## Special Emphasis Session: MSK Rehab: Wearables & Biomechanics

**Session Sponsor:** Canadian MSK Rehabilitation Research Network  
**Date:** Friday June 12, 2020 - [https://cbjc.ca/program/SES_MSKRehabW_B.html](https://cbjc.ca/program/SES_MSKRehabW_B.html)  
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<td>Introduction by Cheryl Kozey &amp; Michael Hunt</td>
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<td>&quot;Axillary crutch length effects on upper extremity kinematics&quot;</td>
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Background: Crutch-assisted gait results in repetitive weight-bearing through the upper extremities (UE). This can result in secondary UE pain and injury. If this occurs, it can worsen disability in a person with impaired ambulation ability. Proper crutch fitting may be important to mitigate the risk of UE injury. Originality: There have been no studies assessing the impact of axillary crutch length on UE kinematics.  
**Objective:** To analyze scapular, elbow, and wrist kinematics during axillary crutch-assisted gait when crutches are fit appropriately and inappropriately.  
**Methodology:** Fifteen able-bodied adult males (mean age: 26) were fit with crutches using standard guidelines, and crutches that were 5 cm longer and 5 cm shorter than standard-fit crutches. Subjects performed 15 gait cycles with each crutch length. A 12-camera motion capture system was used to determine UE and crutch kinematics. Statistical parametric mapping analyses were performed. Results: Crutches that were too long increased scapular downward rotation (p<0.01) throughout the gait cycle. Crutches that were too short increased elbow extension (p=0.02) during crutch advancement and increased ulnar deviation of the wrist (p<0.01) throughout the gait cycle.  
**Significance:** Crutches that are too long increase scapular downward rotation. Increased scapular downward rotation has been associated with neural tension phenomena and may explain why 50% of short-term crutch users report paresthesiae or numbness. The increased elbow extension noted when using shorter crutches may increase triceps-based pain, which has also been reported in 5% of crutch users. There have been case reports of proximal ulna and wrist injuries with crutch use, and shorter crutches may increase these risks. Appropriate crutch fitting may be imperative to reduce the risk of UE injury with short- and long-term crutch use.

| 1:50  | "Physiotherapy Activity Out-Of-Distribution Detection" | Philip Boyer – Sunnybrook; PhD |

Background: When tracking at-home physiotherapy exercise adherence in "real-world" patient scenarios, subjects may perform unrelated activities (e.g., taking a drink) in addition to their prescribed exercises. Training a Machine Learning (ML) algorithm on all possible human actions for activity recognition is impractical and supervised ML algorithms do not accurately classify Out-of-Distribution (OOD) activities. Methods to address the OOD problem exist for image classification, but have not yet been applied to time series activity recognition.  
**Hypothesis:** OOD samples can be accurately detected in a physiotherapy activity dataset using ML (AUROC ≥ 0.95).  
**Methodology:** Our team has collected a novel inertial dataset (SPARS9x) captured by smart watches worn by 20 healthy subjects as they performed supervised physiotherapy exercises (in-distribution), followed by a minimum three hours of data as they engaged in unstructured activities (OOD). The dataset was analyzed using "classical" algorithms on engineered features (One-Class State Vector Machine (OCSVM), K-Nearest Neighbour (KNN), and K-Means), and deep learning approaches (thresholding based on SoftMax "confidence"; confidence calibration via entropy regularization; confidence calibration via temperature scaling and input perturbations (ODIN); and extending the SoftMax layer for prediction of an unknown class (OpenMax). Results: Simple and rapid OOD-detection techniques such as KNN using engineered features were found to outperform deep learning techniques on this time series dataset of physiotherapy exercise inertial data. KNN OOD prediction performed best in cross-validation, achieving mean Areas under the Receiver Operating Characteristic Curve (AUROC) of 0.97. Conclusion: Accurate detection of OOD-activities in physiotherapy inertial data is possible with ML.
**2:00 Robert M Kanko – Queen’s University; Master’s**

“Running Kinematics Measured Using Markerless Motion Capture”

**Background:** Marker-based motion capture systems are well-accepted but are resource intensive, susceptible to marker placement errors, and cannot be used in real-world environments such as outdoors. Markerless motion capture eliminates these barriers and could improve our understanding of motor task performance in real-world conditions. Theia3D is a deep-learning based markerless motion capture software with this potential. **Objective:** To compare kinematics obtained using Theia3D markerless motion capture and marker-based motion capture during running. **Methodology:** 27 adults (15F; mean age: 23) performed treadmill running at a self-selected speed (mean 2.4 m/s) during simultaneous video (8 cameras) and marker-based (7 cameras) motion capture. Markers were tracked and video data were processed in Theia3D to obtain 3D pose estimates, and both datasets were analyzed concurrently in Visual3D. Root-mean-square differences (RMSD) quantified system differences for joint positions and angles. Intraclass correlation coefficients (ICCA-1) were calculated for joint angles.

**Results:** Differences between corresponding joints had RMSD of (mean(SD)): ankle 21(3) mm; knee 19(8) mm; hip 27(7) mm; shoulder 22(6) mm; elbow 25(5) mm; wrist 12(3) mm; movement of markers relative to underlying bone have similar magnitudes [1]. Lower limb sagittal joint angles had very strong correlations (0.9-0.99) and small RMSE (ankle=6.5°, knee=3.5°, hip=7.1°) between systems. Correlations (0.2-0.5) and RMSD (ankle=8.0°, knee=5.7°, hip=4.8°) showed lower agreement in the frontal plane. Both systems measured similar joint angle patterns, but the markerless system showed greater consistency. **Significance:** These results indicate that 3D joint positions and sagittal plane lower limb kinematics can be accurately measured using Theia3D markerless motion capture, significantly reducing the barriers to collecting kinematic data of running.

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**2:10 Jesse M Charlton – University of British Columbia; PhD**

“Knee-biomechanics during gait are reliable between two laboratories”

**Background:** Multi-centre gait biomechanics studies provide opportunities to greatly increase sample size, yet differences between centres may introduce error in the data. Previous research showed that the variance of lower body gait biomechanics can range widely between laboratories. **Rationale:** Due to limited reporting of reliability statistics in earlier work, little is known about relative reliability and measurement error metrics that are needed when interpreting multi-centre studies. **Purpose:** Assess the inter-laboratory and inter-rater reliability of knee biomechanics during gait. **Methodology:** 12 healthy adults attended sessions at 2 independent motion capture laboratories (inter-laboratory). A different researcher (inter-rater) at each lab acquired stance-phase knee joint biomechanics using common methods. **Relative reliability:** ICC: intraclass correlation coefficient, measurement error (SEM: standardized error of the measurement), and the minimum difference to be considered real (MDD: 95% minimum detectable difference) were quantified. Results: Joint angle and moments exhibited ICCs >0.83, except for the knee adduction moment late stance peak (ICC=0.69). Sagittal plane knee angles (peak flexion and extension) exhibited SEMs and MDDs ≤2º and ≤5.3º, respectively. The knee adduction moment (%BW-HT) at early and late peak, and at midstance exhibited SEM of <0.31 and MDD of <0.85. Meanwhile, the knee adduction moment impulse (%BW-HT*s) showed an SEM of 0.09 and MDD of 0.26. Lastly, the peak knee flexion moment (%BW-HT) showed an SEM of 0.54 and an MDD of 1.51. **Significance:** These results suggest knee biomechanics are reliable between laboratories. Moreover, our findings are similar or better than previously reported reliability, even when compared to within-laboratory studies. Though our findings are limited to the laboratories involved, they provide reliability statistics that other groups can compare to or use when designing multi-centre studies.

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**2:20 Jose G Colli-Alfaro – Western University; PhD**

“User-Independent Hand Gesture Recognition Using Sensor Fusion Techniques”

**Background:** Stroke is the third leading cause of disability. 80% of stroke survivors are affected by upper limb hemiparesis, thus requiring extensive rehabilitation sessions to regain motor functions. It has been proven that targeting the motor impairments while using wearable mechatronic devices as a robot assisted therapy can improve the rehabilitation outcomes. However, despite the increased progress on control methods for wearable mechatronic devices, the need for a more natural interface that allows for better human—machine interaction remains. **Objective:** To develop a user-independent gesture classification method based on a sensor fusion technique that combines electromyography (EMG) and kinematic data. **Methodology:** The Myo Armband was used to measure muscle activity and motion data from healthy subjects. Participants were asked to perform 10 types of gestures in 4 different arm positions while using the Myo on their dominant limb. Data from 22 participants were used to classify the gestures using 4 different classification methods. Then, each classification method was trained using the EMG and kinematic data from each participant. The following classification methods were tested: the particle adaptive classifier (PAC), the adaptive least-squares support vectors machines, the bilinear model-based classifier, and multilayer perceptron (MLP) networks. Finally, a 5-fold cross-validation method was used to test the efficacy of each classification method. **Results:** Overall classification accuracies in the range of 33.1%–72.1% were obtained. However, following the optimization of the gesture datasets, the overall classification accuracies increased to the range of 45.3%–84.5%. **Significance:** These results suggest that by using the proposed sensor fusion approach, it is possible to achieve a more natural human machine interface that allows a better interaction with wearable mechatronic devices during robot assisted therapies.
2:30 Lauren C Benson – University of Calgary; Post-Doc Fellow

“A Wearables-Based Lower Limb Asymmetry Metric to Monitor Rehabilitation”

Background: Lower limb asymmetry is used to monitor rehabilitation progress. Rationale: A correlation between ground reaction force (GRF) and tibial acceleration (TA) suggests TA may be used to identify lower limb asymmetries. Objectives: To identify the agreement between GRF and TA-based lower limb asymmetries, and to examine asymmetries among those with a previous severe knee injury. Methodology: Part 1 - Nineteen adults [11F, 8M; 26.8 (5.5) years; 171.6 (8.2) cm; 74.1 (12.4) kg; dominant leg: 18 right, 1 left] performed three countermovement jumps (CMJ) and three squat jumps (SJ) with at least 30 seconds of rest between each jump. A triaxial accelerometer was fastened to the anterior-medial aspect of the tibia and each foot landed on a separate force plate. The peak axial GRF and TA during landing was identified. Lower limb asymmetry was calculated as the difference between the dominant and nondominant leg peaks divided by the maximum peak and expressed as a percentage, with a positive value indicating a greater dominant leg peak. The agreement between the GRF- and TA-based lower limb asymmetries was determined by intraclass correlation coefficient (ICC(3,k)). Part 2 - Twenty-four adults with a history of severe knee injury [14F, 10M; 26.8 (2.9) years; 173.0 (9.6) cm; 82.3 (14.1) kg; injured leg: 19 right, 5 left] performed ten CMJ and ten SJ with at least 30 seconds of rest between each jump. TA-based lower limb asymmetries were calculated as above such that a positive value indicated a greater non-injured leg peak. Results: The agreement between GRF- and TA-based lower limb asymmetries was good for the CMJ (ICC(3,k) = 0.800) and moderate for the SJ (ICC(3,k) = 0.719). Lower limb asymmetries for those with a previous severe knee injury ranged from -25% to 68% (CMJ) and from -33% to 46% (SJ). Significance & Impact: TA may be used to identify lower limb asymmetries, leading to a low-cost and portable method for monitoring rehabilitation progress.

2:40 Annemarie F Laudanski – University of Waterloo; PhD

“IMU-based lower extremity kinematics validation in high knee flexion”

Background: Repetitive exposure to high flexion postures, where the knee flexion angle >120°, is a known factor in the initiation and progression of knee osteoarthritis (OA). Wearable sensors (IMUs) may present a viable means for the measurement of such exposures in occupational settings where they are commonly adopted in order to evaluate their potential association with increased OA risk. Objectives: IMU-based joint kinematics for the hip, knee, and ankle were compared to those synchronously collected using gold-standard laboratory-based motion capture in high flexion postures to determine their suitability for accurate measurement of lower limb joint angles of childcare workers. Methodology: 20 participants were recruited to perform 6 childcare inspired high knee flexion postures: heels-up and flatfoot squatting as well as dorsiflexed, plantarflexed, single-arm supported, and double arm supported kneeling. Participants were instrumented with inertial and optical motion capture on the right lower extremities and pelvis. Joint constraints were exploited to calculate the IMU-based joint angles and estimates were compared to gold-standard optical-based kinematics through root mean squared error (RMSE) and coefficient of multiple correlation (CMC) analyses. RMSE represents the average error of estimates compared to the gold standard in degrees while CMC represents a measure of similarity between waveforms. Results: CMC analysis revealed very good similarity in all postures for the hip and ankle and excellent similarity for the knee. Mean RMSEs were found to be 6.48°, 2.20°, and 2.79° for hip, knee, and ankle respectively. Conclusion: The proposed system may provide an accurate means of measuring lower-limb kinematics in occupational settings and advance the study of posture related OA risk.