are at increased risk of developing knee OA due to increased loading of the medial tibiofemoral compartment. Therefore, if joint loads can be altered prior to the development of OA, the risk of developing OA may be reduced. METHODS: A single, asymptomatic male (age 31, BMI 23.1) with genu varum was recruited. He underwent an 8 session gait-retraining program aimed at reducing medial knee loading. The subject walked at a self-selected speed on a treadmill while receiving visual feedback of his alignment in a mirror. He was instructed to rotate his knees inward to reduce varus mechanics as he walked. His walk time was gradually increased over the first 6 sessions. The feedback was gradually removed during the last 4 sessions. An instrumented gait analysis was conducted following each session to monitor the subject's progress. The primary outcome variable was the peak knee external adduction moment (KEAM). Perceived effort associated with the modified gait was also recorded on a VAS during each session. RESULTS: Using the modified gait, the subject was able to reduce the peak KEAM across sessions by 31% (0.41 ± 0.04 to 0.28 ± 0.03 Nm/kg*wt). This was accomplished in the modified gait primarily through hip internal rotation, which was increased across sessions (8.4° ± 3.1° to 11.7° ± 3.1°). However, the subject initially exhibited increased knee flexion during midstance (16°). He was provided verbal feedback regarding this maladaptation, and corrected the excessive midstance knee flexion (1°) by the third session. Perceived effort decreased from 4/10 to 1/10 by the conclusion of the protocol. Based on these promising results, a larger scale study using real time kinematic feedback is planned. CONCLUSIONS: These results suggest that simple, visual feedback can result in a significant reduction in medial knee loading in patients at risk for knee OA. In addition, faded feedback appears to reduce the perceived effort required to execute the locomotor pattern. Care should be taken to monitor and correct abnormal mechanics with this gait modification, particularly sagittal plane knee motion.

35 DIFFERENTIAL RESPONSES OF MC3T3 OSTEOBLASTS TO DYNAMIC HYDRAULIC PRESSURE AND FLUID FLOW

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In-vivo loading generates various mechanical stimuli on bone that are essential for bone maintenance [1]. Although studies have shown that shear stress, generated by interstitial fluid flow (FF) induces rapid release of ATP in osteoblasts, little attention has been given to the influence dynamic hydraulic pressure (DHP) may have [2]. We postulate that DHP and FF induce a similar response in ATP release and that this response plays a significant role in the re-organization of the cytoskeleton and change in cellular stiffness. MC3T3 osteoblasts were exposed to a DHP gradient of 0-10psi at 0.5Hz, or FF that generated 12 dynes/cm^2 of shear stress. After 5 minutes, ATP release increased by 4-fold due to DHP and 6-fold due to FF. Using an atomic force microscopy, the cell stiffness was shown to increase 4-fold in response to DHP and 6-fold in response to FF. The addition of apyrase (which inhibits the ability of ATP to act as a purnergic signal) attenuated this response for both DHP and FF. Exogenous treatment of static cells with ATP induced an increase in cell stiffness. Confocal images of the cytoskeleton exhibited an increase in f-actin alignment and a complete loss of microtubules in response to FF. In contrast, DHP appeared to enhance the microtubule network, but not affect the f-actin organization. Apyrase did not inhibit the microtubule response to DHP or FF, but did inhibit f-actin re-organization during FF. As we hypothesized, DHP induced a similar response in ATP release as FF. In addition, the change in cell stiffness was dependent upon ATP release induced by DHP or FF. Further studies are needed to evaluate the different response in cytoskeleton re-organization with the loss of microtubules in response to FF.

[1] Owan et al. (1997) *American J. Physiology* 273:C810-C18.
[2] Genetos et al. (2005) *J Bone Miner Res* 20(1):41-49.

36 THE EFFECT OF GIRD ON SCAPULAR UPWARD ROTATION AND PROTRACTION IN COMPETITIVE BASEBALL PLAYERS

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Pathologies such as labral and rotator cuff injury have been linked to decreases in glenohumeral internal rotation (IR) and increases in external rotation (ER). Anecdotal evidence also suggests an association between decreased glenohumeral internal rotation and scapular dyskinesis. OBJECTIVE: To assess the effect of GIRD (glenohumeral internal rotation deficit) on scapular position (upward rotation and protraction) in high school and college baseball players. METHODS: Forty-three baseball players with no current shoulder or elbow injury completed this study. Twenty-two players were placed in the GIRD ≥ 15° group (age = 18.86± 1.93 years, mass = 88.38± 9.88 kg, and height = 183.92± 5.85 cm) and twenty-one players were placed in the GIRD ≤ 14° group (age = 18.33± 2.2 years, mass = 83.81± 13.68 kg, and height = 183.49± 7.78 cm). Participants were assessed pre season with the non-dominant arm serving as a control. GH IR was measured supine with the scapula stabilized. 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 IR; A Vernier Caliper (Mitutoyo Measurement Technology. UK) was used for scapular protraction. RESULTS: Separate 2-way MANOVA's were performed for group comparisons of dominant and non-dominant arm scapular upward rotation and protraction. The GIRD ≥ 15° group had significantly less scapular upward rotation at the 60° (3.58°, p=.025), 90° (5.01°, p=.004), and 120° (2.63°, p=.039) positions in the dominant arm. Scapular protraction at the 90° (0.88cm, p=.019) position was also significantly greater in the dominant arm of the GIRD ≥ 15° group. No significant differences occurred for non-dominant scapular upward rotation or protraction. CONCLUSION: This is the first study to demonstrate that healthy baseball players with ≥ 15° of GIRD also have significant changes in scapular position (upward rotation and protraction) when compared to players with GIRD of ≤ 14°. This suggests that as GIRD increases, baseball players develop decreases in upward rotation and increases in protraction. These alterations have been linked to shoulder and elbow pathology.

37 INNOVATIVE SMART BRACE BALANCE TRAINING: ENHANCEMENT, INVESTIGATION, APPLICATION

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Impaired balance in people can lead to falls, which is a significant issue especially in older adults. Falls are one of the leading causes of injuries and the primary etiology of accidental deaths in persons over the age of 65 years. The mortality rate for falls increases dramatically with age, with falls accounting for 70 percent of accidental deaths in persons 75 years of age and older. In this project, a Smart Knee Brace(SKB) is used to allow the investigation of balance and righting reactions. The SKB enables us to create distrubances to the gait patterns of the subjects so that reactions of the subjects to the disturbances could be observed. The results will be helpful in training programs that challenge balance. The long term goal of the work is to develop training programs that will improve functional mobility in older adults at risk for falling. The current studies are designed to refine and improve the existing SKB hardware and software controls to those appropriate for investigating the response of young, older adult subjects as well as older adults with a risk of falls to novel and creative SKB paradigms. We will develop a mathematical model to predict subject responses to perturbations that will be useful in future training studies, and will complete a study of reactions to perturbation algorithms that might be used during a balance training program that will provide pilot data for a future randomized controlled clinical trial. The results of this study will provide insight into dynamic balance during walking and develop methods for a training program to improve dynamic balance and reduce the risk of falls in older adults.

38 A ROLE OF GASTROCNEMIUS ACTIVITY RELATED TO QUADRICEPS WEAKNESS FOR INDIVIDUALS THREE MONTHS AFTER TOTAL KNEE ARTHROPLASTY

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INTRODUCTION: Knee pathology affects on the neuromuscular system that is not only quadriceps femoris, a primary controller of the knee function, but also the other surrounding muscles of the knee. Individuals after total knee arthroplasty (TKA) have suffered post-operative conditions such as weakness of quadriceps and swelling in over years. Post operative quadriceps weakness affects patients' functional status. The knee mechanics have been reported as internal joint moment, however, only a few of researches reported altered muscle activity of quadriceps and the other muscles of the knee for individuals after TKA. The purpose of this study is to indicate how muscle activity patterns have altered at 3 month after TKA. Our hypotheses are 1) greater activities of quadriceps due to weakness of the muscle, 2) the other muscle will be also altered the timing and magnitude of activities due to quadriceps weakness and 3) the altered muscle activities during gait will be perceived by the patients as stiffness or swelling. METHODS: Twenty four patients were tested 3 months after unilateral TKA for knee osteoarthritis. Day 1 was for assessment of self-report questionnaires and MVIC of quadriceps femoris. On Day 2, gait analysis was performed including knee kinematics and electromyography (EMG) for each limb. Average rectified EMG were divided into three phases; heel strike, weight acceptance, and midstance. Each interval was normalized to the peak muscle activity during MVIC. Cocontraction was calculated for the two intervals, weight acceptance and midstance. Alpha level was set as 0.05, but as 0.1 for the EMG results due to the high variability. RESULTS: Average rectified EMG of quadriceps was significantly lower in the operated limb compared to the nonoperated limb during weight acceptance (p=0.02), however, it was not related to quadriceps weakness (r=-0.12, p=0.59). The other muscle activities also altered; with prolonged duration of hamstring activities (late off; p=0.08), and gastrocunemius (early onset; p=0.08, and early peak activity; p=0.05). Greater activity and early onset for gastrocunemius was significantly related to quadriceps weakness (r=-0.40, p=0.06). Quadriceps activity showed a positive relationship with perception of weakness among the patients (r=-0.38, p=0.09). DISCUSSION: The operated limb showed lower quadriceps activity compared to the nonoperated limb while it did not show a direct relationship with quadriceps weakness. Antagonists showed greater and prolonged activities during stance. Especially, prolonged gastrocunemius activity was related to quadriceps weakness. Since gastrocunemius activity in the other knee pathology was reported as not counter the destabilizing effects of quadriceps activity during walking, this is another impairments to prevent utilizing a proper activity of quadriceps femoris during walking. However, these impairments seemed not to be evaluated by the patients' perceptions as stiffness and swelling, but weakness.

39 FES WOULD INDUCE PREDICTED MUSCLE EXCITATION CHANGE IN POST-STROKE WALKING

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Following stroke, walking ability is often compromised due to impaired ability of the ankle muscles to provide push off and floor clearance. Functional Electrical Stimulation (FES) has been used to improve the walking patterns for stroke patients but the effect of stimulation on individual muscles is still unknown. Computer simulation of human movement has been used to determine muscle excitation patterns and function during walking. In this study, we used the latest forward simulation tool, OpenSim, to generate walking simulations of post-stroke hemiparetic gait with and without FES. The aims of this study were (1) to determine muscle excitations in post-stroke without FES and (2) to determine individual muscle's response to FES. One stroke subject was first asked to walk at his self-selected speed on a split-belt treadmill without FES. FES was then applied to the ankle dorsiflexors (swing phase) and plantar flexors (stance phase) of the paretic side. 3D kinematics, ground reaction forces/torques and EMG signals for ankle muscles were recorded for both trials. OpenSim was used to simulate both trials to predict muscle excitations. Our results showed that forward simulation could be used to determine muscle excitations for post-stroke walking. Model-predicted ankle muscle excitations patterns were changed due to applied FES, resulted in improved ankle excursion in late stance. Future work will address individual muscle function change due to applied FES.

40 HAND FORCE CONTROL IN MULTIPLE SCLEROSIS

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We investigated 12 mildly involved MS patients (EDSS 2.5-5.5) and age, gender matched healthy controls on their hand function using a simplified instrumented device. Participants performed dynamic (lifting) and static (oscillation and ramp-and-hold) tasks. Two single axis transducers that were present in the device recorded the grip force (G; acting perpendicularly and preventing the slippage) and the load force (L; acting tangentially and causing the slippage). Task performance was measured as the ability to exert a stable and accurate pattern of L. Force coordination was measured by G/L ratio, coupling of G and L (correlation coefficients and their corresponding time lags) and G modulation. When compared with healthy controls, MS patients revealed deteriorated task performance and impaired force coordination (increased G/L ratio, decreased coupling of G and L and decreased G modulation) across all the three tested tasks. The results suggest that the above methodology could be applied to quantify the hand impairments in MS, and possibly other neurological diseases in the clinical set up.

41 MECHANOTRANSDUCTION IN OSTEOCYTES: EXPLORING INTERACTIONS OF THE ECM WITH CALCIUM CHANNELS

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Bone is composed of various types of cells, a complex extracellular matrix (ECM) and extracellular fluid. Bone cells include osteoblasts, osteoclasts and osteocytes. Osteocytes are embedded deep within the bone matrix, make up about 90% of all bone cells, and have as a primary purpose to sense mechanical load. Recent electron micrograph data has provided a rationale for the development of a novel hypothesis to account for the ability of osteocytes to sense physiological levels of strain. The images within this study demonstrate the presence of “transverse tethering elements” within the pericellular space around the osteocyte processes. The presence of these “tethering elements” provides a mechanism by which fluid flow within the lacuna-canalicular system can induce physiological responses by deformation of the cell membrane. Based on this structural data, as well as recent modeling data, we hypothesize that the ECM molecule perlecan (PLN) associates with the $\alpha_2\delta_1$ subunit of voltage sensitive calcium channels (VSCCs) in the dendrite-like processes of osteocytes serving as the “tethering complex” in the pericellular space of osteocyte canaliculi. This model provides a mechanism by which fluid flow induced deformation of PLN results in gating of the VSCC allowing influx of Ca^{2+} within the cell and providing a means by which an intracellular biochemical response is elicited by an extracellular mechanical stimulus. Here we provide new data showing expression of PLN and $\alpha_2\delta_1$ transcript and protein within the MLO-Y4 osteocyte-like cell line. We have also characterized the expression of nearly all of the VSCC subunits in the MLO-Y4 osteocyte cells. Immunocytochemistry staining for PLN reveals a unique distribution, especially localized to the cytoplasmic processes of the MLO-Y4 osteocyte cells. Additionally, we demonstrate co-localization of PLN with sugar residues residing on the $\alpha_2\delta_1$ subunit suggesting a possible association of these molecules.

42 EFFECT OF DIFFERENT GRASPING TECHNIQUES ON FORCE COORDINATION IN CONTINUOUS MANIPULATION TASKS

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The ability to properly manipulate objects is of crucial importance for daily life. This ability is based on the way how the forces acting at the hand-object contact area are controlled and coordinated by the CNS. The object-digits interaction force can be observed through two components. One moves the object but also tends to cause slippage (load force – LF: acting tangentially to the object's surface) and the other tends to prevent it (grip force – GF; acting normally to the object's surface). An elaborate GF-LF coordination has been seen in various manipulation tasks that require control of LF. It has been identified by a high positive correlation of GF and LF with virtually no delay between them (GF-LF coupling), low GF to LF ratio (GF/LF; corresponds to GF scaling), and an appropriate modulation of GF with respect to changes in LF (high gain and low offset of GF). Studies from our lab have shown that the CNS uses two distinct strategies to coordinate GF and LF during repetitive LF exertion. While LF is repetitively exerted in one direction (unidirectional task), a high GF-LF coupling, low GF/LF, and high GF modulation have been observed. On the other hand, when LF is consecutively exerted in two opposite directions (bidirectional) all indices of force coordination have become considerably deteriorated. In this study we explore the role played by the skin mechanoreceptors in the observed phenomenon. Thirteen volunteers were asked to exert sinusoidal uni- and bidirectional LF profiles against instrumented using four different bimanual grasping techniques (precision, palm, fist and wrist). The grasping techniques intended to manipulate both the density and sensibility of the skin mechanoreceptors due to the manipulation of skin areas in direct contact with the handles. As expected, the results revealed that the indices of GF-LF coordination were higher in uni- than in bidirectional tasks, but the observed difference was not affected by grasping techniques. Therefore, it appears that the two distinct GF-LF coordination strategies adopted during the tested uni- and bidirectional manipulation activities could not be influenced by the sensory activity. As a consequence, we conclude that the afferent sensory activity of the specialized skin mechanoreceptors may not play an important role in the force coordination in continuous manipulation activities.

43 THE EFFECTS OF CYCLIC VARUS MOMENT LOADING ON KNEE ARTICULAR CARTILAGE AND SUB-CHONDRAL BONE

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Medial compartment, uni-lateral osteoarthritis of the knee results in loss of joint space medially and degeneration of the articular cartilage. Gait studies have shown an increased varus moment during walking compared to normal. It has been hypothesized that this could initiate and progress both the degeneration and the misalignment. Researchers have proposed that osteoarthritis is a disease of an entire joint, including kinematics and loading, and not just of the articular cartilage. This study presents an animal model of increased varus knee moment, intended to simulate the altered loading seen in human subjects.A small motor applied a cyclical adduction moment, of approximately zero to 0.3 Nm at 0.1 Hz, to the tibia of a New Zealand Rabbit. This simulated an increased varus moment of approximately one and a half body weight applied at the center of the medial condyle. For the medial and lateral condyles of the femur at 20 days, the BMD and BVF were significantly decreased compared to contra-lateral control and the Tb.S was increased. In the cartilage, the aggregate modulus, Ha, was decreased. At 10 days, changes in BVF and Tb.S are seen. For both the medial and lateral tibial plateaus, only the cartilage permeability, k, was significantly increased at 20 days. On the medial tibial plateau, though, the BMD and BVF were significantly decreased compared to contra-lateral control and the Tb.S was increased as for the femur. On the lateral plateau the Tb.T was increased and Tb.N decreased. At 10 days, changes in BMD, Poisson's ratio and Ha are seen. From the data that we have collected, we can conclude that the model induces cartilage degeneration and bone changes in the loaded knee. This model can be beneficial for future studies as it is more realistic of age-related osteoarthritis.Histological analyses to support these findings are ongoing.

44 THE DEVELOPMENT OF PERIOD CORRECTION PROCESSES IN MOTOR COORDINATION: ADAPTATION TO TEMPORAL PERTURBATION

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This is the third in a series of studies investigating the development of multi-limb coordination in typically developing children (4, 6, 8, 10 years old) and adults. In this study, the ability to resynchronize limbs after a temporal perturbation was investigated. Participants performed single (clap, walk) and dual (simultaneously clap and walk) motor tasks to the beat of a metronome; after a random interval, the metronome pace was increased or decreased suddenly. Phase error (PE) was measured in the 4 cycles subsequent to perturbation. 4 year olds could not perform the task and were dropped from the analysis. In the walk/metronome coupling, a significant interaction existed in PE between age group and cycle, with post hocs indicating a developmental trend toward less phase error with increased age. In the clap/metronome, main effect existed for cycle and age, but no interactions existed. Neither task (single or dual) nor direction of perturbation (faster, slower) had a statistical effect. The results suggested that developmental trajectories may exist in period correction processes; further research examining continuous data over longer collection periods should be performed to confirm this.

45 REDUCTION OF MAGNETIC RESONANCE IMAGE PROCESSING TIME FOR ASSESSMENT OF TRABECULAR BONE MICROARCHITECTURE

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High resolution magnetic resonance imaging (MRI) can be used to assess trabecular bone microarchitecture (TBM) in vivo. Because image processing can be labor intensive, identifying strategies that limit processing time is desirable. The purpose of this study was to determine if processing a fewer number of magnetic resonance images yields acceptable estimates of TBM in the distal femur of children. Twenty-six high-resolution axial magnetic resonance images were collected from the distal femur of 27 children (6 to 12 y) using a GE 1.5 T MRI. The 20 most central images were analyzed for measures of TBM [i.e., apparent trabecular bone volume to total volume (appBV/TV), trabecular number (appTb.N), trabecular thickness (appTb.Th) and trabecular spacing (appTb.Sp)] in the the distal femur. The average values for appBV/TV, appTb.N, appTb.Th and appTb.Sp for the entire set of images (20IM) were compared against values taken from a single image located at the middle of the image set (1IM), average values from 5 images (5IM; every fourth image), and average values from 10 images (10IM; every other image). The 10IM approach provided the best estimates of TBM from 20IM, with no group differences ($p > 0.05$) and a high proportion of the variance in appBV/TV, appTb.N, appTb.Th or appTb.Sp explained (r^2 range = 0.97 to 0.98). The 5IM approach also provided good estimates of TBM from 20IM with no group differences ($p > 0.05$) and a high degree of variance in appBV/TV, appTb.N, appTb.Th and appTb.Sp explained ($r^2 = 0.93$ to 0.96). The 1IM approach provided the worst estimates of TBM. Although there were no group differences ($p > 0.05$), 1IM explained substantially less variance in BV/TV ($r^2 = 0.75$), appTb.N ($r^2 = 0.73$), appTb.Th ($r^2 = 0.80$) and appTb.Sp ($r^2 = 0.72$) from 20IM than the other approaches. The findings suggest that analyzing as few as one fourth of the magnetic resonance images collected can yield estimates of TBM that accurately represent the entire image set while substantially reducing processing time.

Supported by NIH grant HD050530

46 THE USE OF MOTOR ABUNDANCE IN RESOLVING MULTIPLE TASK CONSTRAINTS SIMULTANEOUSLY

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Most daily activities involve tasks which require solving multiple constraints simultaneously. This study investigated the contribution of motor abundance to the simultaneous solution of such constraints. Eleven right-handed subjects performed 52 trials of each of three tasks that required both positioning and orienting an object similar to putting a key in a keyhole, and a task involving positioning an object alone. One of the orienting tasks required orientation about only two axes. Three-dimensional arm movements were measured with a VICON motion capture system. All trials were divided into transport and adjustment phases based on changes in smoothness of the velocity profile. The Uncontrolled Manifold (UCM) approach was applied to investigate how the structure of joint variance was affected by the task constraints, related to the control of hand position alone (3D) or the combined control of hand position and orientation (6D). Results based on joint variance analysis indicated that the addition of an orientation constraint did not affect control of the hand's position when compared to the task requiring positioning alone. UCM analysis related to the 6D control hypothesis indicated that there was no default control of orientation in the positioning task. Moreover, there was no evidence for control of orientation for the other three tasks during object transport, but only in the final adjustment phase. The control of combined orientation and position was strongest for the two conditions requiring orienting about all three axes for successful insertion of the object. The results support that a major advantage of motor abundance is the ability to solve multiple task constraints simultaneously and is consistent with another study (Zhang et al. 2007).

47 AERODYNAMICS OF BIO-INSPIRED FLEXIBLE WINGS FOR FLAPPING WING MAV APPLICATION

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The unmatched performance of insect flight is a motivation for bio-inspired design of flexible mechanical wings, that could undergo large deformations, and provide more efficient design of flapping wings for micro-air vehicle application. The bio-inspired wing is designed in two steps: (i) static load-deflection characteristics were measured experimentally for Manduca Sexta wings using a camera system; (ii) finite element analysis coupled with an optimization solver was used to design the mechanical wing whose static load deflection characteristics matched with the observed load-deflection of Manduca Sexta wing. The diameter of the veins was selected as the optimization variable to manipulate the stiffness distribution of the mechanical wing. Based on the design, a synthetic wing was constructed. In this study, we experimentally compare the aerodynamic performance of a bio-inspired flexible mechanical wing with the performance of a similar geometry rigid wing. The aerodynamic performance is tested on a robotic flapper with commonly observed kinematics of flying insects.

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