# Wednesday, June 26th: Day 2

**Oral Session 1 – Multi-Modal Assessment**

### O.1.1    Supporting physiotherapy in Parkinson's disease with a remote monitoring system focussed on falls and activity: the Vital@home study

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BACKGROUND: Preventing falls and inactivity are core areas of physiotherapy in Parkinson's disease (PD). Wearable sensors may provide relevant insights into the patients' functioning in daily life. OBJECTIVE: To assess the usability of a pendant sensor, patient app and therapist app to support physiotherapy in PD. METHODS: We tested the system in a realistic setting with 9 physiotherapists and 21 of their PD patients for a period of 4 weeks. From the pendant's accelerometer and barometer, measures of activity were derived such as time spent walking. The patient app encouraged them to provide supplemental data on activities and (near-)falls. Data were presented in the therapist app and discussed during weekly routine therapy sessions. Usability was assessed by exit surveys and interviews. RESULTS: On the System Usability Scale patients rated the system with 63±16 (mean±SD). 3 patients with suspected cognitive problems did not complete the study because of difficulties using the app. Of the other 18 patients, 9 contributed >8 hours of sensor data per day during complete follow-up, and 9 contributed >8 hours for a median of 12 days (min: 4, max: 24). Overall, patients and therapists evaluated the potential of the system as positive. Therapists thought that it was useful to have insight into changes in activity level over time and the context of (near-)falls, and that jointly discussing the data supported patients' self-awareness. For patients, the feedback on their activities was motivating to be more active. However, therapists and patients agreed that the system was not ready yet for use in practice. Most desired features were reliable feedback from the pendant on wearing time, occurrence of falls and quality of daily life gait and transfers. CONCLUSION: PD patients and therapists underscore the potential of a remote monitoring system to support physiotherapy, provided that its usability is excellent and validated algorithms are available for daily life data.

### O.1.2 Combining accelerometry with GPS-triggered e-diaries to investigate physical activity and mood in adolescent's everyday life

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Background: Physical activity has been shown to positively influence mood-dimensions. Although this association has already been investigated in the everyday life of children, adults, and elderly, adolescent's natural physical activity behavior and mood has not been an issue of research. Given that physical activity levels in adolescence predict physical activity levels in adults, this issue is of major interest. Methods: To analyze influences of distinct physical activities, i.e., non-exercise activities (e.g., climbing stairs), competitive exercises (e.g., playing basketball), and non-competitive exercises (e.g., jogging) on mood (valence, energetic arousal and calmness), we equipped 113 adolescents aged 12-17 years with hip-accelerometers and GPS-triggered electronic-diaries, a cutting-edge method for investigating within-person associations of physical activity and psychological variables. Data were analyzed using multilevel-models. Results: Adolescents felt better (p = 0.002) and more energized (p = 0.017) after non-exercise activity as well as better (p = 0.039) but less calm (p = 0.036) after non-competitive exercises and they felt less energized (p = <0.001) after competitive exercises. Moreover, we found that adolescents who felt more content, full of energy, or less calm were more physically active in the timeframes subsequent to their mood-ratings (p < 0.001). Conclusion: Our findings demonstrate that combining accelerometry with GPS-triggered e-diaries is a promising and innovative method to gather knowledge on psychological antecedents and consequences of physical activity in adolescent's everyday life. Furthermore, our finding that adolescents benefit most from non-exercise activities and non-competitive exercises may serve as basis for future real-life interventions.

### O.1.3 Feasibility of a sensor based technological platform for inhospital rehabilitation patients

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OBJECTIVE: A sensor based technological platform can help clinicians to identify patients' rehabilitation progress for the complete inhospital stay. Such platform integrates and analyses various sensors for continuous measurement, like movement, vital and sleep sensors. The objective was to investigate the feasibility of a platform with inertial movement sensors (IMUs) regarding clinical applicability in terms of personal responsibility and technological shortcomings. METHODS: Twelve iSCI and twelve stroke inhospital patients with gait problems wore IMUs (Shimmer3) on both ankles for gait assessment during daytime for a one week period. Additionally, a bed sensor (EMFIT QS) was placed under the mattress to assess time spend in bed however not yet connected to the platform. Data acquired and processed by the platform was systematically registered. Primary outcome was the percentage of available measurement data of the IMUs and bed sensor. Additionally, missing data due to human aspects or technical failure of the platform was reported. RESULTS: A total of 148 measurement days were obtained (median of 6 days/patient). On 115 of these days (78%) sensor data was uploaded. However, only 67 days (45%) were completely automatically processed by the platform. The remaining 81 days (148-67 days) were manually processed of which 21 (14%) could not be processed. The main cause of automatic processing failure was a mismatch in amount of data between the two sensors on the platform due to for example incorrect placement of one of the sensors on the docking station or battery failure. Error cause of the unprocessable data was mostly attributed to missing sensor data probably due to internal sensor errors. For the bed sensor, 136 nights were measured of which data was obtained in 131 (96%) nights. CONCLUSION: Despite some human and technical errors, a sensor based technological platform integrating and analysing multiple sensors seems feasible in clinical rehabilitation practice.

### O.1.4    Improving physical behaviour monitoring by combining Accelerometry with GPS-location tracking to investigate mental health indicators and to inform real-life interventions

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Objectives: Physical behavior (PB) is beneficial for mental health and may thus help to counteract the high prevalence of mental health issues. Cross-sectional investigations revealed, e.g., that physically active people are the ones with good mental health, but only naturalistic studies can inform how PB and mental health indicators (such as mood, or stress) are associated within persons in everyday life, e.g., that people feel better after PB. However, such naturalistic within-person studies are very rare and often limited by PB monitoring methods. Methods: We use activity-triggered electronic diaries to optimize the assessment of within-subject variance. In particular, an accelerometer and a smartphone continuously monitor participant's physical behavior and geo-location and changes in these parameters are analyzed in real-time to trigger e-diary queries for health indicators. Moreover, a combination of objective accelelerometer with geo-location data enables us to objectively differentiate between distinct types of PB such as exercise (e.g., playing tennis) and non-exercise activity (e.g., climbing stairs). Results:We will detail our algorithms and show results from four real-life studies combining accelerometry with geo-location data to prove the feasibility of methods: here, details on the within-person association between PB and mood and on distinct effects of different PB types in a healthy cohortas well as alliterations of this psychological real-life mechanism in patients with depression will be presented. Discussion and conclusion:We aim scientific exchange on how to further improve objective monitoring methods of PB by combining accelerometry and geo-location data. We will discuss method improvements that can facilitate our understanding of dynamic real-life fluctuations between PB and mental health indicators to partially close the gap between technical already feasible real-life interventions and insufficient knowledge about effects in everyday life.

### O.1.5    Spatial distribution of children's physical activity in New York City parks: Accelerometer and GPS assessed patterns in low-income and racial/ethnic diverse communities

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Objectives: This study aims to examine physical activity and spatial patterns of park use among children and how these patterns associate with moderate to vigorous physical activity (MVPA). We would like to determine whether certain types of spaces and their spatial distribution within a park could favor MVPA. Methods: Target population was children (5-10 years old) in New York City, USA. Six parks were selected according to population density by race/ethnicity (Latino and Asian) and the surrounding census block groups having a median household income at 80% of the county's median. Each park must feature at least one playground and sports field/court. Spring and summer 2017, children were asked to wear accelerometers (Actigraph GT3X+) and GPS (QStarz BT1000XT) during park visits for a minimum of 15 minutes. At 5s epochs, data were processed with one-meter buffers in ArcGIS, intersecting with spatial reference of all play areas within the parks (mean=10 target areas). Results: Over 100 hours of monitoring (mean=25 min/participant) and 100km were captured from 228 participants. Basketball courts and playground sets were the most frequent areas within parks (n=15/each) with the higher counts of location points representing the mostly used areas. Time spent on playgrounds was significantly higher on playgrounds (>10min) than other areas (p<0.01). Overall physical activity was moderate (53%). In basketball courts, 57% of time was spent in MVPA, 73% on playgrounds. Conclusions: Spatial patterns of park use show children 5-10 years old seem to prefer playgrounds and basketball courts, areas in which MVPA is more frequent. Individual characteristics such as age, gender, and race/ethnicity should be included in future analysis.

# Oral Session 2 – Research Devices

## O.2.1 Associations between physical activity and sedentary behaviour accumulation patterns and weight status in children and adolescents: A latent profile approach

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Objective: Emerging evidence suggests that how sedentary time (SED) and physical activity (PA) are accumulated across the day impacts on cardio-metabolic risk. However, studies on youth accumulation patterns have rarely considered the accumulation of different PA intensities and SED simultaneously. This cross-sectional study aimed to identify distinct groups of youth based on combinations of activity accumulation patterns and their associations with weight status. Methods: ActiGraph accelerometer data from 7-15 year olds from three studies were pooled (n=1288). Time accumulated in ≥5-min and ≥10-min SED bouts, in ≥1-min and ≥5-min light (LPA), and ≥1-min moderate (MPA) and vigorous (VPA) PA bouts were calculated. Frequency of breaks in SED were also obtained. Latent profile analysis was used to identify groups of participants based on these patterns. Logistic regression models were used to estimate the odds ratio and 95% confidence intervals for the distinct groups for being overweight, based on BMI and waist circumference (WC). Results: Three distinct groups were identified: 'Prolonged sitters' (36%) had the most time in prolonged SED bouts and least in VPA bouts; 'Breakers' (49%) had the highest number of SED breaks and lowest engagement in sustained bouts across SB and PA intensities; 'Prolonged movers' (15%), had the least time accumulated in SED bouts and most in PA bouts across intensities. Whilst 'Breakers' accumulated the lowest amount of time in sustained PA, their total volume of PA was higher when compared to the 'Prolonged sitters', and they had the lowest odds of being overweight (BMI: Odds Ratio [95% CI]= 0.41 [0.29, 0.58]; WC: 0.63 [0.44 , 0.90]). Conclusions: The results highlight different patterns of activity accumulation in youth. Breaking up sitting time and increasing time in sporadic PA may be useful obesity prevention strategies; however, longitudinal and experimental research in this area is needed.

## O.2.2 Heart rate versus accelerometry based physical activity assessment in older adults

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OBJECTIVE Quantification of moderate to vigorous physical activity (MVPA) is usually based on acceleration (ACC), which is converted into absolute intensity of activity. We examined heart rate (HR) based relative assessment of MVPA in older adults with diverse walking capacities. METHODS A single-channel ECG with tri-axial accelerometer was used for activity surveillance as part of a population based AGNES study. A convenience sample (n = 89, mean age 77 (SD 3)) was divided into tertiles based on average speed in a 6 minute walking test at preferred pace, after excluding participants with a cardiac pacemaker, antiarrhythmic or other HR affecting medication, or less than three days of verified HR data. Average HR and mean amplitude deviation of resultant ACC were computed. HR above 40% of heart rate reserve was considered as MVPA. Cut-points for moderate intensity from the literature were used for ACC. Total MVPA normalised to a full week was calculated from both ACC and HR. RESULTS Walking speeds in the tertile groups were 3.7 (0.5), 4.5 (0.1) and 5.3 (0.4) km/h. HR based MVPA amounted to significantly more MVPA minutes than ACC based MVPA in all groups (P<0.01). ACC based MVPA was 192 (114) minutes/week in the low tertile, which was significantly (P<0.01) lower than the higher tertiles (368 (228) and 356 (174) minutes). In contrast, HR based MVPA (558 (471), 649 (422) and 690 (480) minutes) was not significantly different between groups. Walking speed correlated significantly with ACC based MVPA (r=0.45, P<0.001) but not HR based MVPA (r=0.15, P=0.15). CONCLUSIONS Using a HR based relative intensity threshold to quantify MVPA resulted in higher MVPA compared to ACC. Individuals who walked slowest accrued less ACC based activity, which may be due to a lower aerobic capacity and thus higher relative intensity required to reach the absolute ACC threshold. Relative MVPA quantification may be needed to account for the reduced aerobic capacity of older people.

### O.2.3  Description of raw triaxial wrist accelerometer-measured physical activity in mid-age Australian adults

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Aim: The use of raw accelerometry for measuring and describing physical activity (PA) levels in population-based studies has increased in recent years. This study aimed to describe PA assessed with raw triaxial wrist-worn accelerometers in mid-age Australian adults. Methods: Data were from a sub-sample of a population-based cohort of mid-age adults living in Brisbane, Australia (n=606). In 2016, participants (mean age: 60.4; SD:7.1 years) wore a triaxial accelerometer (Actigraph wGT3X-BT) on the non-dominant wrist during waking hours for seven consecutive days. Data were included if wear time was at least 600 min/day over 3+ days (n=447). Overall PA, expressed as acceleration in gravitational equivalent units (1mg=0.001g), and time spent in moderate-vigorous intensity physical activity (MVPA; >100 mg) using different bout criteria (non-bouted, 1-, 5-, and 10-min bouts) are presented by gender, age group and education. Results: Mean acceleration was 23.2 mg (SD: 7.5) and did not vary by gender (men: 22.4; women: 23.7; p-value: 0.073) or education (p-value: 0.375). On average, mean acceleration decreased 10% (2.5 mg) per decade of age from age 55y. The median time spent in non-bouted, 1-min, 5-min and 10-min MVPA bouts was, respectively, 69 (25th-75th: 45-99), 26 (25th-75th: 12-46), 10 (25th-75th: 3-24) and 7 (25th-75th: 0-19) min/day. Overall, men, younger and more educated participants spent more time in MVPA than their counterparts, regardless of bout criteria. Conclusion: This is one of the first population-based cohort studies to provide detailed description of raw accelerometer PA data in mid-age adults in Australia. As expected, mean acceleration decreased with age, and time spent in MVPA was higher in men than women. Higher MVPA in the more educated participants was surprising. These data can be used to investigate how different patterns and intensities of PA across the day/week influence health outcomes.

### O.2.4  Standardised accelerometer metrics: Health, global surveillance and moving towards an evidence-base for deriving physical activity guidelines directly from accelerometer data

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The aim of this paper is to demonstrate how standardised accelerometer metrics can be used to: 1) investigate relative contributions of volume and intensity of physical activity for health; and 2) provide informative data on prevalence of meeting activity guidelines for global surveillance. Secondary data analyses were carried out on five datasets using wrist-worn accelerometers: children (N=145), adolescent girls (N=1669), office workers (N=114), pre- (N=1218) and post- (N=1316) menopausal women, and adults with type 2 diabetes (T2D) (N=475). Markers of health were: zBMI (children); %fat (adolescent girls and adults); bone health (pre- and post-menopausal women); and physical function (adults with T2D). Open-source software (GGIR) was used to generate the following accelerometer metrics: average acceleration (ACC); intensity gradient (IG); the magnitudes of acceleration above which a person's most active 60 (M60ACC) and 30 (M30ACC) minutes are accumulated. 1) Multiple regression analyses showed the IG, but not ACC, was independently associated with adiposity in children and adolescents. In adults, the effects of ACC and IG were additive. For bone health and physical function, associations were strongest if IG was high, largely irrespective of ACC. 2) The proportion of participants with M60ACC (children) and M30ACC (adults) values higher than accelerations indicative of brisk walking (moderate-to-vigorous physical activity) ranged from 17-68% in children and 15%-81% in adults, tending to decline with age. In conclusion, these metrics can be used: 1) to investigate whether volume and intensity of activity have independent, additive or interactive effects on health and 2) for global surveillance, including assessing prevalence of meeting activity guidelines. As accelerometer and corresponding health data accumulate it will be possible to derive evidence-based physical activity guidelines directly from accelerometer data.

### O.2.5 A sequence analysis to examine the transition process between physical behaviours in the workplace: how are these processes linked to cardiometabolic risk factors?

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Background: Total sedentary time (ST) is known to be associated with cardiometabolic risk factors; however, this association is attenuated for occupational ST. Furthermore, there is increasing evidence of the beneficial effects of breaking up long bouts of sitting. The aim of this study was to describe the distribution of physical behaviours during work hours with respect to cardiometabolic risk factors, using sequence analysis; this method can be used to describe the characteristics of complex time-related sequences, as opposed to traditional methods that are used to model the processes that have produced the sequences. Methods: Data on physical behaviours and cardiometabolic risk factors were obtained from the Health Survey for England (annual health survey). In 2008, the ActiGraph GT1M accelerometer was worn by a sub-sample of participants for 7-days: physical behaviour categories (sedentary, light, and moderate to vigorous physical activity) were computed using count data. The predominant physical behaviour for each 5-minute interval of a working day was calculated. Results: Of the 911 adults with accelerometer data (working full-time), 588 provided complete sequence data. Sedentary bouts were significantly shorter in those with elevated blood pressure and high HbA1c data; in contrast, sedentary bouts were longer in those with a high waist circumference (ns) and in those with raised HDL cholesterol (24.54 vs. 22.96 minutes; $p<0.001$). Figure 1 shows the differences in the distributions of physical behaviours for each 5-minute time interval for HDL. The spikes on the 'Low HDL' graph illustrate the higher number of sedentary bouts compared to the 'High HDL' group. Conclusions: The underlying mechanisms of ST in the occupational domain appear to be complex with respect to cardiometabolic risk factors. Sequence analysis methods can be further utilised to identify common sequence typologies to interpret the temporal patterns of physical behaviour in the workplace.

## Oral Session 3 – Machine Learning / Data Mining

### O.3.1 Mine the data, find the correlates of physical activity: A cross-sectional study

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Physical activity (PA) is a multidimensional behavior explained by a multi-level complex web of factors (correlates) of different domains. We have now entered a data-intensive era where data mining approaches that allow to generate data-driven hypotheses from large-scale data have been emerged. Here, we applied a data mining technique on a variety of potentially modifiable factors of different domains in order to identify the correlates of PA, and also to understand the interactions between the factors. Participants (N=4,582) of the NFBC1966 study wore a wrist accelerometer for seven consecutive days. Additionally, their health, socioeconomic situation, lifestyle, built environment, etc. data have been measured with interviews, questionnaires, clinical measurements, and geographical information systems. We differentiated physically active and inactive subjects based on their activity profiles, built using a clustering technique in our previous study. In this study, the Chi-square Automatic Interaction Detector (CHAID) decision tree (DT) that provides an interpretable hierarchy was applied to 171 factors in order to predict physically active and inactive subjects. We then analyzed the association of the factors emerging from the model with time spent on very light, light, and moderate-to-vigorous intensity PA (VLPA, LPA, MVPA). The DT-derived model contained 38 factors of different domains including both novel previously unrecognized surrogates (e.g. skeletal muscle mass) and previously well-known (e.g. education level) factors. The associations between the identified factors and VLPA, LPA, and/or MVPA were significantly positive or negative as expected. For instance, the built environmental factors were significantly associated with LPA. In conclusion, data mining appeared to be a feasible method to capture the hierarchical and complex nature of correlates of PA from empirical large-scale data and discover new set of factors for additional hypothesis testing.

### O.3.2 User verification of actigraphy data

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INTRODUCTION Actigraphy enables capturing real world data related to activity and sleep, allowing remote measurement of health metrics. Remote data capture brings with it the challenge that data may be collected by a person other than the patient. Such a person is referred to as impostor. There are many reasons for the presence of an impostor but, in each case, impostor data possibly leads to wrong conclusions. METHODS We aim to identify impostor data with a user verification algorithm, which detects the presence of impostors and marks the data that they have likely contaminated. This is achieved by creating a patient-specific fingerprint of activities, which includes movement patterns that are very typical or atypical for the patient. The algorithm sequentially processes the actigraphy data until it collects enough evidence to ascribe it to the patient or an impostor. Then, the algorithm recommences checking with the subsequent data. We have run two studies where 94 participants wore an Actigraph GT3X Link device for 4 weeks. Each participant was either a healthy volunteer, or a patient with chronic pain. We evaluate the algorithm by learning a fingerprint of activities for a participant from one week of data, exposing it to data from another participant and measuring how much data the algorithm needs to correctly identify the impostor. RESULTS When the algorithm is tuned to produce no false positive detection over 3 weeks of data, it correctly identifies >95% of impostors after eight hours of wear time, and 100% after 16 hours. DISCUSSION AND CONCLUSION With our user verification algorithm, it is possible to demonstrate when actigraphy data has come from the patients themselves. This increases the reliability of actigraphy data, and of actigraphy-based health monitoring in turn.

### O.3.3 Deep learning and supervised learning models for energy expenditure prediction in preschool children

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Energy expenditure (EE) prediction from accelerometer data is mostly performed by applying supervised machine learning (ML) algorithms which require domain knowledge for complex feature engineering. Although deep learning can eliminate the need of feature engineering by automatically identifying the hidden representation of the input using a collection of multiple neural networks layers, it is yet under-utilized for EE prediction in preschool-aged children. Purpose: To investigate and compare deep learning models to the supervised ML models for EE prediction from body worn accelerometers in pre-school-aged children. Methods: 19 children (4.9 ± 0.8 yrs) performed 10 simulated free-living activities while wearing accelerometers on three body locations: left wrist, right wrist, and right hip, along with a portable metabolic system for direct assessment of EE. For deep learning model, a convolutional neural network (CNN) was used, which consisted of an input layer, 3 x (convolution layers, rectified linear units, max-pooling layers), a fully connected hidden layer, and a regression layer. To make the raw accelerometer data suitable for input, each window of data (1024 samples of x, y, and z) was converted to 3-dimensional matrix (32 x 32 x 3). For supervised ML algorithm, total 27 models were developed for each location by varying feature selection (MRMR, correlation-based, and ReliefF), number of features (10, 15, and 20) and regression algorithms (linear, support vector machine, and neural network regression). Results: Using leave-one-subject-out cross-validation, the results (Figure 1) show that for all accelerometer locations, CNN was able to marginally outperform the performance of best supervised ML models. In both approaches, hip location showed better performance than the wrist locations. Conclusion: Deep learning can eliminate the need for complex feature extraction and selection, and still provide marginally improved EE prediction for preschool aged children.

### O.3.4 Unsupervised learning of behavior changes using raw accelerometry data

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Accelerometers have widely been used in physical activity research in recent years and many methods have been developed to predict the type of physical activity conducted by the wearer of the devices. Many of these supervised learning methods are very accurate, but usually need good quality training data. Our goal is to develop an unsupervised method to automatically identify major patterns of accelerometry data in free living environment. Such methods could be applied to study the cross-sectional differences and longitudinal changes of activity patterns. Tri-axial accelerometry data were collected continuously for 28 days in a population of 30 patients and 15 healthy controls. Overlapping segments of accelerometry time series, called "movelets", were extracted to form the basis of the analysis. The distance between movelets was computed using several methods including Euclidean and K-shape distance. Clusters of movelets were established for each day of every subject. Such clusters were further combined across different days within each subject. The pattern of the clusters as well as the composition of the patterns were compared across days for each subject, and across subjects for disease group and healthy controls. The unsupervised learning framework identified major accelerometry time series patterns, which usually consist of 4 to 5 sedentary patterns and 3 to 4 active patterns. Some of these patterns can be associated with certain known physical activities, such as maintaining standing, sitting and lying posture, or walking with various pace. Variability of the composition of these patterns among days and between disease groups was discovered. The proposed unsupervised learning method based on the movelet prediction enables researchers to identify accelerometry patterns for unspecific physical activity without training data. The composition of such activity patterns may provide valuable information for subjects' physical function and well-beings.

### O.3.5   Building machine learning models using standard tools for detection of postures and physical activities from long-term accelerometer recordings

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Accelerometer recordings allow objective quantification of time with different postures and physical activities without relying on questionnaires. However, to analyze 3-axis accelerometer sensor data at scale, as well as having the flexibility to change the type of activities to be detected, requires an understanding of how machine learning (ML) models can be built and their inherent limitations. This presentation we will focus on how we trained our ML models for recognizing basic postures and activities, such as lying down, sitting, standing, walking, running and biking in the fourth round of the Nord-Trøndelag health study (HUNT4). All participants in HUNT4 were invited to record their physical activity through a thigh and a back-worn sensor over 7 days. In total, we obtained objective measuments from about 6 500 adolescents (13-18 years) and 33 000 adults. To analyze the data, we developed a ML model based on Random Forest classifiers to detect basic postures and activities. The model was built using off-the-shelf tools, with a focus on data preparation, feature extraction and model evaluation. Eventually, we will also discuss the lessons learned on how to prepare accelerometer data so it can be used in ML.

## Oral Session 4 – Clinical Applications

### O.4.1   Objective quantifiable assessment of nocturnal movements in patients with Parkinson's disease using a wearable sensor

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OBJECTIVE:To explore the relationship between impaired bed mobility, disease severity, and other factors putatively related to nocturnal hypokinesia in patients with Parkinson's disease. METHODS:Subjects wore a tri-axial accelerometer on the lower back for >3 days. Nocturnal activity was extracted from 100Hz raw acceleration, with lying defined based on the vertical axis. Orientation was used to define positions in space such that turning reflected a change from one static position to another that was sustained for at least 5 min. Disease severity was classified using the Hoehn and Yahr (H&Y) staging scale, cognitive function was assessed using the MoCA test and

autonomic function was evaluated using the Non-Motor Symptom (NMS) Questionnaire. Analysis was adjusted for age. RESULTS:Data from 272 patients with PD in various disease stages were included in the analysis (H&Y1:n=36,H&Y2:n=150,H&Y3: n=86). Age and disease duration differed between the groups (p<0.005). Sleep duration was similar across the H&Y stages (H&Y1:7.8±1.3hrs; H&Y2:8.1±1.3hrs;H&Y3:8.1±1.4hrs;p=0.35). However, the number and velocity of turning in bed was significantly reduced in H&Y3 patients (H&Y1:6[4-8] turns,16.5±7.5deg/sec; H&Y2:4[4-6] turns,10.5±7.3deg/sec;H&Y3:3[1-5] turns,8.2±6.2deg/sec;p≤0.004). In addition, the number of turning during the night were associated with higher cognitive performance (r=0.12, p=0.03) and less NMS (r=-0.45,p<0.0001). Turn velocity was significantly associated with less NMS(r=-0.25,p=0.004), but not with cognitive performance (p=0.84). CONCLUSIONS:These findings demonstrate that although sleep duration is similar in different disease stages, worse nocturnal movement at night is associated increasing PD severity and worse dysautonomia. From a clinical perspective, the use of a wearables for night monitoring could provide valuable information to enhance clinical care including optimal nighttime dopaminergic treatment and education about turning strategies in bed

## O.4.2    Accelerometry measured walking cadence and mortality risk among U.S. adults

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BACKGROUND: Walking at greater intensity (i.e., speed) is associated with lower mortality risk; however, this association has not been investigated using accelerometry-derived measures of walking intensity. This study examined associations between accelerometer-derived walking intensity, or cadence, and mortality. METHODS: Data are from the 2003 to 2006 NHANES for adults aged ≥40 years (n=4,840) linked with mortality data through 2015. Participants wore an ActiGraph 7164 on the waist for 7 days and cadence (steps/min) was estimated using three metrics: 1) average bout cadence (steps/min) during bouts of ≥ 60 steps/min (i.e., slow walking) that lasted 2 minutes or more; 2) 30-minute peak cadence and; 3) 1-minute peak cadence, as per Tudor-Locke. Cadence metrics were classified into quartiles and Cox proportional hazard models were used accounting for the NHANES complex sample design, to estimate hazard ratios (HRs) and 95% confidence intervals (CI) adjusting for age, sex, ethnicity, education, diet, alcohol, smoking, BMI, comorbidities, and total steps/day. RESULTS: Participants accumulated 9,152±108 steps/day, were followed on average for 10.1 years, and 1,165 deaths occurred. Taking 4,000+ steps/day was associated with lower mortality (HR=0.66, 95% CI [0.61, 0.71]); however, there was no significant association with any of the walking intensity metrics. Walking at the highest bout cadence (> 88.5 steps/min) was not associated with mortality (HR=1.02 [0.84, 1.25]; Ptrend=0.56) compared to the lowest quartile (60.0-76.0 steps/min). Results remained similar for peak-30 minute (HR=0.87 [0.62, 1.22], Ptrend=0.57) and peak 1-minute cadence (HR=1.06 [0.79, 1.42]; Ptrend=0.92) comparing highest to lowest quartiles. DISCUSSION AND CONCLUSIONS: We found no association between walking cadence and mortality after adjusting for covariates and total steps/day. These findings suggest that the total amount of daily walking regardless of walking cadence reduces mortality risk

## O.4.3    Is bias due to reverse causality evident in device-based studies of sedentary behavior, physical activity and mortality?

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Reverse causality bias could arise in studies of physical activity (PA) and mortality if pre-existing or undiagnosed illness reduces PA or increases sedentary time (ST). This bias may overestimate the strength of associations observed, yet it has not been carefully examined in device-based studies. We investigated potential reverse causality bias in NHANES (age 40+ yrs) using new mortality follow-up (2003-06 to 2015). We examined the strength of associations of moderate-vigorous PA (MVPA) and ST with mortality for 2, 4, 6, 8, 10+ yrs of follow-up in the full cohort (N=4,840; 1,165 deaths) and in a "healthy" sub-cohort (n=3,160; 463 deaths) after excluding subjects

reporting heart disease, cancer, stroke, mobility limitations, or poor health. Hazard Ratios (HRs) were adjusted for demographics, BMI, smoking, diet, alcohol, health status, and chronic conditions. Risk estimates comparing extreme quartiles of ST and MVPA2020 tended to be stronger when follow-up time was <=4 years compared to 8 or more years--in the full cohort and in the healthy sub-cohort. For example, the HR for greater ST was 2.4 (95% CI, 1.3-4.4) with two years of follow-up and 1.5 (1.1-2.0) with 10+ years of follow-up in the full sample. Similarly, the HR for low MVPA was 4.1 (1.8-9.4) for two years of follow-up and 2.6 (1.9-3.7) for 10+ years of follow-up. Exclusion of unhealthy individuals did not minimize the influence of follow-up time on the strength of associations. These findings indicate that mortality associations in device-based studies can be stronger earlier in the follow-up period (<=4 years) compared to risk estimates observed with longer follow-up (8+ years). Although the true strength of association remains unknown, our results are consistent with reverse causality bias with shorter follow-up. Interestingly, devices may be picking up actionable information about preclinical illness and mortality risk, a finding that should be examined in future studies.

### O.4.4   Gait irregularity as a predictive marker of exertional heat stroke

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Exertional heat stroke (EHS) is a concern for athletes and military who must train and perform in hot environments. EHS has symptoms of high core body temperatures with central nervous system (CNS) dysfunction. Objective: Develop a predictor of EHS using gait change metrics developed from torso tri-axial accelerometry (128Hz, ±8g) that may indicate CNS dysfunction. Methods: Twenty four soldiers (age 28±4 y, ht 1.8±0.1 m, wt 84±11kg) participated in a 5 mile timed run (Air temp. 23 °C, rel. humidity 91%). One volunteer suffered an EHS and recovered (max. core temp. 41.7°C). Two novel methods assessed gait change. (1) A distance score was computed from mediolateral and forward accelerations containing repeated steps over 5s epochs. Distance scores were individually normalized using the first 10 minutes of the run. A threshold of >4 standard deviations from baseline was used to identify potential EHS. (2) High to low frequency relationships were examined using the joint distribution of torso accelerations over a 20s epoch where eigenvalues were computed from a correlation matrix with time delay embedding. The first two principal components of these eigenvalue features, computed across all subjects, represented the dominant components of torso motion. Motion outside the normal range indicated potential EHS. Results: The combination of the two approaches uniquely identified the EHS patient at least 3 minutes prior collapse with no false positives. For method (1) distance scores for two additional subjects exceeded the threshold suggesting a significant change in gait. However, this appeared to be a systematic gait style change that should have been re-baselined. Method (2) the principal components scores for most subjects were clustered closely together, however three additional subjects' scores were clear outliers. Conclusions: This case study suggests a multispectral gait change marker offers promise as one mode to predict EHS in real-time.

### O.4.5   A home-based mHealth intervention in older cancer survivors to replace sedentary time with intermittent bouts of light physical activity

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OBJECTIVE: To evaluate the feasibility and preliminary efficacy of a home-based mHealth intervention to reduce sedentary time and increase light physical activity. METHODS: Fifty-four older cancer survivors (60-84 years) were randomized to a 16-week intervention group (IG) or a waitlist control group (CG). Intervention participants received a Jawbone UP2 activity monitor to use with their smartphone app. Tech support and health coaching were provided via 5 telephone calls. Sedentary behavior and physical activity were measured using an ActivPAL monitor for 7 days pre- and post-intervention. Effect size (Cohen's d) was used to evaluate differences in sitting, standing, and stepping between IG and CG. RESULTS: Participants, on average, were 70 years old (SD=4.4), 44% male, 22% Hispanic, and 80% overweight or obese. Forty-seven participants completed the trial (13% drop out rate). The mean (SD) minutes per day spent sitting, standing and stepping at baseline were 553 (85), 245 (95), and

96 (35), respectively. Overall, time spent sitting and standing did not change. In the IG, only 54% reduced sitting and 33% increased standing, whereas 67% increased stepping. Small effect sizes were observed for change in steps per day (mean [SD]: +1622 [3054] IG vs. +444 [1927] CG; d=0.44) and minutes spent stepping (mean [SD]: +16 [32] IG vs. +7 [26] CG; d=0.30). This increase was due to moderate- rather than light-intensity stepping. CONCLUSION: A home-based mHealth program to replace sedentary time with stepping was feasible in older cancer survivors. The greater improvement in stepping compared to sitting and standing suggests that the majority of participants focused on increasing their steps rather than disrupting and reducing sedentary time. Furthermore, intervention participants self-selected a higher intensity in order to increase their daily steps. Additional health coaching may be needed to help older cancer survivors change their sedentary and physical activities.

## Oral Session 5 – Research Devices

### O.5.1   Effects of bout size on gait metrics during daily activity

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OBJECTIVES: it is unclear whether to include all bouts or to select particular gait bouts defined by their duration, when comparing between groups the quality of gait during daily activities. The purpose of this study was to determine the effect of bout size on measures of gait quality in people with Parkinson's Disease (PD) and healthy control (HC) subjects over a week of continuous monitoring in daily life. METHODS: We recruited 20 subjects with idiopathic PD and 20 age-matched HC subjects. Subjects wore three inertial sensors (Opals, APDM) attached to both feet and the lumbar region for 7 days with an average of 8 hours per day. A gait bout was defined as a minimum of 3 consecutive steps. Thirty spatiotemporal gait metrics were defined for each bout. For each gait measure, we calculated the ratio of the variance of the model estimated due to number of strides in a gait bout with respect to the total variance. RESULTS: The majority of gait bouts were less than 30 seconds in both groups, with few walks over 2 minutes. For all measures of gait, the effect of bout size was larger in HC compared to PD subjects. The most affected gait measures by the bout size were gait speed, stride length, and maximum foot pitch angle at heel strike. As gait bouts increased in number of strides, subjects walked faster, with longer strides and larger heel strike dorsiflexion, especially in the HC group. Specifically, the average gait speed variance explained by bout size was 9.4% (0-21.9%) for PD, and 15.2% (0.1-40.6%) for HC. The average stride length variance explained by bout size was 8.2% (0-19.7%) for PD, and 12.2% (0.0-34.1%) for HC, and the average maximum pitch angle variance explained by bout size was 6.0% (0.1-13.1%) for PD, and 8.4% (0.1-34.1%) for HC. CONCLUSIONS: As wearable sensors used during normal daily activities are adapted for clinical research and clinical decision-making, the effect of bout length should be accounted for in the study design and analysis.

### O.5.2   How can texting affect your walking?

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Introduction Walking while texting is a familiar sight throughout urban environments around the world. The use of mobile phones in this manner is a relevant example of distracted walking, which has a considerable influence on the risk of trips, slips, falls, and even road safety. The aim of this study was to assess the effects texting while walking on the spatiotemporal aspects of gait, in particular among healthy young adults, when walking at different speeds in an ecologically setting. Methods Ten young healthy adults each completed 2 rounds of the following 4 experimental conditions - (a) walking only and (b) walking & texting on a mobile phone, at self-selected normal and fast walking speeds. Both rounds were preceded by a texting-only assessment of texting performance. Gait velocity, stride length, cadence, and double support time were computed using data collected from two inertial motion units placed over the laces of each shoe. Results Significant decreases were observed in mean gait velocity (-9.7%), stride length (-8.1%), cadence (-2.3%), concurrent with a significant increase in double support time (+9.9%) when walking while texting was compared with walking only. Moreover, texting increased the relative

variability of walking, as demonstrated by a significant increase in the coefficient of variation of cadence (+56.2%), stride length (+73.1%), and double support time (+22.4%). Conclusion The observed spatio-temporal changes in the reported stride parameters indicate that texting while walking may be suggestive of compromised balance, potentially increasing the risk of trips, slips, and falls.

### O.5.3   Is every-day walking in older adults more analogous to dual-task walking or to usual walking? Elucidating the gap between gait performance in the lab and during 24/7 monitoring

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Objective: To compare in-lab usual-walking (UW) and dual-task walking (DTW) to daily-living measures of gait in older adults. Methods: In-lab gait features (e.g., gait speed, step and stride regularity) derived from UW and DTW were compared to the same gait features during daily-living in 150 elderly fallers (age: 76.5±6.3 years, 37.6% men). In both settings, features were extracted from a lower-back accelerometer using the same algorithms. In the real-world setting, subjects were asked to wear the device for one week; pre-processing detected 30-second daily-living walking bouts. A histogram of all walking bouts was determined for each walking feature for each subject and then each subject's 50% (typical, median), 10% percentile (worst) and 90% (best) values over the week were determined for each feature. Statistics of reliability were assessed using Intra-Class correlations. Results: In-lab gait speed, step regularity and stride regularity were worse during DTW, compared to UW. During UW, these values were significantly higher (i.e., better) than the typical daily-living values (p<0.0001) and different (p<0.0001) from the worst and best values. DTW values tended to be similar to typical daily-living values (p=0.205, p=0.053, p=0.013, respectively). ICC assessment and Bland-Altman plots indicated that in-lab values did not reliably reflect the daily-walking values. Conclusions: Gait values measured during relatively long (30 sec) daily-living walking bouts are more similar to the corresponding values obtained in the lab during DTW, but not to UW. Still, gait performance during most daily-living walking bouts is worse than that measured during UW and DTW in the lab. The values measured in the lab do not reliably reflect daily-living measures. Since an older adult's typical daily-living gait cannot be estimated by simply taking a snapshot of walking in a structured, laboratory setting, daily-living measurements should be considered as a complementary view of gait.

### O.5.4   Comparison between accelerometer and gyroscope for the analysis of gait regularity

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*[1]IRCCS FONDAZIONE DON CARLO GNOCCHI*

Introduction Steady-state gait is characterized by well-formed pseudo-periodic kinematic patterns [1,2]. Gait regularity can be assessed by autocorrelation analysis of measurements from an accelerometer and a gyroscope embedded in a single package located on specific anatomical landmarks [3]. The aim of this study is to compare the gait regularity indexes obtained from accelerometer and gyroscope data. Methods Twenty-five healthy subjects performed 1-minute walking trials at 3.6 (W36), 5.0 (W50) and 6.4 (W64) km/h. Sensors were placed on the wrist, C7 vertebra, pelvis (sacrum) and ankle. The regularity index was computed for both sensors (RIa for acceleration, RIg for angular velocity) [3]. Results A summary of (RIa-RIg) difference values is presented in the figure. Statistical analysis evidenced that: 1) RIg and RIa did not differ at the ankle; 2) pelvis and, even more, C7 showed larger (RIa-RIg) differences; 3) wrist was comparable to the ankle at higher speeds, to the pelvis at a lower speed. Discussion Different sensors, on the same location, may lead to different regularity values because of different kinematic patterns. Therefore RIa and RIg show: 1) similar values at the ankle because both accelerations and angular velocities are well-formed [1]; 2) larger trunk RIa values because of the prevalence of translatory movements, particularly at C7; 3) since wrist rotational movements increases with increasing gait speed, wrist regularity is comparable to the ankle at higher speed and with pelvis at lower speeds. The indication is to use accelerometers

to assess gait regularity. This can be extended to other pseudo-periodic movements with a prevalence of linear acceleration, such as upper limb tremor; though other movements mostly involving rotations may be better assessed by a gyroscope. References [1] Kim, Joo, Jeong, Jeon, Jung. J Mech Sci Technol 2016 [2] Moe-Nilssen, Helbostad. J Biomech 2004 [3] Rabuffetti, Scalera, Ferrarin. Sensors 2019

### O.5.5   Gait speed assessed by a 4-meter walk test is not representative of daily-life gait speed in community-dwelling adults

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BACKGROUND AND AIM: Standardized gait speed tests are regarded clinically valuable, but are typically performed under optimal conditions, and may not reflect daily-life gait behavior. The aim of this study was to compare 4-meter gait speed to the distribution of daily-life gait speed. METHODS: We included 254 community-dwelling participants ranging from 20 to 91 years (median age 66.7 years [IQR 59.4 - 72.5], 66% female), from the cross-sectional Grey Power cohort. A timed 4-meter walk test at preferred pace from a standing start was assessed with a stopwatch. Daily life gait speed was obtained from tri-axial lower back accelerometer data over seven consecutive days and the distribution of gait speed over all gait episodes >10sec was attained. Pearson's correlations were used to compare gait speed assessed using a timed 4-meter walk test at preferred pace, and different percentiles from the daily-life gait speed distribution. RESULTS: Participants had a mean 4-meter gait speed of 1.43 m/s (SD 0.21), and a mean 50th percentile of daily-life gait speed of 0.90 m/s (SD 0.23). Ninety-six percent had a bimodal distribution of daily-life gait speed, with a mean 1st peak of 0.61 m/s (SD 0.15) and 2nd peak of 1.26 m/s (SD 0.23). The percentile of the daily-life distribution that corresponded best with the individual 4-meter gait speed had a median value of 91.2 (IQR 75.4 - 98.6). The 4-meter gait speed was very weakly correlated to the 1st and 2nd peak (r=0.005, p=0.936 and r=0.181, p=0.004), and the daily-life gait speed percentiles (range: 1st percentile r=0.076, p=0.230 to 99th percentile r=0.399, p<0.001; 50th percentile r=0.132, p=0.036). CONCLUSION: The 4-meter gait speed is only weakly related to daily-life gait speed. Clinicians and researchers should consider that 4-meter gait speed and daily-life gait speed represent two different constructs.

## Oral Session 6 – Algorithms (1)

### O.6.1   Fast and robust algorithm for detecting standing periods using wrist-worn accelerometers

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Purpose: Wrist-worn accelerometers have been gaining popularity in large epidemiological studies for quantification of physical activity and sedentary behavior. The latter is typically estimated based on low activity levels neglecting the assessment of body position. To fill this gap, we introduce a novel approach called SedUp (Sedentary and Upright body posture classification method). Methods: SedUp distinguishes between different postures based on the wrist elevation and motion variability using logistic regression. The classification is performed utilizing two statistical features estimated from the raw accelerometry signal collected on the axis parallel to the forearm. We tested the performance of SedUp on data collected at the University of Pittsburgh from N=45 community-dwelling older adults. All subjects wore ActiGraph GT3X+ accelerometers on the left and right wrist as well as activPAL placed on a thigh in the free-living environment for seven days. ActivPAL measurements provide the ground truth about sedentary and upright periods. We report SedUp's classification accuracy of upright vs. sedentary periods via sensitivity, specificity, mean absolute percentage error (MAPE) and mean percentage error (MPE). We present the results for each wrist separately. Results: For the classification from the left wrist, median sensitivity was estimated to be 0.841, median specificity - 0.905, MAPE - 12.7%, and MPE - 3.1%, while for the classification from the right wrist median: sensitivity was estimated to be 0.861, specificity - 0.919, MAPE - 15.1%, and MPE - 4.4%. The estimated average daily standing time differed from the ground truth by about

0.05h and 0.10h for the left and right wrist, respectively. Conclusion: SedUp provides accurate classification of standing posture using wrist-worn accelerometers worn on both wrists in a sample of community-dwelling older adults.

### O.6.2 Improving hip-worn ActiGraph posture detection with artificial intelligence on a free-living dataset

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The hip-worn ActiGraph GT3X (AG) is used in most epidemiological studies due to its accurate physical activity classification. However, the sensor lacks any validated posture information. This study therefore developed a new posture detection algorithm for AG raw data using artificial intelligence by calibrating the sensor against a thigh-mounted ActivPAL (AP) in free-living. 38 subjects concurrently wore both sensors for 8.8 ±1.0 days. After removal of sleep and non-wear time, AG data was processed as follows: 1) Calculate 563 signal features for each minute with constant AP classification; 2) Rank the features according to relevance using an established random forest feature ranking method; 3) Iteratively include the 25 most relevant features in a random forest classifier with 30 trees; 4) Identify optimal feature number with leave-one-subject-out cross-validation, considering a penalty of 0.1% on balanced sensitivity-specificity for each additional feature. Each participant provided 62.1 ±13.6 hours sitting, 19.2 ±8.7 hours standing, and 6.7 ±3.5 hours stepping (AP classification). Using 13 signal features (6 time based, 5 frequency based, and 2 dynamic time warping), the new algorithm classified 89.1% of all minutes correctly. Sensitivity and Specificity was 95.0% and 75.3% for sitting, 66.6% and 95.5% for standing, and 99.4% and 99.9% for stepping. This is among the first algorithm developed in an entirely free-living population considering feature relevance and number. Although we used a very simple random forest classifier with only 30 trees, the algorithm predicted the true posture with moderate (standing) to very high accuracy (sitting and stepping). Due to the identification of the most relevant features and the simple classifier with only few features, we expect an above-average generalisability of the algorithm's classification performance. However, further optimisation of the algorithm architecture and validation in an independent sample is recommended

### O.6.3 Evaluating the performance of bout detection algorithms for wearable sensors: the transition pairing method

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It is becoming more common to use bout detection algorithms to segment data from wearable sensors, but there is no established way to assess how effective such algorithms are. OBJECTIVE: To present and demonstrate the Transition Pairing Method (TPM), a new method for evaluating the performance of bout detection algorithms. METHODS: The TPM assesses whether a bout detection algorithm captures the correct number and timing of bout transitions, using classification metrics and parametric tests, respectively. The core challenge is determining which predicted and criterion transitions should be compared with one another, i.e., paired together for analysis. The TPM assigns the pairs using an extended Gale-Shapley algorithm, where preference is proportional to the time difference between transitions, and pairs can be prevented from forming if they are too far apart. Each pair is considered a true positive, and unpaired predictions and criteria are false positives and false negatives, respectively. In the demonstration, 99 youth wore an ActiGraph GT9X on the right hip and non-dominant wrist during simulated free-living. Raw acceleration data were processed using two previously-developed youth Sojourn models (one for each attachment site), which predicted bout transitions and the intensity of each bout. The TPM was used to compare predicted bout transitions to a criterion measure of direct observation. Performance metrics were calculated for each participant, and then hip-versus-wrist means were compared using paired T-tests ($\alpha$ = 0.05). RESULTS: When using the strictest TPM settings, the hip and wrist algorithms each had true positive rates <21% (3% difference from one another, p<0.001) and positive predictive values <10% (1% difference from one another, p<0.001). CONCLUSIONS: The TPM can be used to evaluate a bout detection algorithm and compare it to other algorithms. Thus, the TPM makes a substantial contribution to the continued use of such algorithms.

### O.6.4 Active Travel: identifying periods of cycling using an accelerometer

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Objective One of the challenges in understanding active travel choices is objectively identifying periods of cycling which are generally not well reported by body-worn accelerometers. Using the dynamic acceleration of the thigh we are able to identify periods of reciprocal leg movement. As cycling involves a different range of thigh inclinations from stepping, we hypothesised that inclination could be used to discriminate between cycling and stepping activities. Stepping also features a heel strike acceleration not found in cycling. By identifying and test the key accelerometer characteristics of cycling and stepping we aimed to develop a robust algorithm for identify periods of cycling. Methods 9 subjects wore an accelerometer on their thigh for 7 days and completed an activity diary. The accelerometer data were processed to extract summary data for reciprocal leg movements. We then examined this data to identify features that could be used to differentiate periods of cycling. The characteristics extracted on each inclination cycle were mean and median flexion/extension angles; peak acceleration change; and peak vector magnitude. The median value for each of the features across the whole activity bout was used to classify the bout. Results The inclination feature which provided the greatest separation was the median flexion/extension angle. The acceleration feature which provided the best separation was acceleration change per cyclical thigh movement. Using either the mean angle or peak vector magnitude resulted in considerable overlap between cycling and stepping. Conclusions In this study, cycling could be distinguished from stepping activities using two features of the acceleration signal in free-living subjects. There were some confounding upright activities, such as field hockey and speed skating which exhibited intermediate cyclical inclination patterns. These confounders represented only 0.35% of upright time across the dataset.

### O.6.5 Visualisation to support automatic identification of time in bed using a thigh-worn accelerometer

Objective Using a thigh-worn accelerometer it has been shown that separation of non-upright and upright activities can be achieved. However, to provide a measurement of sedentary time (as defined), non-upright activities must be further separated into waking day sitting/lying postures, and time in bed. The objective was to use visualisation to investigate the automatic identification of time in bed (TIB) in free-living data. Methods The simplest TIB consists of a single uninterrupted non-upright bout with rolling, bounded by upright activity. At the other extreme, non-upright bouts are broken equally throughout the day, indicating no clear diurnal cycle. An algorithm was developed to address these extremes and identify the most likely primary TIB period in a day. The algorithm in brief: identifies all non-upright bouts > 1h in a day with rolling of the thigh; expands to include adjacent non-upright bouts, breaking on upright activity, to create TIB containers. The longest expanded container is labelled as primary TIB and any others labelled as secondary TIB. The data were visualised on a daily spiral using: colour for posture; height for duration of continuous accelerometer stillness; and markers at the start and end of the TIB container. Results Visualisation of free-living data highlighted the key challenges for automatic TIB identification to be: couch lying in the evening with short upright breaks, which follow a similar pattern to broken sleeping bouts with toilet breaks; and waking up during the night, sitting for a period, then going back to bed, splitting up the primary TIB period. Conclusions Visualisation provided a means to identify the issues with the TIB algorithm applied to different datasets. It was also used to identify additional criteria, such as accelerometer stillness, which could be used to provide more robust TIB separation. In addition, manual adjustment of the TIB classification markers can be facilitated using the visualisation.

## Oral Session 7 – Clinical Applications (2)

### O.7.1 The contribution of dog walking to daily moderate to vigorous physical activity in dog owners aged ≥ 65 who walk their dog regularly.

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Objectives. Dog owners are more physically active compared with non-dog owners, but the relative contribution of dog walking to physical activity (PA), including moderate to vigorous physical activity (MVPA), is unknown. Methods. Older adults wore an activPAL monitor and completed a self-report diary of outdoor walks (start time, end time, purpose), for three 7-day assessments across a year. The free-text purpose of each walk was coded as dog walking or other. Secondary data analysis was conducted on a subsample of dog owners who regularly walked their dog(s) (at least 6 (out of 7) days/assessment). Each continuous walking event from the activPAL was coded as a dog walk, other purpose, or not reported, based on the start and end times (±5 min) and purpose from the walking diary. The relative contribution of dog walking and other purpose walking to outcome measures of number of steps, time spent walking, and time spent in MVPA (walking events with cadence>100 steps/min) was compared using Mann-Whitney U tests. Results. Participants (n=13; 62% female; aged 69±4 years) spent significantly more time in MVPA (median [interquartile range] 29 [16,38] vs. 10 [7,20] min/day; p=0.02), walking (40 [34,51] vs. 17 [14,18] min/day; p=0.03) and took more steps (4581 [4029,5222] vs. 2755 [1595,3217] steps/day; p=0.02), when walking the dog compared to other outdoor walking. Self-reported diary walks covered 75% of total MVPA, but only 26% of total time walking. The remaining time was either walking in the home (not covered by the diary), or missing data (no diary entry). Conclusions. For regular older adult dog walkers, most (56%) of their MVPA was accrued during dog walking. This confirms, using objectively measured MVPA, that dog walking is responsible for increased PA in dog owners compared to non-dog owners. Future work should explore whether this is also true in less-regular dog walkers, especially as dog walking may be more consistently recorded in the diary than other walks.

## O.7.2 Assessing the effect of pain on function via home-based active tasks measured by a wrist-worn accelerometer

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Background Evaluation of pain and stiffness in patients with arthritis is largely based on self-reported questionnaires. This is subjective and may not accurately reflect the true impact of therapeutic interventions. We now have access to actigraphy sensors to capture objective information regarding movement and activity. Objectives The first objective was to explore whether the participants would correctly perform, in their home environment, an unsupervised version of a standard motor task, known as the Five Times Sit to Stand (5×STS) test. The second objective was to demonstrate that the measurements collected would enable us to derive an objective signal related to morning pain and stiffness. Methods We recruited 45 participants, 30 participants with either osteoarthritis, rheumatoid arthritis, or psoriatic arthritis and 15 healthy controls. All participants wore an Actigraph GT3X Link on their wrist for 4 weeks. The participants were asked to perform the 5×STS test every Monday, Wednesday, and Friday in their own home environment in the morning right after getting up. We investigated the relationship between pain/stiffness and physical function by comparing the 5×STS test duration derived from wrist actigraphy with patient-reported outcome (PRO) questionnaires, filled in via a smartphone. Results and Conclusions The participants performed 56% of the prescribed 5×STS tests, and executed the tests in a consistent way. We show that 5×STS test duration (the time taken to complete the 5×STS test) was significantly and robustly associated with the pain and stiffness intensity reported via the PROs, particularly the questions asked in the morning. This study demonstrates the feasibility and usefulness of regular, sensor-monitored physical tests to objectively assess the impact of pain on function in the home environment.

## O.7.3 The optimal threshold of device-assessed physical activity required for weight loss at 24 months: A receiver operating characteristic curve analysis

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Objective: High levels of physical activity (PA) are consistently associated with long-term weight loss. Our goal was to determine the optimal PA threshold that discriminates achievement of clinically significant long-term weight loss. Methods: Adults (n=170, 40±9 y, BMI 34±4, 84% female) with overweight/obesity participated in an 18-month weight loss intervention involving a reduced calorie diet, a progressive exercise prescription, and group-based behavioral support. To assess long-term weight loss, participants (n=76, 41±10 y, BMI 34±4, 75% female) were re-assessed at 24 months. Moderate-to-vigorous PA (MVPA) accumulated in bouts ≥10 minutes (bout MVPA) was measured with the SenseWear Mini armband over 1 week. Receiver operating characteristic curve analyses were used to determine PA thresholds that discriminate between ≥10% vs. <5% weight loss, or ≥5-9.9% vs. <5% weight loss at 24 months. Thresholds were determined with the Youden Index (Sensitivity (Se) + Specificity (Sp) - 1). Results: Adults who met ≥5-9.9% weight loss (n=17) or ≥10% weight loss (n=21) demonstrated significantly higher levels of bout MVPA at 24 months vs. those who lost <5% (n=38) (mean±SD 321±272, 273±185, 170±154 min/wk, respectively; p=0.04). A threshold of ≥112 min/wk of bout MVPA (Se 94%; Sp 55%, AUC 0.71; p=0.02) optimally discriminated ≥5-9.9% weight loss. A threshold of ≥203 min/wk of bout MVPA (Se and Sp each 71%; AUC 0.68; p=0.03) optimally discriminated ≥10% weight loss. To achieve a Sp of 95%, a threshold of ≥421 min/wk (Se 18%) or ≥406 min/wk (Se 19%) of bout MVPA was required for discriminating ≥5-9.9% or ≥10% weight loss, respectively. Conclusions: Clinically significant (≥10%) long-term weight loss can be achieved with ~200 min/wk of bout MVPA, although some adults may require higher levels of bout MVPA. Results may help drive realistic PA goals for weight management, while still encouraging high PA levels to ensure that the majority achieves long-term weight loss.

### O.7.4   Sensor-enabled physical activity recognition in children and adolescents with cerebral palsy

*Alok Chowdhury¹, Emmah Baque², Matthew Ahmadi¹, Denise Brookes¹, Margaret O'Neil³*

*¹Queensland University of Technology, ²Griffith University, ³Columbia University*

Inadequate physical activity (PA) is a major problem impacting the health and well-being of children with Cerebral Palsy (CP). Valid measures of PA are required to evaluate the effectiveness of interventions to increase PA. Wearable sensors such as accelerometers are routinely used to assess PA in youth with CP; however, existing data processing methods are associated with significant error and underestimate the PA levels of children with more severe functional limitations. As such, there is a critical need to develop valid activity recognition algorithms for this patient group. Purpose: Develop and test machine learning algorithms to predict PA type from accelerometer data collected on the hip, wrist, and ankle in ambulant children with CP. Methods: 38 children (mean age=12.0 ± 3.1 y, 65.8% male) with CP classified as GMFCS level I (N=10), II (N=20), or III (N=8) completed a series of activity trials while wearing an ActiGraph GT3X+ on the least affected hip, wrist, and ankle. Trials were categorised as lying down, sitting, standing utilitarian movement (SUM), walking, and stair climbing. Random Forrest (RF) classifiers for each placement were trained using 52 features extracted from 10 sec non-overlapping windows. Recursive Feature Elimination was used to select the best 15 features for each placement. Performance was evaluated using leave-one-subject-out cross-validation. Results: Overall classification accuracy for the hip, wrist, and ankle classifier was 85.0%, 82.2%, and 89.7%, respectively. Recognition accuracy was excellent for lying down (92-97%), SUM (81-87%), and walking (90-94%); but modest and dependent on location for sitting (69-82%) and stair climbing (38-68%). For the wrist RF, recognition accuracy for walking exceeded 85% for all GMFCS levels. Conclusion: RF classifiers trained on accelerometer data from the hip, wrist, and ankle provide accurate recognition of clinically relevant activities in youth with CP. Supported by NIH grant 5R21HD086745-02

### O.7.5   It takes a week to obtain reliable estimates of tremor characteristics: a pilot study in organic and functional tremor patients

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Objective: To determine the minimum number of days needed to obtain reliable estimates of quantified tremor characteristics from long-term tremor recordings using accelerometry. We chose to investigate tremor presence

and tremor frequency variability since they are two of the most used characteristics to quantify tremor. Methods: Inertial sensor data were recorded from 30 tremor patients (15 functional tremor (FT), 15 organic tremor (OT)) during unconstrained activities of daily living during 30 days. Sensors were attached to the dorsal side of the forearm (close to the wrist). Information on the start of recording per day was obtained from electronic patient diaries. Time synchronization across days was performed first. The accelerometer signal and a tremor identification algorithm [1] were used to identify windows with tremor, from which percentage of tremor and tremor frequency variability were calculated per ten minutes for ten hours across days for all patients. Non-parametric distributions were generated and signed rank tests performed to determine whether estimates of tremor characteristics obtained from the first one to fifteen days were representative of estimates obtained from anyone to fifteen days within the thirty days. Results: Tremor percentage ranged from 11.2 to 31.2% for FT patients and from 10.17 to 70.0% for OT patients. Frequency variability ranged from 0.73 to 2.0 Hz for FT patients and from 0.4 to 1.5 Hz for OT patients. Seven days are needed to obtain reliable estimates of tremor presence in FT patients and four days in OT patients, while one day suffices to obtain reliable estimates of tremor frequency variability in both groups. Conclusions: The difference in the minimum number of days needed to obtain reliable estimates of tremor presence between groups could be due to higher variability in tremor presence in FT patients across time. Our findings may have a potential impact on future diagnostic and monitoring purposes in tremor disorders.

## Oral Session 8 – Research Devices (2)

### O.8.1 How do body attachment site and signal aggregation metric affect accelerometer-based physical activity?

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We aimed to: 1) study the associations between different acceleration metrics across right hip, dominant wrist and non-dominant wrist attachment sites during different periods of the day (i.e., 24 hours, waking and sleeping hours); and 2) use previously established cut-points for accelerations measured at the non-dominant wrist to propose and cross-validate cut-points in adults. Forty-five young adults (23 women, 18-41 years) were included and GT3X+ accelerometers (ActiGraph, Pensacola, FL, USA) were placed on their right hip, dominant, and non-dominant wrist for 7 days. We derived Euclidean Norm Minus One g (ENMO), Low-pass filtered ENMO (LFENMO), Mean Amplitude Deviation (MAD) and ActiGraph activity counts over 5-second epochs from the raw accelerations. Metric values were compared using correlation-analysis, and by plotting the differences by time of the day. Cut-points for the dominant wrist were derived using Lin's concordance correlation coefficient optimization in a grid of possible thresholds, using the non-dominant wrist estimates as reference. They were cross-validated in a separate sample (N=36, 10 women, 22-30 years). Shared variances between pairs of acceleration metrics varied across sites and metric-pairs (range in r2: 0.19-0.97, all p<0.01), suggesting that some sites and metrics are associated and others are not. We observed systematically higher metric values in dominant vs. non-dominant wrist, thus, we developed cut-points for dominant wrist based on ENMO to classify sedentary time (<50 mg), light PA (50-110 mg), moderate PA (110-440 mg) and vigorous PA (≥440 mg). Our findings suggest systematic differences between dominant and non-dominant wrist (Figure 1), which could be attenuated by applying the correction factor provided. Furthermore, ENMO and LFENMO were the metrics that compared the best, and to some extent, they also showed good comparability with MAD. However, counts were less comparable to the previously-mentioned metrics.

### O.8.2 Consistency of thigh-worn accelerometry data across ActiGraph Gt3x+, Axivity Ax3, and ActivPAL Micro4 devices using the Acti4 software

*Emmanuel Stamatakis[1], Jørgen Skotte[2], Mette Aadahl[3], Mark Hamer[4], Matthew Stevens[2], Vegar Rangul[5], Paul Mork[5], Andreas Holtermann[2]*

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Introduction Generating and pooling accelerometry data to concurrently quantify physical activity types, volume, time patterns, and body postures is the next generation of evidence on physical activity and health. A single thigh-worn accelerometer is sufficient for collecting this data. However, different studies use a variety of accelerometer devices, often containing different features and software analysis packages, which hinder data pooling efforts. A single analysis package capable of processing data from multiple sources could provide a solution to this problem. Our aim was to test the Acti4 software for processing acceleration data from three of the main accelerometer brands - ActiGraph G3tx+, Axivity AX3, and ActivPAL Micro4. Method We recruited 26 healthy participants who wear the accelerometers 24 hours a day for 7 days. The three accelerometers were placed in a vertical line on the midsection of the thigh. Raw accelerometry data was processed into 8 physical activity types using the Acti4 software. Results Absolute difference and coefficient of variation (CV) were calculated in minutes (mins) for 19 participants. When averaged over 24 hours, the mean absolute difference (CV) between devices were: 1.2 mins (0.001) for lying/sitting, 3.4 mins (0.02) for standing, 3.5 mins (0.06) for moving, 1.9 mins (0.03) for walking, 0.1 mins (0.19) for running, 1.2 mins (0.19) for stair walking, 1.9 mins (0.07) for cycling. Moreover there was an average absolute difference of 282 steps (0.03) over 24 hours. Conclusions Acti4 software can calculate posture, movement, and activity type data from thigh mounted accelerometers with marked consistency, even using accelerometers from different manufacturers. These results encourage the development of consortia to pool data from different accelerometer.

### O.8.3 Automatic estimation of step asymmetry in a split-belt treadmill experiment using high-resolution accelerometry data

*Ryan Roemmich¹, Ciprian Crainiceanu², Amy Bastian¹, Jacek Urbanek²*

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Precise estimation of gait characteristics has significant potential in health research and can help guide clinical decision making. Reproducible estimation of walking strides can provide useful, precise, and time-varying estimators of the number of steps, cadence, stride and step asymmetry. We propose a novel stride segmentation approach and quantify its effectiveness in the estimation of gait and gait asymmetry. The method consists of a first phase, where a flexible pattern matching approach, called ADaptive Empirical Pattern Transformation (ADEPT), is used to conduct stride segmentation. A parametric nonlinear transformation of time is then used to characterize the level of asymmetry in strides relative to a reference template. The advantage of the approach is that its second phase allows quantification of walking asymmetry in one parameter that is directly related to the speeding and slowing down of one of the treadmill belts, thus providing a mechanistic interpretation of the process. Methods are applied to data collected in an experiment where a healthy adult walked on a split-belt treadmill under different conditions, including gait speed of 1.0, 1.25, 1.56 and 2.0 m/s as well as right foot ahead of left and left foot ahead of right (total N=671 walking strides.) Accelerometry data were collected at 100 Hz simultaneously by three wearable sensors located on the left wrist, left hip and left ankle. The Optotrak motion capture system provided the gold-standard reference for gait characteristics. Results indicate that: (1) the time-warped version of ADEPT estimates of stride cadence agree closely with the gold-standard (mean absolute percentage error was 1.67%, 1.7%, and 4.34% for left ankle, left hip, and left wrist, respectively); (2) the time-warping parameter is highly correlated with the known, imposed stride-asymmetry. Results suggest that the one-parameter characterization of time-warping is a useful and accurate representation of stride asymmetry.

### O.8.4 Accuracy of processing methods and sensors differs by activity domain in free-living environments.

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Objective: Different procedures (i.e., wearable sensors, attachment sites, and processing methods) produce disparate estimates of time spent in moderate-vigorous physical activity (MVPA). The purpose of this study was to compare MVPA from video-recorded direct observation (DO) to estimates from different procedures across five activity domains. Methods: Twenty-six adults (16F and 10M; age 18-57y) each participated in two, 2-hr DO sessions that were categorized by activity domains; household (H, N=10), active leisure (AL, N=12), sedentary leisure (SL, N=10), work (W, N=10), and transportation/errands (TE, N=10). Sessions took place in the participant's natural environment while they wore an activPAL (AP), and ActiGraph (AG) on the hip and wrist. To estimate MVPA, the following processing methods were used: AG-hip, Sojourn 3-axis (S3x), 1-axis (S1x), Crouter (C2), and several cut-points (e.g., Freedson [F], Sasaki [VM]); AG-wrist, random forest (RF). We used equivalency testing to compare each of the methods to the criterion at a level of 10%. Within each domain, we computed mean average percent error. Results: Overall, participants spent (mean [SD]) 20.2 (26.2) min in MVPA. The S3x, S1x, and AP were statistically equivalent to DO, while wrist-RF and C2 significantly overestimated MVPA and the cut-point methods underestimated MVPA. Across domains, C2 and RF consistently overestimated MVPA, F consistently underestimated, VM both over and underestimated. Percent errors varied across methods within the same domain (e.g., AL ranged from -11 to 8%, TE from -63 to 34%, H from -76 to >200%, and W from -36 to >200%). Conclusion: Three methods produced statistically equivalent estimates of MVPA compared to a criterion of DO. The magnitude of errors varied dramatically across domains, both within and between monitors, highlighting the importance of using representative activities in validation studies.

### O.8.5    Determination of device orientation, wrist of wear and hand dominance using raw accelerometer data

*Alexander Montoye[1], Charles Sweetland[2], Melitta McNarry[3], Kelly Mackintosh[3]*

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Various factors are critical to the accurate analysis of wrist-worn accelerometer data, yet no standards regarding device orientation, arm of wear and hand dominance currently exist. Indeed, large population level studies such as the UK Biobank and NHANES differ in the use of the dominant or non-dominant wrist, leading to considerable differences in acceleration metrics derived. Therefore, the aim of this study was to develop analytical methods to determine i) wrist-worn accelerometer orientation, ii) side of the body (left vs. right) of accelerometer wear, and; iii) hand dominance of the wrist on which the accelerometer was worn from free-living accelerometer data. Forty-one participants wore a GENEActiv on both wrists for seven consecutive days and completed an Edinburgh Handedness Inventory survey, providing information about hand dominance. Subsequently, the raw acceleration data were calibrated with valid days identified and analysed in 1s epochs. The distribution of accelerations for each axis with respect to the wrist were analysed to determine accelerometer orientation and hand dominance. Furthermore, an analysis of system constraints provided a deductive approach for assessing side of wear. Accuracy of the analytic methods was determined by comparing the known orientation, wrist of wear and hand dominance with the predictions from the acceleration data alone. The results indicate that orientation could be accurately assessed for 90% of the weeks of wear and, where the orientation was correct, the side of wear was 100% accurate. The dominance estimation achieved an accuracy score of 70%. The analytical methods developed in this study for device orientation and side of wear provide a viable route for harmonising data arising from studies with different wear protocols; further validation is required on larger data sets. The determination of dominance remains more limited, but the proposed methods will enable further improvements in future research.

## Oral Session 9 – Validations

### O.9.1    Comparing a short physical activity questionnaire with accelerometer measures as criterion validity: The Tromsø Study

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*[1]Norwegian School of Sport Sciences, [2]UiT the Arctic University of Norway, [3]University of Cambrigde*

Objective: To assess the criterion validity of self-reported physical activity (PA) against accelerometer-measured PA. Methods: 5902 women and men aged 40-84 years completed a questionnaire on PA frequency (never, <1, 1, 2-

3 or >5 times per week), intensity (no sweating (3METs), sweating (6METs), to exhaustion (9METs)), and duration (<15min, 15-29min, 30-60min, >1hour) as an indication of their habitual PA level, and wore an ActiGraph wGT3X-BT accelerometer (ACC) for seven consecutive days. We calculated MET-hours per week from the questionnaire, which was compared (Pearson Correlation) with two volume measures from the ACC; steps per day and mean vector magnitude counts per minute (VM CPM) per day, and two intensity measures; accumulated moderate and vigorous physical activity (MVPA) per day and MVPA accumulated in bouts of at least 10 minutes per day. The cut-point for MVPA was set to >2690 VM CPM. Results: MET-hours per week correlated with steps (r=0.43), VM CPM (r=0.43), MVPA (r=0.39) and bouted MVPA (r=0.44) (all p<0.01), which was consistent across sex (women: n=3173, r=.035-46, p<0.01, men: n=2728, r=0.33-43, p<0.01). The sensitivity of the questionnaire to correctly classify participants to fulfil the World Health Organization (WHO)´s recommended level of PA (reporting ≥7.5 MET-hours·week-1) according to the ACC estimate (≥22 minutes MVPA per day in at least 10-minute bouts) were 83.3% (n=1085), where 16.7% (n=218) underestimated their PA level. The specificity of the questionnaire to correctly classify participants as not fulfilling the WHO´s recommendations were 54.6% (n=2513), where 45.4% (n=2086) overestimated their PA level. Conclusion: Self-reported PA frequency, intensity and duration calculated as MET-hours per week were associated with both volume and intensity measures from the ActiGraph wGT3X-BT ACC. Thus, the short PA questionnaire appears to be able to rank individuals according to their PA level.

## O.9.2    Validation of the VitaBit Sit-Stand Tracker: Detecting sitting, standing, and activity patterns

*Gill ten Hoor[1], Guy Plasqui[1]*

*[1]Maastricht University*

Prolonged sitting in the workplace is a risk factor for non-communicable diseases and psychological malfunctioning and should be minimized. In order to understand and reduce sitting, we developed and validated a tool to measure and monitor sedentary behavior: the VitaBit Sit-Stand tracker. We invited participants to the laboratory and compared the output of the VitaBit device with direct observations. Thereby, the participants performed several predetermined activities such as sitting, standing or walking at different paces. Additionally, the device was challenged by slower sit-stand transitions and tight transition times. In a free-living condition, we compared the VitaBit output to a current best-practice device, the ActiGraph, based on both minute-by-minute comparisons and overall daily activity. We calculated sensitivity, specificity, positive, and negative predictive rates. Compared to direct observation, the VitaBit monitor correctly detected activity for 97.3%, while sitting and standing were correctly detected for 74.6% to 85.7%. In a free living setting, the activity distributions of the VitaBit corresponded with the ActiGraph (57.4% vs. 57.5% for sitting, 31.1% vs. 27.5% for standing, 11.5% vs. 15.0% for walking). The minute-by-minute comparisons with the ActiGraph as criterion measurement revealed lower results from 66.0% (sensitivity walking) to 81.5% (sensitivity sitting), which was lower than expected from a sub-study (71.4% - 96.9%). According to the laboratory findings, high performance for sitting, standing, and walking makes the VitaBit eligible for sedentary behavior monitoring. However, daily life activities (such as car driving and cycling) still need to be validated in the future.

## O.9.3    Time2Move: changing the way we assess sleep, physical activity and sedentary behaviour in children

*Kim Meredith-Jones[1], Barbara Galland[1], Anna Graham-DeMello[1], Jill Haszard[1], Tom Stewart[2], Lisa Mackay[2], Jono Neville[3], Scott Duncan[3]*

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Objectives: Researchers are now recognising the importance of considering all movement behaviours across the full 24-hour day. Currently, few devices adequately measure all behaviours of interest - namely sleep, physical activity, and sedentary time. Existing algorithms are typically device- and placement-specific, limiting comparisons across datasets. These algorithms also have limited external validation, either not being tested against polysomnography (PSG) - the gold standard for assessing sleep - or with validation of movement/posture restricted to laboratory settings, limiting their real-world applicability. In this talk, we will outline methods involved in a large New Zealand study aiming to develop new algorithms using pattern recognition for the accurate assessment of sleep, physical activity and sedentary time in children. Methods: 160 healthy children aged 8-16 years will wear

three AxivityAX3 accelerometers (wrist, lower back, mid-thigh), two Actigraph wGT3X-BT accelerometers (wrist, waist), and a heart rate monitor (Polar H10) for 48 hours. Criterion measures of sleep will be obtained using portable PSG in the home over one night. Criterion measures of physical activity and sedentary behaviour will be obtained during a laboratory session where children participate in 8 different activities ranging in intensity from sedentary to vigorous. Chest-worn GoPro videos will be collected during four 2-hour time frames over the course of two days (i.e. during school time, and in the evening) as criterion measures in the free-living environment. Children will be randomised and stratified by age and sex to development and test samples. Algorithms will be developed using machine learning and cross-validation techniques. Conclusion: We aim to develop user-friendly, open source software for researchers to accurately measure 24-hour movement patterns, regardless of device and site of placement, that more closely represent real-world activity patterns.

### O.9.4 Validity of a sleep/non-wear algorithm designed for 24-hour wear when applied in a cohort of Swedish older adults wearing the activPAL3TM in a daytime wear protocol

*Ing-Mari Dohrn[1], Paul Gardiner[2], Charlotte Edwardson[3], Bronwyn Clark[4], Anna-Karin Welmer[1]*

*[1]Karolinska Institutet, [2]Centre for Health Services Research, [3]University of Leicester, [4]The University of Queensland*

Objectives: As large-scale studies increasingly incorporate devices to measure physical activity and sedentary behaviour, accurate, low-burden data processing methods are needed, including to isolate waking wear time from sleep and non-wear. This study tested the validity of a freely available sleep/non-wear algorithm (previously designed and validated for 24-hour wear protocols) among older adults who wore the activPAL during waking hours only. Methods: Participants were 591 adults aged ≥66 years (64% women) from the population-based Swedish National Study on Aging and Care in Kungsholmen, Stockholm with available activPAL data, collected February 2016 to October 2018 via 7-day, daytime wear protocol. Automated classifications were obtained using the algorithm, with thresholds chosen to suit older adults. These were compared against the referent method (monitor-adjusted diary-recorded on-off times) for minute by minute agreement in waking wear classification (yes/no) via kappa (K) and for agreement in average daily waking wear time (mean difference, 95% Limits of Agreement [LoA], and absolute percent error [APE]). Analyses used the 3677 days valid by both methods (≥500 steps, ≥10 h waking wear, <95% of time in one activity). Results: Agreement in the classification of each minute as waking wear or not was excellent, with median [25th, 75th percentile] K = 0.96 [0.93, 0.98] and 'almost perfect' agreement (K >0.8) seen in 98% of individuals (n=580). The two methods had high correlation and good agreement in average daily waking wear time (r=0.86; mean difference =-14.7, 95% LoA -86.2, 56.8 min; mean ± SD APE = 2.9 ± 3.5). Both methods yielded similar values of physical activity and sedentary measures. Conclusions: An automated estimation algorithm designed for 24-hour wear protocols performed acceptably among Swedish older adults in a daytime wear protocol. Performance was similar or better to the initial validation in Australians aged 36-89 years.

### O.9.5 Validating estimates of sedentary time across multiple domains

*Mami Takeda[1], Rachel Barnett[2], Scott Strath[3], Sarah Keadle[1]*

*[1]California Polytechnic State University San Luis Obispo, [2]California Polytechnic State University, [3]University of Wisconsin-Milwaukee*

Purpose: To assess the accuracy of Actigraph (AG) and activPAL (AP) in classifying sedentary time (ST) across multiple activity domains using free-living video-recorded direct observation (DO) as the criterion measure. Methods: Participants (n=26; 16F and 10M; age 18-57y) wore an AP monitor (mid-thigh) and an AG monitor (right hip and non-dominant wrist) for two, 2-hour DO sessions. Sessions were categorized into five activity domains: work (W; n=8), household (H; n=8), errands/transportation (ET; n=7), sedentary leisure (SL; n=8), and active leisure (AL; n=11). The criterion measure was time spent sitting/lying based on video-recorded DO. AG-hip data were processed using Sojourn 3x (S3x), Sojourn 1x (S1x), refined Crouter two-regression (C2), 100 cpm vertical-axis and 200-vector magnitude cpm cut-points. A random forest method (RF) was used to process AG-wrist data. The two one-sided tests (TOST) method was used to test the equivalency between method estimates and DO at a 10% level, overall and within domains. The root mean squared error (RMSE) and mean average percent error (MAPE) were calculated. Results: Overall, an average of 54.8 (SD: 39.5) minutes of ST was measured from the criterion. AP

estimates were statistically equivalent to DO measures overall and in all domains except H. S3x was statistically equivalent to DO in the SL domain only. For the AG methods, accuracy varied by domain and processing method. The W domain had the highest RMSE (25-43.7 min). MAPE show the S1x (-19.2%) and 100 cpm (-21.5%) methods overestimated while the C2 (12.3%) and RF (13.8%) underestimated ST. All AG methods overestimated ST (-18.6%-102%) in the H domain. Conclusion: AP estimates were the most accurate compared to DO. Longer standing bouts common in the W and H domains may affect the accuracy of AG methods to classify ST. Differences in monitor estimates within and between domains highlight the importance of using a wide range of activities in validation studies.

# Thursday, June 27th: Day 3

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**Oral Session 10 – Special Populations - Children**

### O.10.1 Objectively measured physical activity patterns in overweight and obese children; baseline data of a multidisciplinary tailored intervention program

*Anita Vreugdenhil[1], Guy Plasqui[2], Elke Dorenbos[1]*

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INTRODUCTION - International guidelines recommend that children spend a minimum of 60 minutes each day in moderate- to vigorous physical activity (PA). Fifty-two % of the Dutch children do not reach this recommendation. This study reports the baseline PA data of children participating in a multidisciplinary tailored intervention program. METHODE - In total 157 children with overweight and (morbid) obesity (53.5% girls, 12±3y of age, BMI z-score +3.10 ±0.70), who were referred to the Centre for Overweight Adolescents and Children's Healthcare (COACH, Maastricht UMC+) were included. BMI of children was used to classify their weight status as overweight, obese and morbid obese. PA behavior was measured with the GT3X Actigraph accelerometer. Subjects were asked to wear the accelerometer for 7 days. Minimum wear time was defined as 480 min/day for at least 4 days. The cut off points of Evenson et al. were used to classify PA into intensities. RESULTS - Gender and age were equally distributed between the three BMI classes. There was no significant difference between the different intensities of PA between children with overweight, obesity or morbid obesity. Overall, children performed on average 40±18 min/day of moderate to vigorous intensity PA. They spent 608±139 min/day on sedentary behavior and 217±62 min/day on light intensity PA. Girls were significantly less moderate to vigorous physically active compared to boys (-13±3min/day, p<0.01). Fifteen % off the children met the PA guideline (26% boys and 5% girls (p<0.01)). CONCLUSION - Eighty-five % of the children with overweight and obesity did not meet the recommended PA per day. This study emphasizes the importance of PA promotion on moderate to vigorous intensity as part of lifestyle intervention for children with overweight and obesity, especially for girls. Follow up results of PA of children participating in the COACH program will be evaluated to determine the effect of lifestyle intervention

### O.10.2 MOVI-daFIT! Baseline: Physical Activity and Lipid Profile among children 9-11 years old

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Introduction: Evidence shows that adults who performed vigorous physical activity (PA) had better Lipid Profile (LP) and higher high-density lipoprotein cholesterol (cHDL) than sedentary subjects, this could be a protective factor for coronary heart disease. Otherwise, sedentary behaviour is related with higher tryglicerides values. Moreover, high cholesterol's levels during childhood have been associated with higher levels on adults. Therefore, it would be worthwhile to study the relation between PA and LP on children. Objective: To determine the relation between LP

and PA on children 9-11 years old by gender classification. Methods: A cross-sectional analysis of baseline date from MOVI-daFIT! study was performed. A sample of 252 children of ten schools from Cuenca province, Spain, were evaluated at September 2017. PA was objectively measured using GENEActive accelerometers (ActivInsights) for seven consecutive days (including nights). We considered as valid measurements those of at least five days, including one weekend day. Conversely, cholesterol, tryglicerides, cHDL and low-density lipoprotein cholesterol (cLDL) measurements were performed using Cobas 8000 Roche Diagnostics system. Results: In boys, we found positive significant correlations between sedentary activity and cholesterol (r=0.255), cLDL (r=0.191); and negative correlations between moderate PA, sum of moderate-vigorous PA and cholesterol (r=-0.247; r=-0.252), cLDL (r=0.196; r=-0.211), respectively. In girls, we found negative significant correlation between light PA and cHDL (r=-0.227); possitive significant correlations between light PA and triglycerides (r=0.195) and between vigorous PA and cHDL (r=0.244). Conclusions: The amount of PA behaves differently in LP on children by gender classification. Sedentary behaviour in boys is positive correlated with cLDL. Otherwise, vigorous PA is positive correlated with cHDL in girls.

### O.10.3 Comparison of WHO guideline adherence in self-reported vs. accelerometer-measured physical activity among German children and adolescents

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Introduction: When obtaining a comprehensive picture of physical activity (PA), there are considerable limitations in both subjective (e.g. recall bias) and objective methods (e.g. reactivity). To expand the current knowledge on PA assessment the Motorik-Modul-Study assessed both. Objectives: The purpose of the present study was to compare adherence to the WHO guidelines among a representative sample of German children and adolescents measured by accelerometer and by self-report questionnaire. Methods: Participants aged 6-17 were randomly chosen and data was collected at 167 sample points throughout Germany. PA of n=2694 participants (52.3% woman) was measured via ActiGraph accelerometer (ACC)[1] & physical-activity-questionnaire (PAQ)[2]. The sample was divided into three age groups (6-10 yrs. n=788, 11-13 yrs. n=823, 14-17 yrs. n=1083). Number of days per week with at least 60 min moderate to vigorous PA were analyzed for both methods with repeated measurements ANOVA ($\alpha$=0.05). Results: PA guideline adherence by ACC is significantly lower than by PAQ (mean=2.03d (ACC)/3.86d (PAQ); Fmethod=1650.7; $\eta^2$=.38; p<.01). Age and sex show effects on PA in both methods (Fage=286.5, $\eta^2$age=.18; Fsex=117.2, $\eta^2$sex=.04; both p&.01). PAQ and ACC show consistent results that especially the 6-10 year olds adhere the WHO guidelines significantly more often (23.2% PAQ, 7.2% ACC, p&.01) compared to 14-17 year olds (7.5% PAQ, 0.2% ACC; comp. table). 15.3%(PAQ)/4.4%(ACC) of the boys achieved the WHO norm on every day within a week. Girls significantly less.(10.2% PAQ /0.9% ACC, p&.01). Conclusion: Compared to ACC the PAQ overestimates PA. However, significant age and gender differences can be found within both methods. Combination of both procedures gives a more comprehensive view on PA and should be used simultaneously. [1]Anedda et al. (2017) DOI:10.13140/RG.2.2.24691.63528 [2]Jekauc et al. (2013) DOI: 10.1026/0012-1924/a000083

### O.10.4 Evaluation of laboratory-based and free-living algorithms for energy expenditure estimation in preschool children under free-living conditions

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Machine learning (ML) models have traditionally been trained on accelerometer data from laboratory-based activity trials. However, performance is typically attenuated when implemented in free-living samples. It is hypothesized that accuracy can be improved if models are trained on free-living data. To our knowledge, no studies involving preschool children have compared energy expenditure (EE) prediction models trained on laboratory (LAB) and free-living (FL) data using indirect calorimetry as the criterion measure. Purpose: To compare the performance of LAB and FL EE prediction models in free-living preschool children completing an active play session. Methods: LAB EE prediction models were trained on hip and wrist accelerometer data from 19 children (4.9 ± 0.8 y) performing 12 activity trials. 81 models were trained and evaluated by varying feature selection

algorithm, number of features selected, and supervised learning algorithm. Performance (RMSE) was evaluated using LOSOCV. For the FL evaluation, 25 children (4.1 ± 1.0 y) completed a 30-min active play session. FL EE prediction models were trained and cross-validated using data from 12 children, while the remaining 13 children served as a hold-out sample for comparison of the LAB and FL models (paired t-tests). Results: The best performing LAB model for the wrist and hip were SVM (MRMR feature selection, 15 features, RMSE = 0.64 kcal/min) and ANN (MRMR feature selection, 10 features, RMSE =0.60 kcal/min), respectively. Cross-validation accuracy of the FL models (same features and supervised learning algorithms as LAB) was 0.83 kcal/min for both hip and wrist. In the hold out sample, RMSE for the FL models were significantly lower than the LAB models (p <.01) (wrist: 0.77 ± 0.08 vs. 0.90 ± 0.05 kcal/min; hip: 0.77 ± 0.07 vs. 0.86 ± 0.05 kcal/min). Conclusion: ML models for prediction of EE perform better in the field when trained on free-living data. Funding: ARC Discovery Grant: DP150100116

### O.10.5 Longitudinal effects of physical activity patterns on adiposity and fitness from preschool to school-age

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Aim: Both greater frequency and longer duration of moderate-to-vigorous physical activity (MVPA) bouts are favourably associated with aerobic fitness and adiposity in school-age children. However, how MVPA is accumulated and its association with health indicators across early childhood is less understood. The aims of this study were to 1) examine longitudinal changes in MVPA accumulation from preschool to school-age and 2) determine if MVPA bout frequency and/or duration is associated with longitudinal changes in body fat percentage (BF%) and cardiorespiratory fitness (CRF). Methods: Children (3-5 years-old, n=418) completed 3 annual assessments as part of the Health Outcomes and Physical activity in Preschoolers (HOPP) Study. Physical activity was measured over 7-days using ActiGraph accelerometers and analyzed in 3-second epochs using Pate cut-points to determine average bout duration (s) and frequency (bouts/hour) of MVPA. BF% was measured using bioelectric impedance analysis and CRF was assessed by time to exhaustion on a progressive treadmill test. Mixed effects modeling was used to examine how 1) patterns of MVPA accumulation changed over time, and 2) if overall patterns of MVPA accumulation were associated with changes in BF% and CRF. Results: Average bout duration increased over time (Est=0.23, p<.001), whereas the frequency of bouts/hour decreased (Est=-0.79, p=.01). Favourable overall main effects for bout frequency and duration were found for both BF% (Est=-0.02, p=.02; Est=-0.23, p=.03) and CRF (Est=0.01, p=.03; Est=0.18, p<.001). Neither bout frequency nor duration had an effect on the rates of change in CRF, however children who engaged in more frequent MVPA bouts had the steepest decline in BF% (Est=-0.02, p<.05). Conclusions: Frequency of MVPA bouts declines from preschool to school age. As greater bout frequency is associated with reductions in BF%, providing young children more frequent opportunities to be active should be encouraged.

## Oral Session 11 – 24-Hour Activity Cycle (1)

### O.11.1 Levels of physical activity, sedentary behavior and sleep among Finnish adults measured 24/7 by a tri-axial accelerometer

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Background: Several population-based studies have measured physical activity (PA) and sedentary behavior (SB) with device-based measurements. However, only few studies have used the devices collecting data in raw mode 24/7 to cover activity pattern of the whole day. The purpose of the present study was to describe PA, SB and sleep of Finnish adults using 24/7accelerometer measurements. Methods: The study is based on the FinFit2017 - population-based study where PA, SB and sleep of 20-69-year-old Finns was measured by a tri-axial accelerometer (n=1785, mean age 49.4 years, SD=13.5) for 7 consecutive days. During waking hours, the accelerometer was worn on an elastic waist-band on the right side of the hip. When measuring sleep, the device was removed to a wristband worn on the non-dominant hand. PA-parameters were based on mean amplitude deviation (MAD) of

acceleration analyzed in 1min exponential moving average (epoch length 6s). SB (sitting and reclining) and standing were based on the angle for posture estimation. Sleep measurement was based on the movement of a non-dominant wrist. Parameters analyzed were total daily times of SB, standing, light PA, moderate-to-vigorous PA (MVPA), sleep and mean number of daily steps. Results: Participants (59% women) wore the device on the wristband slightly over 8h/d, but they slept on average slightly under 7h. The device was worn on the waistband nearly 16h/d. Participants spent most of their waking hours sedentary (9h 18min/d) and standing covered nearly 2h/d. Participants spent over 3.5h/d in light PA and less than one hour in MVPA. Participants took on average 7377 steps per day. Men were on average more active than women. The most active hours of men were at noon and those of women at noon and at early evening. Discussion: Measuring and analyzing PA, SB and sleep 24/7 helps to draw the whole picture of these patterns. This will be useful in identifying the most potential moments of the day to increase PA and decrease SB.

## O.11.2  Calibration of self-reported physical behaviours among office workers: A compositional data analysis

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The aim of this study was to develop and evaluate calibration models to predict objectively measured time spent sitting, standing and walking during office work from self-reported time-use compositions using a compositional data analysis (CoDA) approach. Ninety-nine office workers (49 women) at the Swedish Transport Administration participated in an intervention study on relocation to activity-based offices. At baseline and at a 3-months follow-up, physical behaviours (sitting, standing and walking) at work were assessed for five days using a thigh-mounted accelerometer (Actigraph) and by self-report (IPAQ). The time-use composition of the three behaviours was expressed in terms of isometric log-ratios (ILR). Calibration models predicting accelerometry-based time-use from self-reported compositions were constructed using linear regression on baseline data, and then validated using follow-up data. The accelerometer data showed that, on average, workers spent 69.9% of their day sitting, 23.7% standing, and 6.4% walking. The corresponding percentages for self-reports were 71.7%, 21.6%, and 7.4%, respectively. Non-calibrated self-reports were biased: the RMS errors obtained from the ILRs expressing sitting, standing and walking were 0.73, 1.09 and 1.05, respectively. Calibration models reduced these errors by 45% (sitting), 56% (standing), and 76% (walking). Validation of the calibration models using follow-up data from the same workers showed calibration remained equally effective; RMS errors were reduced by 55% (sitting), 58% (standing), and 75% (walking). In conclusion, calibration models for compositional time-use data were effective in reducing bias in self-reported physical behaviours at work, and the models remained effective when used on new data from the same workers. Calibrated self-reports may represent a cost-effective method for obtaining physical behaviour data with a satisfying accuracy in large-scale cohort and intervention studies.

## O.11.3  Daily activity levels of undergraduate first-year students: An observational study

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There has been increasing awareness of the detrimental effects of excessive sedentary behavior on physical health. Current guidelines on what constitutes as excessive is still vague, although governmental bodies across the world recommend no more than 20-120 minutes of sitting at a time, with an overall goal of minimizing sedentary behavior (Jochem, Schmid, & Leitzmann, 2018). With educational activities generally scheduled for 60-120 minutes per session, university programs are a contributing factor to the amount of sedentary behavior carried out by the students. Therefore, the aim of the current study is to have a clear understanding of the current activity levels of first-year undergraduate students. 317 First-year undergraduate students of Maastricht University wore the activPAL3? triaxial physical activity logger for seven consecutive days. Time spent in sleep and sedentary activity was recorded. Times spent in low (LPA) and moderate-to-vigorous intensity physical activity (MVPA) were calculated based on the participants' step cadence. On average, participants did meet the World Health Organization's recommendation of 150 minutes of MVPA per week. Nonetheless, 66.1% (9.8 hours/day) of their waking time was spent in sedentary behavior. Furthermore, we found that time spent in sedentary behavior had a

significant negative relationship with LPA, but was not significantly correlated to MVPA. From this finding we conclude that, in order to reduce sitting time, it will be more effective to promote LPA than to stimulate students to participate in exercise-like MVPA. Presently, we advocate for universities to consider interrupting long periods of sedentary behavior with LPA, for example by standing for 5 minutes after 30 minutes of sitting in lectures (Rutten, Savelberg, Biddle, & Kremers, 2013).

## O.11.4  Physical-behavior profiles and aerobic capacity: A latent profile analysis of 24-hour time-use composition among Danish workers

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Introduction Obtaining a balance between exercise and recovery is an established approach in Exercise Science to improve aerobic capacity. However, it is unknown how different 24-h time-use profiles depicting a balance between physical behaviors (i.e. physical activities, sedentary behavior and sleep) across main domains of the day are associated with aerobic capacity. We aimed to identify such 'physical-behavior (PB) profiles' and to investigate their association with aerobic capacity. Methods Workers (n=807) participated in thigh-accelerometry to determine 24-h time-use composition of physical activity, sedentary and standing during work and leisure, as well as time in bed. Åstrand submaximal cycle ergometer test was used to estimate aerobic capacity. The PB profiles were determined using latent profile analysis of isometric log-ratios representing the 24-hour composition. Linear models were applied to determine the cross-sectional association between physical-behavior profiles and aerobic capacity. Results Four PB profiles were identified that were labeled based on animal traits; Chimpanzees (n=226), Lions (n=179), Ants (n=244), and Koalas (n=158). Compared to Chimpanzees (at work, in mins; sedentary=197, standing=145, physical activity=117; and at leisure in mins; physical activity=114, standing=121, time in bed= 440); Lions were more active at work, sedentary at leisure and spent more time in bed; Ants had more physical activity at work and similar physical activity and time in bed at leisure; Koalas were more sedentary at work and leisure and spent more time in bed. Compared to Chimpanzees, Koalas had lower aerobic capacity (mlO2/kg/min): -3.7 (95%CI -6.0,-1.5), followed by Lions -3.6 (-5.5,-1.7) and Ants -1.8 (-3.7,- 0.1). Conclusions Physical-behavior profiles based on 24-h time-use composition are associated with aerobic capacity. Obtaining a balance between physical behaviors at work and leisure may be a promising approach for improving aerobic capacity.

## O.11.5  Estimated effects of replacing sedentary time with walking on risk factors for coronary heart disease and stroke: a cross-sectional compositional data analysis of accelerometer data from the Copenhagen City Heart Study

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Objective: The objective of this study was to investigate the effect of replacing time spent sedentary with time spent walking (overall and with different cadences) on risk factors for coronary heart disease and stroke using a compositional data analysis approach. Methods: In the fifth examination of the Copenhagen City Heart Study, participants' (≥20 years) daily physical behaviours were measured 24-hours per day for seven days using accelerometers (skin-attached; right thigh and iliac crest). Time spent sedentary, standing, moving, walking (overall; slow [<100 steps/min] and fast [≥100 steps/min]), climbing stairs (up/down), running/cycling, and time in bed was derived using the Acti4 software, and described using compositional geometric means and a variation matrix. The outcomes were systolic blood pressure (SBP), waist circumference (WC) and low-density lipoprotein cholesterol (LDL-C). We will investigate the effects of replacing time spent sedentary with time spent walking on these outcomes using iso-temporal substitution models. Results: Among the 1670 included participants (inclusion criteria: ≥5 days with ≥16 h of daily accelerometer measurements), the compositional geometric mean time spent sedentary, standing, moving, walking (overall), climbing stairs, running/cycling, and time in bed was 594, 187, 71,

78, 4, 2, and 505 min/24-hour day, respectively. Overall, 41% had a SBP ≥140 mmHg; 55% women and 48% men had a WC >80 cm and >94 cm, respectively; and 50% had an LDL-C level ≥3 mmol/L, reflecting an increased risk of coronary heart disease and stroke. Results of the iso-temporal substitution models are in progress. Conclusions: Knowledge about the effect of replacing sedentary time with overall walking and walking with different cadences on risk factors for coronary heart disease and stroke may inform public health initiatives and recommendations for cardiovascular disease prevention.

## Oral Session 12 – Research Technologies

### O.12.1  Evidence of the respiratory magnetometer plethysmography for the estimation of minute ventilation during low to moderate intensities.

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Background Estimation of minute ventilation (VE) from dimensional changes of the rib cage and abdomen is useful to assess the performance of the respiratory system during daily life and physical activities (PA). Respiratory magnetometer plethysmography (RMP) is one of the devices that have been validated for this purpose by Gastinger et al (2010) during rest and walking conditions. The purpose of our study is to improve the accuracy of RMP to estimate VE during different types of exercises. Methods Thirteen subjects (mean ± SD; age 24.1 ± 3.4 year, BMI 22.21 ± 2.32 kg/m2) performed 13 activities ranging from sedentary to PA of moderate intensity (Walking 4 and 6 km/h, course 9 and 12km/h, biking 90 and 110W). A Nomics RMP device was worn by each subject during experiments. An iWorx spirometer was used to measure VE which was calculated for each segment that consists of 5 respiratory cycles. Features of the RMP data (interpercentil, dominant frequency) were extracted from each window and used as inputs of the VE prediction models. An artificial neural network (ANN) was used as a prediction model. Model was developed using two approaches: subject specific approach (model 1) and subject independent approach (model 2). ANN was compared to the RML model used by Gastinger et al (2010). Model accuracy was determined using root mean square error (RMSE) and bias. Results For each activity, the bias and RMSE were significantly higher ($p<0.05$) for model 2 (bias range 0.36-4.78 l/min, RMSE range 0.85-2.85 l/min) than for model 1 (bias range 0.03-0.78 l/min, RMSE range 1.6-7.87 l/min) and RML model (bias range 0.73-3.89 l/min, RMSE range 2.73 - 5.19 l/min). Then, ANN improve the accuracy of RMP to estimate VE during sedentary and PA of moderate intensity. However, an individual calibration is necessary for the best estimation of VE. Future works would be to incorporate the RMP into a jacket to estimate energy expenditure (EE) in real time and during free living conditions.

### O.12.2  Assessing physical activity using floor vibrations in a smart home setting

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*[1]Ochanomizu University*

Background: Despite the development of advanced monitoring devices embedding ever more efficient algorithms, performing accurate and robust predictions of the daily physical activity remains a challenging task. In the present study, the physical activity related to housework has been assessed using a floor vibration-assisted smart-home system. Method: The OchaHouse is an independent experimental house (~50m2) located in Tokyo. High sensitivity accelerometers have been installed on the floor to monitor the vibrations related to human activity. A data processing algorithm has been designed to estimate the number of steps and calculate the "ocha-count" parameter, i.e. an original unit of measure reflecting the volume of activity performed in the house. Ten subjects performed 4 activities of the compendium of physical activities (sitting and watching TV [1.3 MET], ironing and folding clothes [1.8-2.0 METs], cooking [2.5 METs], cleaning the room [3.5 METs]) for 5 min each in the OchaHouse while wearing an Actigraph GT9X on both the waist and the wrist. Results: A good agreement has been noted between the waist-worn GT9X and the OchaHouse (-1±29 steps) for the estimated number of steps. The analysis of variance and pairwise comparisons conducted on the ocha-count data shows significant differences between the 4 activities (sitting, etc.: 72±14, ironing, etc.: 106±32, cooking: 132±72, cleaning: 198±98, epoch length: 20 sec). The

ocha-count parameter increases commensurately to the theoretical intensity of each activity. A good correlation (r=0.8, p<0.001) was found between the ocha-count and the waist-worn GT9X activity count estimations (see figure). The wrist-worn GT9X produced inconsistent results. Conclusion: A floor vibration-assisted smart-home system can produce valid assessments of the physical activity related to housework. In the future, connected smart-home systems might contribute to a more continuous and accurate evaluation of the daily energy expenditures.

### O.12.5  Which vertical ground reaction forces variable is most associated with the in vivo 3D hip joint contact forces?

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Objective The objective of this study is to investigate parameters that can relate vertical ground reaction forces (vGRF) to hip contact forces (HCF) at 3, 6, 12 and 50 months post total hip replacement (THR). Though previously used to quantify post-THR functional recovery[1], it remains unclear if vGRF are indicative of changes in HCF. Methods Eight THR patients (6 males, BMI=29.8±4.7kg/m², age=56.9±6.2years) walked at a self-selected speed over a 10m walkway in a gait laboratory. HCF were collected with an instrumented hip implant[2] and vGRF with 2 embedded forceplates. Mean curves were calculated using dynamic time warping[3]. First and second peaks, impulse, loading rate and unloading rate were calculated for HCF and vGRF. Loading rate was calculated as the first peak divided by the time from heel strike to the first peak force unloading rate as the second peak divided by time from second peak to toe-off. Linear correlation of means was performed with HCF as the dependent variable and vGRF as the independent variable. Results Significant associations between HCF and vGRF were observed for loading rate at 6 and 50 months post-THR, and for impulse at 12 and 50 months post-THR (Figure 1). Peak force magnitudes and unloading rate of HCF and vGRF were not related. Figure 1 - vGRF vs HCF for loading rate (top) and impulse (bottom) for 6, 12 and 50 months post-THR. Linear fits illustrate correlations at 6, 12 and 50 months for loading rate and impulse. Discussion and conclusions This study showed that vGRF is associated with HCF when analyzing loading rate and impulse but not the pure maximum forces. Loading rate computations may be challenging at slower speeds and in pathological cohorts. Measurements of vGRF aiming to estimate HCF should ideally use rather impulse analyses as an indicator for functional recovery over the pure maximum forces. References [1]McCrory Gait Post 2001;14:104 [2]Damm Med Eng Phys 2010;32:95 [3]Bender Comp Meth Biomech Biom Eng 2012;15:761

## Oral Session 13 – Real World Applications (1)

### O.13.2  Measuring the response to prompts to stand: an exploration of a pilot study of UK office workers

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Objectives. Prompts to stand have been used in interventions to reduce sedentary behaviour (SB). Previous evaluation considered total SB, but it is unclear how individuals actually use prompts (direct cue to stand/diffuse reminder), or how prompts interact with usual behaviour. Understanding this would inform use as a behaviour change technique in evidence-based interventions. Methods. Secondary analysis of a pilot RCT in UK office workers (age 29-58; 43%men), prompts+education (n=14) versus education (n=14). Participants wore an activPAL3 for 7 days at: baseline; early intervention (weeks 2-4); late intervention (weeks 8-10); follow-up (week 22). The prompts group received 1 prompt/hour at work (random time; at least 30min apart; weeks 1-10). Prompts were pre-generated, delivered using Microsoft Outlook, not linked to actual SB or presence at desk. Response to prompts was assessed (prompts group, early & late intervention) by comparing time of prompt to the next standing event (activPAL). To explore how prompts might interact with usual behaviour (both groups, baseline & follow-up) a set of virtual prompts was applied to analysis. Results. During the intervention, prompts group participants were sitting for 5 prompts/day (mean [range] 69% [13%-93%] of all prompts). When seated, the mean time to stand after a prompt was 28min [7-126min]; participants stood within 1min of 10% [0-40%] and within 10min of 45%

[18-77%] of prompts. During baseline/follow-up, all participants were sitting for 70% [33-95%] of virtual prompts. When seated, the mean time to stand after a virtual prompt was 34 minutes [6-84min]; participants stood within 1 min of 7% [0-32%] and within 10min of 38% [15-81%] of virtual prompts. Conclusions. Most prompts were received when seated, indicating potential to directly change behaviour. However, intervention group response times suggest most prompts were not used as a direct cue and behaviour was indistinguishable from analysis of virtual prompt data.

### O.13.3  The contribution of commuting to total daily moderate-to-vigorous physical activity

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Background: Commuting to and from work can increase moderate-to-vigorous physical activity (MVPA) and increase adherence to physical activity guidelines; however, there is lack of evidence on how different modes of commute and continuous stepping bouts contribute to physical activity. Many commuting studies employ the use of self-reported physical activity measures. The aim of this study was to objectively determine the contribution of MVPA during commuting to total MVPA, using cadence to define MVPA, and to explore how the length of stepping bouts affects adherence to physical activity guidelines. Methods: Twenty-seven university staff wore an activPAL activity monitor for seven days and kept an activity diary; the activity diary collected information on commute times and modes of commute. The activPAL quantified the cadence and length of stepping bouts. MVPA was defined as stepping with a cadence of more than 100 steps/min. Results: Twenty-three participants had valid data and were included in the analysis. The average total time per day spent in MVPA was 53.1 (±30.2) minutes, with commuting contributing 33% or 17.7 (±14.7) minutes. Walking (32.2 (±9.6) minutes) and mixed-mode (27.2 (±15.3) minutes) commuters spent more time in MVPA than car commuters (9.1 (±8.3) minutes). Seventeen of the 23 participants achieved more than 30 minutes of MVPA per day, with five achieving this in their commute alone. At a cadence of over 110 steps/min, there was a greater proportion of stepping during commuting compared to other cadence bands (Figure 1), and stepping bouts of greater than 210 seconds were only undertaken whilst commuting. A significant positive association was found between commute time spent in MVPA and total MVPA (p<0.001). Conclusion: Commuting can be a major contributor to total MVPA, with the mode of commute having a significant role in the level of this contribution to total MVPA: public health messages should encourage active or mixed-mode commuting.

### O.13.4  Bouts are out: What is the impact of removing the bout requirement from the Physical Activity Guidelines?

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In 2018 the Physical Activity Guidelines Recommendations (PAGR) were updated and the requirement for moderate-to-vigorous intensity (MVPA) activity to be accumulated in bouts of at least 10 minutes in duration was removed. Purpose: The purpose of this study was to determine how bout removal impacts on the number of people meeting the recommendations and the activity volume (accelerometry), activity energy expenditure (AEE) (doubly labeled water) and fitness (VO2max) of individuals who meet the PAGR. Methods: This study made use of the publicly available data from the Interactive Diet and Activity Tracking in AARP (iData) study. Participants in the iData were middle to older-aged, healthy men and women. Accelerometry data were collected using the activPAL activity monitor and these data were used to classify individuals into 3 mutually exclusive groups 1) not meeting guidelines (NO), 2) meeting non-bouted guidelines (NBG) or 3) meeting bouted guidelines (BG). Results: Of the 881 participants (mean (SD), age=64y (6.9)) with valid accelerometry data, 9.6% were classified as NO, 80.2% as NBG and 10.1% as BG. Significant differences (p<0.05) in MET.hours, steps/day, MVPA and AEE existed between all groups (Figure). Significant differences in VO2max (ml/kg/min) existed between BG and NBG compared with NO. Conclusion: These data from a middle- to older-aged adult cohort suggest that removing the bout requirement from the PAGR significantly influences not only the number of individuals who meet the guidelines, but also the activity volumes of those who achieve vs. don't achieve PAGR. Surveillance researchers must consider these

differences when comparing data collected and summarized according to the 2008 PAGR compared with the 2018 PAGR.

## Oral Session 14 – Algorithms (2)

### O.14.1  Comparison of free-living activity classification between sojourns and epochs using a wrist-worn accelerometer

*Greg Petrucci Jr.[1], Melanna Cox[1], Patty Freedson[1], John Staudenmayer[1], John Sirard[1]*

*[1]University of Massachusetts Amherst*

Background: The intermittent and sporadic nature of free-living activities may degrade the performance of epoch-based classification approaches. However, it is unclear how activity classification accuracy is impacted by processing wrist-worn accelerometer data using time-varying activity periods, or sojourns. Objective: To evaluate free-living activity classification from a wrist-worn accelerometer using either sojourns or different epoch windows.  Methods: Forty-eight participants (age:20.4±1.3 years, 45.8% male) were video-recorded during four 1-hour sessions in different settings (home, community, school, environment) while wearing an ActiGraph GT3X+ accelerometer (AG) on the right hip and non-dominant wrist. Videos were coded for postural orientation and activity type (e.g. walking). Sojourns were identified from the hip-worn AG using Lyden's Sojourn-3x algorithm. Time- and frequency-domain AG signal characteristics were computed from raw wrist data within sojourns and various epoch lengths (5, 10, 15, 30, 60 secs). Random forest models were trained using computed signal characteristics to classify activity (sedentary, standing, ambulatory, bicycling, dynamic activity) and evaluated using 5-fold cross-validation. Results: Of the 9,677.2 minutes of observation, 61.8% of the time was spent sedentary, 17.9% ambulatory, 15.9% standing, 3.5% bicycling, and 1.1% in dynamic activity.  Overall classification accuracy was marginally improved using sojourns (68.9%) compared to the different epoch windows (range: 64.8-65.3%). In general, increasing epoch window length resulted in increased classification accuracy for standing and ambulatory, however sedentary and bicycling classification accuracies were reduced. Conclusion: Estimates of physical behaviors may be improved using sojourns compared to epoch windows. Development of a wrist sojourn algorithm is needed to improve activity classification across a range of free-living behaviors. Supported by NIH NIDDK 1R01DK110148

### O.14.2  Three distinct physical behavior types in fatigued patients with multiple sclerosis

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BACKGROUND: Multiple sclerosis often leads to fatigue and changes in physical behavior (PB). However, considerable variability in fatigue, PB and their interaction was found across and within patients over time. Also, multiple dimensions of PB seem to be affected. Better understanding of the variability in multidimensional PB by identification of PB subtypes may help to develop personalized rehabilitation programs. Therefore, this study aimed to identify PB subtypes in fatigued patients with multiple sclerosis based on multidimensional PB outcome measures. METHODS: Data of the TREFAMS-ACE participants (n=212) including 7-day objective PB measurements were used for secondary analysis. Fifteen PB measures were derived from the Actigraph accelerometer. Principal component analysis was performed to define key PB outcome measures. Key PB outcome measures were used as input in a two-step cluster analysis to identify PB types. RESULTS: Analysis revealed five key outcome measures: percentage sedentary behavior, total time in prolonged moderate-to-vigorous physical activity, number of sedentary bouts, and two types of change scores between day parts (morning, afternoon and evening). Based on these outcomes three valid PB clusters ('sedentary', 'moderately sedentary' and 'active') were derived. DISCUSSION & CONCLUSION: Despite that all patients reported sufficient levels of fatigue, three distinct and homogeneous PB subtypes could be distinguished. These PB subtypes, based on a unique set of PB outcome measures, offer an opportunity to design more individually-tailored interventions in rehabilitation. Further research should focus on the clinical feasibility of PB subtypes in the design of interventions.

### O.14.3 Real-world detection and analysis of locomotion using single wrist sensor: validation and application to a large population

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Real-world assessment of locomotion is challenging due to the influence of context and the need to have a non-intrusive measurement system. In everyday situations, wearing single sensor on wrist provides high compliance of people, crucial for long-term measurements. However, unlike trunk or lower limb, wrist might have more movements independent of locomotion. This study proposes and validates an accurate method to detect locomotion in real life using a wrist accelerometer. Preliminary results from a large cohort are also presented. 67 subjects worn a 3D accelerometer on wrist during daily life for one or two days, 8h/day. Acceleration was recorded at 40 Hz and segmented into 6 s windows. 15 features were extracted according to intensity, periodicity, and noisiness of the signal as well as hand posture. A Naïve Bayes classifier and a temporal state-machine was devised to recognize locomotion. Using one-subject-out cross-validation, the method was validated against a wearable multi-sensors reference [1], worn during measurements. 900 h of free-living activities were employed for validation. For locomotion detection, the method achieved a median sensitivity, specificity, accuracy and precision of (%) 92.2, 97.9, 97.5, and 82.8, respectively. The proposed method was applied on 2980 subjects wearing the wrist sensor during 2-week/person. We observed a power-law distribution for walking bouts duration, in agreement with [2]. Moreover, speed and cadence were also estimated (according to [3]) showing multi-modal Gaussian distributions. In addition, aging and obesity led to a significant reduction of both speed and cadence. The proposed method provided a high performance in free-living situations. The method was also optimized for low-power usage to be integrated into a watch. Further analysis should allow evaluating the system in the presence of movement disorders. [1] A. Paraschiv, Giat Post., 2004 [2] A. Barabasi, Nature, 2005 [3] F. Benedikt, Med. Bio. Eng. Com.

### O.14.4 Population-specific algorithm development: do activity classification models developed in children generalise to the adult population (and vice versa).

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Background: The application of machine-learning to classify physical behaviour is a growing field. Most predictive models are developed in one population group (e.g. adults). It is unclear how these models perform when applied to other populations (e.g. children). This study examined the interchangeability of machine-learning models developed in free-living adult and child populations. Methods: Thirty participants (15 adults, 15 children) were equipped with two Axivity AX3 accelerometers worn on their thigh and lower back. A wearable video camera recorded their free-living movement behaviours (criterion measure). The video recording was annotated second-by-second into seven distinct activity classes (e.g. sitting, standing, walking, running, lying, cycling, dynamic standing). For each sample, a random forest classifier was trained to classify each activity type using time- and frequency-domain features of the accelerometer data. Both models were first evaluated using leave-one-out cross-validation before their performance was tested on the other sample (e.g. adult model applied to child dataset, and vice-versa). Results: For adults, the adult-developed model showed 95.5% (95% CI: 95.2-95.8) accuracy but dropped to 93.7% (93.6-94.0) when using the child-developed model. Walking showed the largest individual decline (-7%). For children, the child-developed model showed 95.1% (94.8-95.1) accuracy but dropped to 93.3 % (92.9-93.7) when using the adult-developed model. Running showed the largest individual decline (-6%). Conclusions: Classification models developed in one population may not perform equally when used in another population group; some activity types are affected more than others. Future studies should confirm these findings in larger and more diverse samples (e.g. older adults) and explore model performance with training data pooled from multiple groups.

**O.14.5  A system for data harmonization and federated analysis of accelerometer and GPS data**

*Emiliano Molinaro[1], Jesper van der Zwan[1], Jens Hjort Schwee[1], Mikkel Baun Kjærgaard[1]*

*[1]University of Southern Denmark*

Objective Collection of GPS and (raw) accelerometer data is now possible on a large scale, however data processing involves many different decisions and comparing or pooling data across multiple studies is difficult because of lacking harmonization. With the increased use of raw accelerometer data to classify activity events, the problem has increased as there are many different algorithms. Furthermore, processing raw accelerometer data is computationally intensive, especially if multiple algorithms are to be used on large pooled meta-analysis datasets. A new system developed at the University of Southern Denmark aims to assist researchers in processing their data, facilitate data harmonization, and make federated meta-analysis of accelerometer and GPS data possible. Methods The system consists of three separate elements: 1) secure data storage, 2) user interface with processing algorithms, 3) data processing on the ABACUS 2.0 High Performance Computer (HPC). Researchers upload their data to a personal virtual hard disk which is fully compliant with all GDPR regulations for sensitive personal data. Processing choices are made in a Shiny (Rstudio) user interface. Once the processing decisions are made, the system temporally loads the data onto the HPC where it is processed. The original data, as well as a processed dataset are returned to the secure data storage. If a researcher allows their data to be used for meta-analysis, the system can run a confederated analysis across multiple virtual hard disks without revealing the original data to the analyst. Results The first system tests showed that the data processing speed improved at least 1000 times compared to a workstation computer. The Shiny interface furthermore made easy integration of existing classification algorithms written in R possible. Conclusions This system offers high-speed data processing of raw accelerometer and GPS data and facilitates data-harmonization and confederated meta-analysis.

## Oral Session 15 – Computer Vision / Video Analysis

**O.15.1  Challenges and opportunities using webcams and time lapse cameras to evaluate physical behaviour in public open space**

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The Archive of Many Outdoor Scenes (AMOS) has captured and archived images every 30 minutes from 36,000 international outdoor, public, webcams resulting in a repository of over 1.1 billion images. Ten percent of these webcams are systematically capturing images of open spaces allowing for the audit of built environments and annotation of human behaviors. Extending beyond webcams, in 2016 our research team worked with four rural counties in North Carolina, USA, to install 15 time-lapse cameras in parks set to undergo renovations and programmatic interventions. Objectives. To create a protocol for evaluating use and physical activity patterns in open spaces using webcams and time lapse cameras. Methods. For webcams in the AMOS dataset, we used a crowdsource and machine learning algorithms to annotate over 100,000 images across over 40 outdoor environments. Use across space and time has been analyzed using space-time cubes. We deployed time-lapse cameras to systematically take one photo every 29 minutes from 6am to 9pm, each day. We are measuring the percent of time the space is used, how many people are using the space, and where in the captured scene is use occurring. Results. Webcams are reliable, valid method for evaluating use of public open space. Crowdsources and machine learning have also proven to be an inexpensive and reliable source of images. We completed an analysis of an open space scene to reveal different spatio-temporal patterns before and after redevelopment, allowing direct study of effect of changes on human behavior (attached). We have collected over 100,000 images from North Carolina parks, using machine learning to annotate images. Each renovation and programmatic change is associated with significant change in the use of the individual parks (both significant increases and decreases). Cameras provide an opportunity to collect long-term data for monitoring spaces in as well as assess the effectiveness of interventions for promoting activity.

### O.15.2 Applying COMPUTER VISION TECHNIQUES TO PREDICT PHYSICAL ACTIVITY FROM VIDEO IMAGES

*Philip Saponaro[1], Haoran Wei[1], Richard Suminski Jr.[1]*

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Objective: To examine if computer vision techniques can estimate physical activity (PA) type, intensity, and energy expenditure (EE) from video images. Methods: After assessing age, sex, height, weight, and percent body fat, 50 healthy adults were fitted with a chest-worn Polar H7 heart rate monitor and a hip-worn ActiGraph GT3X+ accelerometer. On an outdoor field, participants sequentially performed 1-minute of standing, 3 minutes each of slow walking, moderate walking, and jogging, and a 50-meter sprint. Bouts were recorded from a pair of GoGloo video glasses (1920x1080 resolution and 30 frames/second). Accelerometer data were processed using the Freedson Vector Magnitude 3 algorithm, which provided "ground truth" data for PA intensity and EE. To detect PA type, elbow and knee joint angles and speed were used as features, with new samples compared against a model distribution using the Kolmogorov-Smirnov and Mahalanobis distances, respectively. Joint angles were calculated from a 2D skeletal pose estimated by the Realtime Multi-Person Pose Estimation algorithm. Speed (mph) was estimated from the distance traveled using ground markers and time elapsed in the video. To detect intensity and EE, a random forest classifier and regressor were used with age, sex, PA type, and speed as input. To test the system, we used a 5-fold cross-validation with 80% training and 20% testing. Results: Accuracy and confusion matrices for different prediction models were examined for PA type and intensity, while mean differences were examined for EE. For PA type, the best performing model included speed and joint angle, resulting in an accuracy of 96.8%. Predictors for intensity and EE were speed, PA type, age, and sex. Intensity accuracy was 89.5% and mean error for EE was 1.96±1.5 Kcal/min. Conclusion: Findings indicate the potential to use computer vision to automate PA estimates in public spaces (e.g. parks) without relying on data from wearable sensors.

### O.15.3 Automating direct observations of physical activity in settings using computer vision

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*[1]University of California San Diego, [2]North Carolina State University, [3]Children's Mercy Kansas City*

Objective. To test computer vision algorithms for providing automated video-based ecological assessment of physical activity (i.e., automated SOPARC). Methods. Data were collected from 9 sites, including parks, schoolyards, paved surfaces, and gymnasiums. Video cameras were mounted to tripods 10-25 feet high and used to capture 12 different perspectives per site across 3 visits, totaling ≈3.1 hours of video per site (27.8 hours total). All people (primarily youth) in view of the camera wore an ActiGraph and engaged in their usual activities, which included active play, sports, or structured activities (e.g., Physical Education). 6005 10-second video segments were used to train computer vision algorithms to predict the number of people in the scene, total METs across people, and proportion of people in MVPA, using accelerometer counts as the ground truth. Mean absolute deviation (MAD) was used to assess the algorithms' accuracy in 3929 10-second video segments. Results. Across all 10-second video segments, the mean number of people in the scene was 18.7 (range=9-56). Overall, MAD was 15.4% for predicting the number of people in the scene, 16.1% for predicting the total METs across people, and 38.5% for predicting the number of people in MVPA. Camera height was not correlated with accuracy. Other correlates of accuracy are being explored, and additional features are being extracted from the video in effort to improve predictions of the number of people in MVPA. Conclusions. This study of real-world settings and free-living activities suggests that computer vision is promising for supporting automated assessment of physical activity in settings. Such tools would require less manpower than traditional direct observation, produce a greater amount of and potentially more accurate data, and allow for ongoing monitoring and feedback to support interventions. Further development and testing is needed before such tools are ready for application.

**O.15.4 From pixels to sidewalks: Using Google Street View and computer vision to create a national sidewalk inventory**

*S. Saeed Oloonabadi¹, Hrishikesh Garud¹, Pratik Bhave¹*

*¹NC State University*

In 2015, the US Surgeon General released Step it Up! Call to Action to Promote Walking and Walkable Communities. In this Call, the importance of physical activity and the role communities can play in supporting an active lifestyle are underscored. The 2overarching recommendations to increase walking and improve walkability are to 1) design communities and streets that support walking, and 2) promote programs and policies that support walking. These are laudable goals. However, to effectively support and advocate such efforts we must know the availability and current state of our national walking infrastructure: sidewalks. There is no national dataset, no state dataset, and limited city datasets of geospatial location of sidewalks. It may be dangerous and counterproductive to, for example, advocate for walking groups where sidewalks do not exist, or to promote safe routes to schools policies without the necessary infrastructure. To understand how Google Street View (GSV) has been used in built environment and physical activity related research, as well as how computer science and engineering have been using GSV in research, we first conducted two separate guided literature reviews. Concurrent to the literature reviews we began the process of automatic detection of sidewalks in Google Street View images. To date we are using deep Convolutional Neural Networks (CNN) to segment pixels into the binary of sidewalk or not per image. We have achieved a 97% specificity rate. We are also using the Pyramid Scene Parsing Network (PSP-Net) and have achieved similar results. Given evidence in th literature reviews and CNN/PSP-Net advances, we believe automatic capture of sidewalk presence in Google Street View is very much possible. We also believe this capture can be transitioned to Geographic Information System shapefiles or geodatabases that will be useful for municipalities, researchers, and advocates. There are several important challenges that will need to be overcome.

**O.15.5 Insights on free-living behavior from a novel direct observation coding system**

*Greg Petrucci Jr.¹, Melanna Cox¹, Patty Freedson¹, John Staudenmayer¹, John Sirard¹*

*¹University of Massachusetts Amherst*

Background: People's behaviors and how they are performed naturally differ between free-living- and laboratory-conditions, thus limiting the generalizability of laboratory-based accelerometer calibration studies. An in-depth profile of free-living physical behaviors would better inform free-living device calibration efforts. Objective: To provide descriptive characteristics of young adult free-living behaviors using the Movement Observation in Children and Adolescents (MOCA) coding scheme. Methods: Forty-eight participants (age: 20.4±1.3 years, 45.8% male) were video-recorded while completing four 1-hour sessions in different settings (school, home, community, exercise). Videos were coded in Noldus Observer XT using MOCA to annotate second-by-second changes in whole-body movement (WBM), such as postural orientation or gross movement (e.g. walking), and activity type (ACT; e.g. eating), which provided contextual detail to the WBM. WBM and ACT were derived from the Compendium of Physical Activities. Results: Most of the observed time (9,677.2 minutes) was spent in the following WBM: sitting (59.9%), standing (15.8%), walking (13.2%), bicycling (3.4%), running (2.8%), elliptical trainer (2.1%), and lying (1.7%). The majority of standing and locomotor behaviors were performed in ≤15-sec bouts (Figure). However, a greater proportion of total time spent in each whole-body-movement was accumulated in bouts >1-minute (range: 55-99.7%). Sixty-four different ACT were observed in addition to the WBM. Of the 9,370 WBM bouts observed, 21.8% of them contained more than one ACT, accounting for 66.4% of the total observed time. Conclusion: Free-living behaviors are complex, characterized by numerous short duration bouts and activities performed simultaneously. Future accelerometer calibration studies should consider these observations when developing data processing methods. Supported by NIH NIDDK 1R01DK110148.

## Oral Session 16 – Real World Applications (2)

### O.16.1  Self-perceived gait stability modulates the effect of daily-life gait quality on falls in older adults

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Purpose: Quality of gait during daily life activities and perceived gait stability are both independent risk factors for future falls in older adults. We investigated whether perceived gait stability modulates the association between gait quality and falling in older adults and aim to replicate our findings in an ongoing cohort. Methods: We used two prospective cohorts of older adults over 65 years of age, the FARAO (N = 272) and the ongoing VIBE (N < 286) cohort. One-week daily-life trunk acceleration data was collected. Sample entropy (SE) of the 3D acceleration signals was calculated to quantify daily life gait quality. To quantify perceived gait stability, the level of concern about falling was assessed using the Falls Efficacy Scale International (FES-I) questionnaire and step length, estimated from the accelerometer data. A fall calendar was used to record fall incidence during a six-month follow up period. Logistic regression analyses were performed to study the association between falling and SE, step length or FES-I score, and their interactions. Results: From the FARAO cohort we showed that high (i.e., poor) SE in vertical direction was significantly associated with falling. FES-I scores significantly modulated this association, whereas step length did not. Subgroup analyses based on FES-I scores showed that high SE in the vertical direction was a risk factor for falls only in older adults who had a high (i.e. poor) FES-I score. The VIBE cohort is still ongoing and preliminary results will be presented at the congress in relation to the results from the FARAO cohort. Conclusion: Perceived gait stability may modulate the association between gait quality and falls in older adults such that an association between gait quality and falling is only present when perceived gait stability is poor.

### O.16.2  Context matters - The effect of context-specificity on the association between the built environment and physical activity in individuals with and without health-related problems

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Purpose: Research suggests associations between the built environment (BE) and physical activity (PA), but is inconclusive due to differences in measuring methods and (exposure to) context. Also, health-related factors may impact on this association. Therefore, we compared associations between the perceived neighborhood walkability (PNW), and overall and context-specific moderate-to-vigorous PA (MVPA) in individuals with and without health-related problems. Methods: Data were collected in 2016-2017, in two cities in the Netherlands. In total, 509 participants (18+) provided valid data. MVPA was measured using the Actigraph GT3X+ accelerometer and location using the Qstarz BT-Q1000XT GPS-logger, for 7 days. Street network buffers of 1.0 km around the participants' home address defined the home neighborhoods (HN). Exposure to HN was determined by the time spent in the HN. Health-related problems were measured using the EQ-5D and PNW using the Neighborhood Environment Walkability Scale (NEWS). Multiple linear regression models were used to assess associations between PNW and overall and context-specific MVPA. Results: We found weak associations between PNW and overall MVPA (e.g. access to facilities, â=.090), and HN-MVPA (â=.099). Stronger associations were found between PNW and HN-MVPA (â=.166) in individuals without health problems, but not for overall MVPA or for individuals with health problems. When taking in account the exposure to the HN for individuals without health problems, no associations were found the less exposed individuals, but even stronger associations were found for the more exposed individuals (â=.212). Conclusion: Associations between the BE and MVPA are affected by personal, health-related factors, by the physical context in which PA takes place and by the amount of exposure to this context. This emphasizes the need to use information on personal health problems and context-specific PA measurements when investigating the effect of the BE on PA.

### O.16.3  Habitual physical activity patterns of vocational education students and the association with executive functioning: The PHIT2LEARN study

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Previous research on the effects of physical activity (PA) and sedentary behavior (SB) on executive functioning (EF) has mainly been performed in children in primary school and secondary school. Research in vocational education and training (VET), lower tertiary education, is lacking. The current study focuses on the association between objectively measured PA and SB on the one hand and EF of VET students on the other. The current study, part of the PHIT2LEARN study, had a cross-sectional design. Participants were recruited from 19 classes of a VET institution in the South of the Netherlands, representing different study years, VET levels, and educational subjects. Participants wore an ActivPAL3 accelerometer on the thigh for a week, measuring PA objectively. After this week, cognitive tests were conducted measuring EF using the Color-Shape Test and the Letter-Memory Test. ActicPAL Data was classified into sitting, standing, light-intensity PA, and moderate-to-vigorous PA. An open-source software program was used to process the data (https://github.com/UOL-COLS/ProcessingPAL/). Linear regression models were used to analyze the data. The program with which the data are being analyzed just came available shortly before the date of submitting this abstract. The data is analyzed before the conference. The first author of this abstract already had experience with the program, as he collaborated with the makers of the program when he visited Loughborough University in May 2018. Preliminary results using the PA data of 188 students analyzed with a predetermined MATLAB script indicate clear differences in PA patterns between different educational tracks and no association with EF. The results of the use of this program for processing ActivPAL accelerometer data will be discussed in this presentation. Additionally the results of the findings in this research will be presented.

### O.16.4 Monitoring of walking performances of ten non-professional athletes during the 2018 Berlin 100-km Mammutmarsch

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Introduction Gait performance may be quantified by autocorrelation analysis of accelerometric measurements by wearable sensors [1,2]. Such methods may quantify period (inverse of cadence), motor activity (MA) and regularity [2]. A method extension to epoch-based analysis produces indexes' time profiles. The "2018 Berlin Mammutmarsch" is a mass competition whose participants walk, not run, for 100 km. The aim of the present study was to monitor locomotion during the performance of non-professional athletes at the 2018 Berlin Mammutmarsch, to disclose any effect of the prolonged effort. Materials and methods Ten participants (males, 22-45 years) had Faros accelerometer (Bittium, Finland) fixed at the chest. Autocorrelation analysis was applied to 20-seconds epochs. A cluster analysis of regularity classified walking and not-walking rest phases. Two athletes dropped out and excluded from analysis. For each phase, for each index, average and hourly trends were computed. Overall values were computed as average weighted for phases' durations. Individual dataset included Finish Time, Body Mass Index BMI, Regularity and Periodicity (averages and trends). Results The method let to obtain indexes' profile during the performance (see figure). The individual Finish Time ranged 21,5 to 25.5 hours and directly correlated with rest/walk ratio (15 to 20 %) and cadence hourly trend (-2 to 1 %). BMI (20.8 to 25.9) correlated with rest/walk ratio. Regularity (0.94 to 0.97) evidenced no correlations. Discussion As to group analysis, best performing athletes reduced cadence and needed less time to recover between walking phases; athletes with smaller BMI recovered faster. The adopted metrics evidenced no correlation for regularity, though it was modulated during the performance. Nonetheless, individual profiles may provide relevant information to the athlete. References [1] Moe-Nilssen R, Helbostad JL. J Biomech 2004 [2] Rabuffetti M, Scalera GM, Ferrarin M. Sensors 2019

### O.16.5 Physical activity and sedentary patterns of semi-nomad pastoralist Senegalese Fulanis are deeply altered in urban context.

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Over the last century urbanization, mechanization and passive transportation have reduced the demand of being active. Understanding the impact of modernization on overall physical activity (PA) and sedentary behaviors, two determinants of non-communicable diseases and early mortality, is however challenging because most contemporary societies have already been submitted to these changes. Here we aimed to objectively characterize PA and sedentary patterns in an African population being in an early stage of this transition, the Senegalese Fulanis. Two groups of Fulanis male adults, originated from the Ferlo region, wore an ActiGraphTM accelerometer for 10 days; one was still living in Ferlo, with a pastoral semi-nomad way-of-life (rural); the other had moved to Dakar at least 10 years ago (urban). Valid data (≥3 days with 10h waking-wearing-time) were obtained in 27 urban (37±2 y; BMI 19.9±0.7 kg/m2) and 49 rural (37±2 y; 20.5±0.6 kg/m2) Fulanis. Several metrics were calculated from counts-per-minute, steps, raw accelerometry and automatic-activity-recognition. Active and sedentary bouts and breaks of different lengths were identified. Groups were compared using ANOVA. Walking, notably at brisk cadence, and running times were 1.5-2-fold higher in rural than urban Fulanis (p<0.01). Brisk activity bouts number and length were higher in rural Fulanis (p<0.01). Although sedentary time and breaks were similar, postures differed with and less reclining/sitting (p<0.01) rather than lying in rural Fulanis. Our study indicates that in the Fulanis, compared to rural environment, urbanized environment was associated with a similar sedentary time, but with a less active behavior and contrasted activity/postures patterns. Thoroughly characterization of longitudinal changes in PA and sedentary behaviors in populations still undertaking their epidemiological transition will further help understanding the impact of urbanization on the different dimensions of PA and on health

## Oral Session 17 – Upper Limb Monitoring

### O.17.1 Development of a taxonomic structure to support automatic recognition of eating behaviors

*Tianna Jordening[1], Natalia Dmitrieva[1], Timothy Behrens[1]*

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Historically, unhealthy eating has been operationalized as various aspects of nutritional intake, and research is underway to move beyond self-reported assessment in order to develop more objective measures of nutrition. Such objective measures are lacking for behavioral characteristics of activities that comprise eating such as frequency, duration, speed, and timing of actions associated with eating, which have been shown to predict health outcomes such as poorer metabolic outcomes observed among individuals who engage in more rapid food consumption and nighttime eating. Behavioral characteristics of eating are typically assessed using self-recall reports and food diaries, a method that is prone to measurement bias and participant non-compliance in the context of eating behaviors. Therefore, more effective methods of measuring food intake are necessary in order to meet the needs of those seeking help in developing a healthier lifestyle. In order to develop an objective method for measuring food intake, a tool to accurately evaluate eating behaviors for various data collection devices is necessary. Our taxonomy fulfills this need by providing an effective and comprehensive method for describing eating habits which is applicable to future research addressing health and eating habits. The taxonomy was based on observations in free-living ecologically valid settings such as restaurants, cafes, and campus cafeterias. It describes eating behaviors such as preparation, eating, and non-eating behaviors which break down into more specific motions as well as describing manner and mode of eating. Our team utilized the taxonomy for a study to identify eating motions via wrist worn accelerometers. In the study, participants were video recorded during their normal eating period while wearing the accelerometers. This and similar research is made possible by the taxonomy, and is necessary in order to address health related concerns such as obesity and eating disorders.

### O.17.2 Daily activity monitoring of robotic arm support users with muscular weakness

*Anneliek Peters[1], Alessio Murgia[1], Kenneth Meijer[2]*

*[1]University Medical Center Groningen, [2]Maastricht University Medical Centre+*

Lower arm support orthoses increase performance during activities of daily life by providing gravity compensation to people with residual arm functionality. However, perceived benefits and reported time of daily usage have been found on average to be moderate and quite diverse suggesting that most supports are not effective nor entirely satisfactory. In contrast, subjective reports might not reflect actual usage and misrepresent information of

performed activities. The aim of this study is to provide long-term and objective measurements to quantify dynamic arm support usage in daily life. Aspects of current usage could provide information for further development and stimulate methods to increase usage of arm supports. Nine people with progressive muscle wasting who use a dynamic arm support system in daily life were monitored continuously for a week. Four accelerometers (MOX, Maastricht Instruments) were placed on the upper arm and forearm, support brace, and wheelchair. Intensity and gravity-based orientation were calculated to quantify temporal and spatial activity while not using and using the support. Time spent in, and transfers between, three orientations were calculated for the forearm (low: <75°, middle: 75-120°, and high: >120°, with 0° representing the orientation downwards). Results show that participants were inactive for an average of 13.2±2.8hrs/day. They were active for 8.9±3.6hrs/day while not using the support and for 2.0±1.8hrs/day (or 20.1±17.6% of total active time) while using the support respectively. A negative correlation was found between being active and using the support (r = -0.40, p<0.01, Fig.1). The arm supports were used in 40% and 18% of all low-to-middle and middle-to-high transfers respectively. Daily usage of support was relatively short and depended on users' overall activity. A support most likely assisted the users in moving and maintaining the forearm gravity-free to achieve tasks that required arm elevation.

### O.17.3  Validity of the Apple Watch® for monitoring push counts in people using manual wheelchairs

*Kati Karinharju[1], Alexander Boughey[1], Kelly Clanchy[2], Stewart Trost[3], Sean Tweedy[1]*

*[1]The University of Queensland, [2]Griffith University, [3]Queensland University of Technology*

Objective: A recent Apple Watch® activity-monitoring innovation permits manual wheelchair users to monitor daily push counts. The aim of this study was to evaluate the criterion validity of the Apple Watch® push count estimate. Methods: Twenty-six manual wheelchair users from Finland and Australia were filmed completing a standardized battery of activities while wearing the Apple Watch® (dominant wrist). Activities were designed to mimic activities of daily living for people using manual wheelchairs. Wheelchair pushes as determined by the Apple Watch® were compared to directly observed pushes. Agreement between Apple Watch® push counts and directly observed pushes was evaluated using intraclass correlation coefficients (ICC), Pearson correlations and Bland-Altman analyses. Results: Apple Watch® pushes and directly observed push counts were strongly correlated (ICC=0.77, P<0.01) (r=0.84, P<0.01). Bland Altman plots indicated that the Apple Watch® underestimated push counts (M = -103; 95% ULoA = 217; LLoA = -423 pushes). Mean absolute percentage error was 13.5% which is comparable to studies evaluating agreement between pedometer-based step counts and directly observed steps. Conclusions: Apple Watch® push-count estimates are acceptable for personal, self-monitoring purposes and for research entailing group-level analyses, but less acceptable where accurate push-count measures for an individual is required.

### O.17.4  How does the upper limb activity of adolescents with upper limb absence differ from anatomically intact adolescents, and does this change during sport?

*Natalie Chinn[1], Alix Chadwell[1], Laurence Kenney[1], Malcolm Granat[2], John Head[1]*

*[1]The University of Salford, [2]University of Salford*

Background: Despite physical and psychosocial benefits, disabled people are half as likely to participate in sport than able-bodied peers. Active adolescents typically become active adults; therefore, early engagement in sport is encouraged. For those with an upper limb absence, sport participation levels are poorly understood, with limited literature on how prostheses are used. Previously, we developed methods to objectively evaluate patterns in upper limb prosthesis wear and use, including the display of 7-day time-series data using spiral plots. Building on this, the aims of this feasibility study were to capture objective prosthesis wear and usage pattern data from physically active adolescents using prostheses, gather data on sports participation, capture participants' views on prostheses and reasons for use/non-use in sport, and identify whether activity patterns reflect those found in adult myoelectric prosthesis users. Methods: Data for two unilateral prosthesis users and four anatomically intact adolescents were collected and analysed. Participants wore an Axivity sensor on each wrist over a 2-week period and completed activity diaries. We also conducted semi-structured interviews with the prosthesis users. Results: In line with previous findings, prosthesis users were 72% reliant on their intact arm overall, and 68% reliant during sports where a prosthesis was worn. Anatomically intact adolescents showed a similar level of reliance on both

arms (51% on dominant overall, 50% during sport). Conclusions: Accelerometer and interview data suggest minimal use of prostheses during sport, with devices only being used when the user felt they offered a specific benefit. When prostheses were worn for sport, patterns of activity were still skewed towards the anatomical side. The findings raise questions over the value of currently available upper limb prostheses to adolescents for use during sport, and larger studies using similar techniques are warranted.

### O.17.5 Towards an activity tracker for wheelchair users

*Marika Leving[1], Kristel Lankhorst[2], Johannes Bussmann[3]*

*[1]UMCG, [2]HU University of Applied Sciences, [3]Erasmus MC University Medical Center*

Wheelchair-dependent individuals are in general more inactive than their ambulatory peers and therefore at greater risk to develop hypoactive-related diseases. Daily wheelchair activity is assumed to be one way to counteract the negative effects of hypoactive behavior. As for non-disabled people, objective feedback on activity through an activity tracker can contribute to increasing activity.[1] Therefore we developed and validated an activity monitor for wheelchair users. The device is based on two Activ8 sensors, one on the wrist, and one attached to the spokes of the manually propelled wheelchair. Data from both sensors are synchronized and counts (acceleration level) and time assigned to pre-defined ambulant movement classes from both sensors were used in a decision-tree algorithm to classify the following wheelchair related activities: driving at normal and fast speed, maneuvering, assisted propulsion (being pushed), and wheelchair non-move. Count thresholds for wheel and wrist acceleration, related to respectively wheelchair speed and arm propulsion movement, were set based on pilot data. We conducted two video-controlled validation studies, one with healthy people driving a wheelchair (n = 16)[2] and one with children with cerebral palsy (n = 7) who use a wheelchair. The results were satisfying. Agreement for wheelchair driving was on average higher than 85% and for non-move higher than 90%. To better separate normal (self-chosen) and fast speed driving individual calibration might be necessary. Meanwhile, in collaboration with the manufacturer of Activ8, the system is transformed into a wheelchair activity tracker (WheelActiv8), with feedback on a smartphone app or computer. If needed, data can be transmitted to a therapist or lifestyle coach. A study has been started aimed at developing a model with which also energy consumption of wheelchair users can be estimated on the basis of data from accelerometers.

## Oral Session 18 – Assessment of Sleep

### O.18.1 Comparison of non-wear and sleep detection algorithms in ActivPAL data

*Jan Behrens[1], Hermann Pohlabeln[1]*

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Purpose: The correct classification of non-wear periods (NW) and sleep in accelerometer data is important for the assessment of physical activity (PA). Here we compared several standard NW and sleep detection algorithm (SlpD) with machine learning (ML) algorithms. Methods: We collected labeled ActivPAL accelerometer data in 18 volunteers who recorded NW and sleep including interruptions in a diary. We considered a simple NW detection of consecutive zeros (NW0), the Choi and Troiano algorithms as well as naïve Bayes (nBay) and random forests (RF) ML algorithms. First we tried different parameter combinations to minimize misclassification rate (MCR) and used 50% of the datasets to train the ML algorithms and then compared the models. We did the same for sleep detection algorithms, where we compared the Sadeh, Cole-Kripke, logistic regression (LogR), gradient boosting (GBM), nBay and RF. Results: For NW detection NW0 had a mean MCR of 3.79%, Troiano 3.84%, Choi 4.2%, RF 6.7% and nBay 57.6%. For sleep detection RF had a mean MCR of 7.89%, LogR 21.4%, GBM 23.7%, nBay 38.3%, Sadeh 65.7% and Cole-Kripke 67.8%. SlpD identified only a small proportion of NW incorrectly as sleep, while the NW algorithms detected quite a lot of sleep as NW. Conclusions: Although the NW detection algorithms NW0, Choi and Troiano were developed for other devices, these algorithms seem to be suitable for detecting NW in ActivPAL data after parameter adjustments. Surprisingly they performed superior to ML algorithms. For SlpD we were not able to tune the parameters to fit ActivPAL data. Although the LogR and GBM follow the same approach as Cole-Kripke, the data did not allow us to find a prediction model. RF performed well for SlpD, but more labeled data should be collected preferably in combination with an objective sleep assessment, like the SOMNOwatch for more

generalizable results. The sequential application of first sleep and then NW detection can improve data analyses and reduce overall MCR

## O.18.2 Can accelerometry data alone detect sleep stages?

*Kevin Murray[1], Berwin Turlach[1], Leon Straker[2], Peter Eastwood[1]*

*[1]University of Western Australia, [2]Curtin University*

Accelerometry is a low-cost and noninvasive method that has been used to discriminate sleep from wake, however, its utility to detect sleep stages is unclear. Using simultaneously measured Actigraph GT3X+ and polysomnography data from 242 healthy young adults (22 years old) in the Western Australian Pregnancy Cohort (Raine) Study we developed and compared methods which utilised raw, 30Hz, triaxial accelerometry data to classify varying stages of sleep, ranging from sleep/wake detection to discriminating rapid eye movement sleep, stage one sleep, stage two sleep, deep sleep and wake. First- and second-order hidden Markov models (HMMs) with time-homogeneous and time-varying transition probability matrices, along with continuous acceleration observations in the form of a Gaussian-observation HMM and K-means classified acceleration in a discrete-observation HMM were explored. In addition, generalised linear mixed models (GLMMs) with binary and multinomial responses and logit link functions were considered as was whether incorporating adjoining acceleration information into the models improved prediction. Model predictions were compared to the reference-standard in sleep detection (polysomnography) and outcome accuracies were calculated. Consistently, HMMs yielded greater sleep stage detection than GLMMs but there was little difference between first- and second-order HMMs. Varying degrees of difference were observed when comparing Gaussian-observation HMMs to discrete-observation HMMs, and time-varying HMMs yielded greater discrimination than time-homogeneous HMMs, as did models which considered adjoining acceleration information. Sleep detection ranged 61-95%, whilst wake detection ranged 61-78%. These results suggest that wrist-worn accelerometry data alone may be able to detect sleep stages but that further investigation is required to optimise classification accuracy.

## O.18.3 Validation of a count-scaled algorithm to assess sleep in children using polysomnography

*Claire Smith[1], Rachael Taylor[1], Barbara Galland[1]*

*[1]University of Otago*

Objectives: There are few algorithms beyond Sadeh for measuring sleep using actigraphy in children that have been validated against the gold standard polysomnography (PSG). Those that have are site or device specific or require each day to be analysed separately; a laborious process. Our count-scaled algorithm (CSA) automatically scores sleep and activity across 24 hours and has been validated against PSG for assessing naps in infants. The aim of this study was to validate the CSA against overnight PSG in older children. Methods: 28 children (5-8 years) with no history of sleep disturbance wore two types of accelerometer (Actigraph GT3X+, Actical) at two sites (waist, non-dominant wrist) for 24 hours. Data were cleaned and scored using our CSA. Overnight PSG data were recorded using a digital portable monitor (Embletta MPRPG, ST+Proxy, TX Proxy) at home following standard procedures. Agreement with PSG was measured epoch by epoch to determine specificity and sensitivity for sleep/wake epochs and agreement of summary sleep outcomes. Results: Children were 7.2 (SD 1.2) years, 61% were male, and 29% overweight. Sensitivity was high for both devices whether worn at the waist (Actigraph 97%, Actical 99%) or wrist (96% and 98%). Specificity was highest for the wrist-worn Actigraph (61%). Sleep onset was measured accurately by the waist-worn Actigraph (+6 mins, p=0.328) and wrist-worn Actical (-3 mins, p=0.652). Differences in total sleep time ranged from 9 (wrist Actical, p=0.420) to 59 (waist Actical, p<0.001) minutes. No significant differences in sleep offset were observed for either device at either placement site (all p≥0.084) compared with PSG. The CSA significantly overestimated sleep efficiency by 5-6% with both devices at the waist, but not Actigraph worn at the wrist (-0.6%, p=0.717). Conclusion: The CSA performs well against PSG for assessing sleep variables, with lesser accuracy for those incorporating wake; a limitation and characteristic of all actigraphy.

## 0.18.4 OpenCoDa: Advancing compositional analysis of 24-hour time-use and movement behaviour data through open science

*Duncan McGregor[1], Javier Palarea-Albaladejo[2], Philippa Dall[1]*

*[1]Glasgow Caledonian University, [2]Biomathematics and Statistics Scotland*

Background It is well-known that physical activity has a positive effect on health outcomes, whilst sedentary behaviour is associated with worse health outcomes. However, the interplay between these behaviours remains an open question. Such quantities convey relative information and are inherently interdependent (e.g. if you do an extra hour of vigorous activity you must be doing an hour less of some other type of activity). Conventional multivariate analysis techniques are not generally designed to deal with these data constraints, prompting the development of specialised theories and methods for compositional data analysis (CoDa). Recently there has been increased interest in these techniques but uptake remains low, perhaps due to their perceived complexity. The OpenCoDa project aimed to help address this within the physical activity research community. Methods A website was created (www.opencoda.net), with initial resources such as online programs, R code, introductory presentations, and selected published CoDa papers uploaded by the core team, then other researchers were invited to contribute materials. All materials were made freely available in line with open science principles. Following this, the first open science collaboration (a large harmonised meta-analysis) commenced in September 2018. This online presence was supplemented by other forms of outreach including a Hackathon organised in 2018 to provide researchers with an opportunity to spend a day learning about CoDa methods and apply them ina data challenge. Outcome The site is currently live and contains a variety of resources including online tools to perform some common data analyses using a simple point and click interface, which can form a useful starting point for researchers. The Hackathon was well received by participants in general. An increased number of physical activity researchers are aware of CoDa techniques, and have greater familiarity with the methods.

## O.18.5  Joint and individual representation of domains of physical activity, sleep, and circadian rhythmicity

*Junrui Di[1]*

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Developments in wearable technology have enabled researchers to continuously and objectively monitor various aspects and physiological domains of real-life including levels of physical activity, quality of sleep, and strength of circadian rhythm in many epidemiological and clinical studies. Current analytical practice is to summarize each of these three domains individually via a standard inventory of interpretable features, and explore individual associations between the features and clinical variables. However, the features often exhibit significant interaction and correlation both within and between domains. Integration of features across multiple domains remains methodologically challenging. To address this problem, we propose to use joint and individual variation explained (JIVE), a dimension reduction technique that efficiently deals with multivariate data representing multiple domains. In this paper, we review the most frequently used domain-specific features and illustrate our approach using wrist-worn actigraphy data from 198 participants of the Baltimore Longitudinal Study of Aging.

# Friday, June 28th: Day 4

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## Oral Session 19 – Special Populations

## O.19.1  The relationship between gait cadence variability and mobility impairment in acute stroke patients

*Jesse Dawson[1], Terry Quinn[1], Craig Speirs[2]*

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Background and Aim While most stroke patients recover some walking function, the slow, immutable walking speeds typically achieved after rehabilitation poorly equips them for the varying demands of walking in the community. The ability to regulate cadence suggests a retention of the motor skills necessary to navigate round the community. The aim of this study was to measure the cadence variability of stroke patients and test for agreement with a clinical measure of mobility impairment. Methods Medically stable patients referred for physiotherapy and within 6 weeks of their stroke were recruited from two stroke units. Participants (n=37) were aged 66.3 years (SD 13.1) and 8.3 (SD 7.1) days since their stroke. Following consent a research nurse carried out the Modified Rivermead Mobility Index (MRMI) which rates performance on 8 functional tasks using a 6 point scale. An activPAL (PAL Technologies, Glasgow, UK) was then attached to the front of their non-hemiplegic thigh and left in place for 14 days of continuous monitoring. Results Data containing walking bouts exceeding 10 s were available from 26 participants over 323 days. This group had an MRMI score of 21.0 (10.6) and a median stride cadence of 20.15 (range 11.4-35.8) steps per minute. The spearman's rho showed a moderate positive correlation (r=0.61, P=0.001) between MRMI and the cadence range (max-min), see figure. Figure: Scattergraph of cadence range and MRMI Discussion The moderate relationship between gait cadence range and mobility impairment is expected with less impaired individuals more likely to walk for longer periods. The relationship does however highlight the importance of training speed variability during rehabilitation to reflect the range required by the higher functioning participants in our study. Future studies should investigate whether the ability to vary cadence is a predictive factor in the recovery of community walking function.

### O.19.2  The effects of multiple sclerosis on community ambulation: beyond reduced activity

*Shirley Shema-Shiratzky[1], Anat Mirelman[2], Keren Regev[1], Arnon Karni[1], Jacob Sosnoff[3], Jeffrey Hausdorff[2]*

*[1]Tel-Aviv Sourasky Medical Center, [2]Tel Aviv Sourasky Medical Center, [3]University of Illinois at Urbana-Champaign*

OBJECTIVE:To explore differences in activity patterns and quantitative gait measures during daily life between people with MS (pwMS) and healthy controls. METHODS:Forty-four pwMS were compared to 61 healthy adults. Community ambulation was assessed using a tri-axial accelerometer (Axivity AX3) worn on the lower back for 7 days. PwMS reported on the impact of MS-induced fatigue and gait disability on their daily function using the modified fatigue impact scale and the MS walking scale, respectively. Disability levels were determined using the Expanded Disability Status Scale (EDSS). RESULTS: Participants were 50.8±8.9 yrs old; 63% were female. Age, gender, and height were similar between groups (p>0.08). PwMS (mean EDSS 3.7±1.5) had lower step counts (p<0.001) and almost 3-times fewer long walking bouts (i.e., above 60 sec) compared to healthy controls (4.4±3.0 vs. 11.2±7.0, p<0.001 respectively). Moreover, pwMS walked slower, with smaller steps, higher stride time variability, and lower step and stride regularity (p<0.004). Among pwMS, a lower number of steps was correlated with a higher disease duration (r=-0.52, p<0.001) and worse gait disability (r=-0.40, p=0.015). Greater disability was also correlated with lower gait speed and regularity (r<-0.34, p<0.026) and with higher stride time variability (r=0.45, p=0.006). Worse fatigue scores were associated with increased lying periods during the day (r=0.45, p=0.008), but were unrelated to any of the gait features. CONCLUSIONS:Using a wearable device, the present findings provide objective evidence that pwMS are less active compared to age-matched controls and they have much fewer long walking segments in daily life. The use of a single sensor sheds light on the quality of daily ambulation, above and beyond the amount of activity, indicating a poor gait pattern, unsteadiness and a higher fall risk in MS. Interestingly, MS-fatigue was not associated with gait itself but was reflected in greater daytime resting.

### O.19.3  Week and weekend day cadence patterns long-term post-bariatric surgery

*Ryan Reid[1], Tiago Barreira[2], Charlotte Haugan[1], Tyler Reid[3], Ross Anderson[1]*

*[1]McGill University, [2]University of Syracuse, [3]Stanford University*

Obesity can negatively effect walking, reducing the intensity of daily activities, increasing the risk of weight gain. Purpose: Objectively describe walking cadence long-term post-bariatric surgery. Methods: 58 subjects, 51.2(8.9) yrs old, with a BMI 34.6(10.1) kg/m2, 10.0(3.1) yrs post-surgery wore an activPAL accelerometer for 7-consecutive days. Using a Matlab script and activPAL event files, walking events were extracted including start time, duration, number of steps and average cadence of these events. All walking events were analyzed to determine the

distribution and relative contributions of these events within different cadence bands to the overall volume of walking. Cadence of all walking events was analyzed: Number of min spent walking within specified cadence bands; proportion of steps taken above a specified cadence; cadence of purposeful walking (>30seconds (s), >60s and >120s). Data was analyzed using subjects current BMI, dichotomized by obesity status, < or ≥30 kg/m2. Results: On average, subjects spent 5124(2549) steps/day on week days and 6097(786) steps/day on weekend days (p = .003). Subjects spent the majority (75%) of daily steps at a slow-walking average cadence (Non-Obese: Week = 65.3(5.0) and Weekend = 63.8(6.7) steps/min; Obese: Week = 67.8(8.2) and Weekend = 63.3(6.9) steps/min), with no difference between groups for week or weekend days (p=.153 and .774). Cadence of subjects with obesity was significantly lower on weekends compared to week days for walking events >30s (p=.002) and >60s (p=.008) in duration. Week day cadence of subjects without obesity was similar to weekend day cadence across all walking event durations. Most walking events occurred <30s in duration. Conclusions: Long-term post-bariatric surgery, most movement occurs in short duration bouts at a slow-walking cadence. Individuals without obesity have similar movement patterns on week and weekend days while subjects with obesity decrease their cadence on weekend days.

### O.19.4  Added value of a within-subject approach of stress and physical behaviour in stroke patients

*Marlou Limpens[1], Uli Ebner-Priemer[2], Tuna Aliskan Turkbey T[3], Marco Giurgiu[4], Ingrid Brands[3], Gerard Ribbers[1]*

*[1]Erasmus MC University Medical Center Rotterdam, [2]Karlsruher Institute of Technology, [3]Libra Revalidatie & Audiologie, [4]Karlsruhe Institute of Technology (KIT)*

Background Stress is a prevalent and disabling problem in stroke rehabilitation. There is conflicting evidence of the underlying mechanisms and its relationship with physical behaviour. This might be caused by the most common measurement and analyses approach, which is based on between-subject analyses. It is hypothesized that a within-subject approach might elucidate relationships that are hidden while using a between-subject approach. Aim To explore the relationship between momentary stress and momentary physical activity (based on within-subject analyses), and the relationship between self-reported stress and physical activity over prolonged periods of time (based on between-subject analyses) in people with chronic stroke. Methods 20 chronic stroke patients were included. 5-day ambulatory measurements were performed, including continuous activity monitoring (Activ8) and ecological momentary assessment (EMA) of momentary stress. Besides, experienced overall stress was measured with The Perceived Stress Scale (PSS). The relationship between momentary stress and momentary physical activity (15 minutes before the EMA) was studied with multilevel analyses, whereas the relationship between overall stress and physical activity was studied with regression analysis. Results Momentary physical activity positively predicted momentary stress (beta coefficient = 0.124; p = 0.002). There was no relationship between overall physical activity and experienced overall stress. Discussion/conclusion Levels of physical activity are positively related to subsequent stress levels when using the within-subject approach, while this relationship is absent while using the between-subject approach. We propose the more frequent use of within-subject analyses in research aiming at the determinants of physical behaviour.

### O.19.5  Comparison of upper limb use in people with different levels of upper limb impairment early post-stroke

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Introduction: Accelerometry has been used to quantify upper limb (UL) use post-stroke, but studies have largely investigated people with varying impairment levels together. As paretic UL use may be dependent on motor impairment, analysis according to impairment level may be useful to guide strategies to increase use. This study aimed to characterize paretic UL use in people with different levels of impairment early post-stroke during and outside therapy; and compare UL use in people early post-stroke to age-matched controls. Methods: A prospective cohort study of inpatients with first-time stroke ≤4-weeks (n=60, 61±12 years) categorized by Fugl Meyer UL score for impairment subgroups: mild (51-66), moderate (23-50) and severe (0-22) was conducted. Age-matched, community-dwelling individuals without a history of stroke were also recruited (n=30, 60±11 years). Bilateral wrist-

worn accelerometers (ActiGraph GT3X+) measured duration of paretic UL use and use ratio of paretic/non-paretic and non-dominant/dominant UL over 24hours. Results: Most stroke participants with mild impairment (63%) used their paretic UL >6 hours/day (median(IQR): 6.7(3.3); use ratio 0.9 (0.3)). Those with moderate impairment demonstrated wide variation of use with 13.3% achieving >6 hours/day (median(IQR): 4.5(3.8); use ratio 0.5(0.2)). People with severe impairment demonstrated limited use with none achieving >6 hours/day of use (median(IQR): 1.7(0.7); use ratio 0.3(0.2)). Paretic use and use ratio were greater during therapy sessions compared to outside therapy in moderate and severe groups (p<0.05). Age-matched controls used their non-dominant UL for 8.7(3.0) hours; use ratio 0.9(0.08), significantly more than the combined stroke cohort (p<0.001). Conclusions: Patterns of UL use differed by severity of impairment. Moderate and severe groups used their paretic UL more during therapy, inferring that it is possible to increase paretic use despite motor impairment.

## Oral Session 20 – 24-Hour Activity Cycle (2)

### O.20.1  One Million Days of Mortality: An open science federated analysis of the impact of daily time use on health

*Javier Palarea-Albaladejo[1], Philippa Dall[2], Sebastien Chastin[3]*

*[1]Biomathematics and Statistics Scotland, [2]Glasgow Caledonian University, [3]Glasgow Caledonian University, Ghent University*

Purpose: Techniques from compositional data analysis can be used to investigate the association between physical activity and mortality, however such analyses are often underpowered. The "One Million Days of Mortality" study is an Open Science project organised by OpenCoDa to investigate this association utilising these techniques in a large harmonised analysis across multiple datasets. Methods: Multiple research teams will analyse their own datasets using harmonized methods (Cox regression using compositional covariates). Each team can publish their own results, but at the end of this study a meta-analysis based on the full set of results will be published. The study will run from 1 September 2018 to 1 September 2019, and already includes datasets such as "NHANES 2005-06", "REGARDS", "Whitehall Study 2", and "UK Biobank" but remains open to new teams. Results/findings: The latest available results will be presented, but based on the results at the time of writing the composition of time spent in sedentary behavior (SB), light intensity physical activity (LIPA), moderate-to-vigorous physical activity (MVPA), and sleep was significantly associated with mortality rates after allowing for age and sex effects (p < 0.001). The association is driven primarily by the ratio of MVPA to other behaviors, however significant changes are also attributable to LIPA relative to SB and Sleep, and SB relative to Sleep. After incorporating lifestyle factors, the overall composition remains significant (p < 0.001), however the balance between Sleep and SB ceases to be significant. The effect sizes are typically smaller than are seen in traditional analyses. Conclusions: This study will give us a more comprehensive understanding of how mortality rates are associated with the allocation of time between different physical behaviors across the day by combining data sources and applying a compositional approach which allows for co-dependencies between behaviors and synergies.

### O.20.2  Issues with analysing complex 24-hour accelerometry data to assess sleep, sedentary time, and physical activity

*Jill Haszard[1], Kim Meredith-Jones[1], Barbara Galland[1]*

*[1]University of Otago*

Objectives: Interest in 24-hour accelerometry to assess all movement behaviours is increasing but analyses are complicated. This talk will i) show how to handle missing data (e.g. non-wear time) or that containing lots of zeros (e.g. wake after sleep onset, WASO), and ii) illustrate how the presentation of estimates from compositional analyses (minutes versus proportion of time use) affects relationships with body mass index (BMI z-score). Methods: 24-hour waist-worn accelerometery data (Actigraph GT3X) were collected for 5.2 (SD 0.8) days from 742 children (33.7% overweight/obese) aged 5-12 years. Data were scored using a count-scaled algorithm. After accounting for sleep duration and WASO, time spent in sedentary, light, moderate-to-vigorous activity (MVPA) were determined using Evenson cutoffs and normalised to 24 hours. Associations with body mass index (BMI) z-score were determined using isometric log ratios of the time-use composition variables in regression models.

Results: Across 24 hours, children spent 591 (SD 36) minutes asleep, 433 (57) minutes in sedentary time, 307 (44) in light activity, and 67 (23) minutes in MVPA, with 42 (32) minutes identified as non-wear. Appropriately re-allocating non-wear time to awake-time components (not sleep) changes the estimated difference (95% CI) in BMI z-score from -0.11 (-0.23 to 0.002) to -0.20 (-0.32 to -0.08) if 10% more time is spent asleep. By contrast, reallocating WASO made little difference to BMI estimates. If reallocating time from one component to another is expressed in minutes, increasing MVPA has the largest effect on BMI z-score (-0.10, -0.13 to -0.06 per 10 minute increase). If time is expressed as a proportion, then reallocating more time to sleep has the largest effect on BMI z-score (-0.20, -0.32 to -0.10 per 10% increase). Conclusion: How 24-hour accelerometry data are cleaned and presented can markedly change estimates of the relationship with indices of health.

### O.20.3  The ProPASS multi-dimensional 24-hour movement behavior construct

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Background Most accelerometer-based constructs of physical activity are based on total daily time spent in different intensity bands. However, thigh-worn accelerometers and software tools have opened new avenues for incorporating a variety of other equally important characteristics of physical activity, like posture, activity types and sleep. The aim of ProPASS (Prospective Physical Activity, Sitting and Sleep Consortium) is to develop harmonized thigh-worn pooled accelerometry data sources for prospective individual participant meta-analysis. For this purpose, a new movement behavior construct for thigh-worn accelerometer data was developed. Method Based on a 3-day workshop held in Copenhagen in October 2018 that involved international experts and representatives of major cohorts of thigh-worn accelerometry, we developed a new movement behavior construct tailored to thigh-worn accelerometry data. Results We agreed upon a construct which incorporated multiple layers of movement behavior with different levels of characteristics. The 24-hour construct of movement behavior consists of the following dimensions: A: Intensity (sedentary, light intensity, moderate and vigorous), B) Posture and activity type (lying down, sit, stand, walk, run, cycle, stair walk), C) Time patterns (short, moderate, long uninterrupted periods), D) Domain (work and non-work), E) Biological state (awake, sleep) and F) 24-hour movement profiles. Conclusions This novel movement behavior construct is the starting point towards a unified framework for processing and harmonizing thigh-worn accelerometry data for individual studies and ProPASS. This multi-dimensional comprehensive construct based on thigh-worn accelerometry data will expand our knowledge about the importance of posture, activity type, biological state, time-pattern, domain, and movement profiles within a 24-hour framework.

### O.20.4  Sleep versus activity versus sedentary time: A non-parametric approach to isotemporal substitution regression

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Purpose: Our purpose is to present a new and more flexible statistical methodology that generalizes isotemporal substitution regression (ISR) and compositional data analysis (CDA). Background: A number of large heath surveys such as the National Health and Nutrition Examination Survey (NHANES) include both accelerometer-based estimates of how participants allocate their time between physical activities, sedentary behaviors, and sleep and health related outcomes. The time allocation covariates add up to 24 hours for each participant, and analyzing how those covariates relate to a health related outcome faces a technical challenge (perfect co-linearity) that makes standard regression techniques infeasible. There are two existing approaches to address that challenge: ISR and CDA. ISR is a regression technique that uses all but one of the covariates (typically untransformed) a generalized linear regression models and estimates how reallocation of time from one activity to another relates to the outcome. CDA uses models from the compositional data literature to non-linearly transformations the covariates before they are put into the regression model. Both techniques assume a regression model structure (up to a few unknown coefficients), and, as a result, they are susceptible to mis-specification. Additionally, the multivariate regression relationships make standard residual based lack of fit analyses challenging. Proposed methodology and

application: As an alternative, we developed a non-parametric approach to these data. This approach allows the data to determine form of the relationship between how participants allocate their time and health related outcomes. ISR and CDA are both special cases of the non-parametric model. The new approach also allows the substitution effects to change with different levels of the covariates. We apply our methods to NHANES and examine the relationship between time allocation and body mass index.

## Oral Session 21 – Consumer Technologies

### O.21.2  A comparison of Smartphone-based and Accelerometer-based physical activity measures in bipolar disorder

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Physical activity (PA) in ambulatory assessment (AA) settings can be mesured either with activity monitors (AM) or with smartphones, where both devices use the signal of integrated triaxial acceleration sensor chips. Both devices have different advantages and disadvantages, relying e.g. on wear position and on weartime compliance, whereas it is expected that the AM should outperform the smartphone. Furthermore the acceleration sensor signal provides only a rough estimation of the intensity of PA. Therefore a combination of both devices may increase the accuracy of PA measures. In an AA study, smartphone use was tracked from 27 outpatients with bipolar disorder for one year which, in addition, wore an AM to assess physical activity. From the acceleration raw data of the AM we computed duration and intensity of PA (bandpass filtered Euclidean Norm - BFEN) as well as movement frequencies. Algorithms included in the smartphones Android OS used the acceleration sensor signal to compute steps and the duration, not intensity, of different activity classes (in a vehicle, on foot, on a bicycle, still). Furthermore distances moved and movement speeds were calculated from the GPS signal. Due to technical dropouts and noncompliance AM activity data were available on average from 151 days/subject. The duration of assessed activity (larger than 50 milli-g or about 0.5 MET) was on average 6.6 h/day. In contrast, activity detected by the smartphone algorithm revealed on average 55 minutes of physical activity per day (3 min cycling, 26 min on foot, 26 min moving the smartphone) plus 41 min/day spent in a vehicle. Subsequent analysis were performed to differentiate into activity classes, sleep, and non wear time, and relate this to the smartphone data.

### O.21.3  Development of a GPS measurement based smartphone application to conduct outdoor walking sessions in peripheral artery disease patients

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Objective. To develop a smartphone application (App) - based on the use of external wearable monitors - in order to propose a new solution to conduct home-based outdoor walking programs in peripheral artery disease (PAD) patients. Methods. A dedicated smartphone App for the assessment of outdoor walking capacity in PAD patients was developed on Android, as a part of the SHERPAM project that aims to implement an open platform for mobile e-health applications. Results. The smartphone App enables the patient to manage walking sessions through different dedicated graphical interfaces: i) entry of the targeted effective walking duration; ii) management of both Bluetooth connection with an external GPS receiver (Qstarz BTQ1000XT?) and satellites reception by the receiver; iii) automatic detection by the App of walking/stopping bouts using a specific algorithm; when a stop is detected a pop-up window together with a phone vibration is emitted. The patient indicates whether the walking stop was due to pain or not. If yes, the patient selects the pain level reached before to stop using a validated pain scale. GPS data are continuously transmitted to the smartphone, which stores and then transmits the data to a distant aggregation server using available radio technology (e.g., Wi-Fi or 4G). At the end of the walking session a summary is shown to the patient and then is automatically sent to the medical staff. A WEB interface enables the medical staff to visualize and re-analyze data. Conclusions. Although an increasing number of smartphone App to assess physical activity are available, the present App focuses on the assessment of walking capacity in people with walking limitations, allowing the use of currently available and external wearable devices (not only GPS). The App

is currently under testing in a population of PAD patients (Funding: i. National Research Agency CominLabs Excellence Laboratory program -reference ANR-10-LABX-07-01; ii. SFETD - APICIL foundation grant).

### O.21.4  Validity of consumer monitors for estimating steps in youth

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OBJECTIVE: 1) Compare steps from hip, wrist, and ankle-worn ActiGraph GT9X (AG) devices to hand-counted steps across a wide range of activities in youth; and 2) compare steps from five consumer monitors to the best performing AG location from part 1. METHODS: Youth (N=100; ages 6-18 yrs) completed two lab visits. During each visit, participants performed eight different semi-structured activities (16 total activities, ranging from sedentary to vigorous intensities) while wearing an AG on the right hip, both wrists, and both ankles, an Apple Watch 2 (AW, left wrist), Mymo Activity Tracker (MT, right hip), and two Misfit Shine 2 (MSH, right hip; MSS, right shoe). Participants also wore a Samsung Gear Fit 2 (SGF) or a Fitbit Charge 2 (FC) on the right wrist. For part 1, video recordings from 43 participants were reviewed and only periods where the feet were visible were used. Hand-counted steps (criterion) were regressed against time synced AG steps from each wear location, with and without applying low-frequency extension (LFE). For part 2, paired sample t-tests were used to compare the total step counts from both visits from each consumer monitor to the best performing AG step estimate from part 1. The AG was used as the criterion as we did not have time-stamped step counts from the consumer monitors. RESULTS: There were 429 stepping periods lasting (mean±SD) 2.8±1.8 min and including 127±155 steps per bout. The hip-worn AG with LFE had the only slope not significantly different from one (b1=1.002, p=0.85) and an intercept close to zero (b0=-4.5, p=0.02). Thus, the hip-worn AG with LFE was chosen as the criterion in part 2. Part 2 results are summarized in table 1. CONCLUSIONS: Hip-worn AG devices with LFE enabled may be useful for step counting in free-living youth. Caution should be used when tracking steps using consumer monitors in youth as output is highly variable between devices. Study supported by NIH grant R01HD083431

### O.21.5  Examining the congruence of relative exercise intensity estimates between chest and wrist-worn heart rate monitors

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Objective: Wrist-worn heart rate (HR) monitors (e.g. Fitbit) are shown to underestimate HR compared to criterion measures. This study examined the congruence of relative intensity estimates from two divergent HR sensors using heart rate reserve (HRR). We also investigate the extent to which activity type and intensity affect Fitbit accuracy. Methods: Participants (N=39) were young adults who concurrently wore a Fitbit Charge HR (FB) and Polar H7 (H7) HR monitor for 7 days while recording the type and duration of any purposeful exercise. Exercise type was defined by seven unique categories. Relative intensity (%HRR) was summarized as light, moderate, and vigorous (%HRR=20-39%, 40-59%, >/=60%, respectively). Overall congruence of HRR intensity levels was found for each exercise type and then sorted by congruence. Correlation of congruence was tested against total minutes recorded in each exercise type, the variability (SD) of FB HRR, standard error of the mean (SEM) of FB HRR, spread (VAR) of HRR intensity level, and percent time in moderate to vigorous intensity activity (MVPA). R-squared measured congruence correlation to each variable. Results: Congruence between the two HRR based intensity levels ranged from 45-79%. Congruence was not correlated with the number of minutes recorded in each exercise category (Rsq=0.002), or the FB HRR SEM (Rsq=0.028). Congruence was found to correlate to the FB HRR SD (Rsq=0.673) and both H7 and FB determined HRR intensity level VAR (Rsq=0.436, 0.556). Finally, the H7 HRR assessed time in MVPA (criterion measure) did not relate to the overall agreement (Rsq=0.065), while the FB HRR time in MVPA was found to positively relate to device congruence (Rsq=0.400). Conclusion: Congruence varied by exercise type and is notably stronger for aerobic versus anaerobic exercises. FB HR error appears to decrease as overall FB HRR increases, but not necessarily by the actual (H7 measured) HRR level.