



## Automatic Detection of Respiratory Events During Sleep Using Bidirectional LSTM Networks

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**Methods:** Phenotypes were measured within age-matched male DO mice ( $n=338$ ) and the 5 common [A/J ( $n=6$ ), C57BL/6J ( $n=14$ ), 129S1/SvImJ ( $n=6$ ), NOD/LtJ ( $n=6$ ), NZO/H1LtJ ( $n=6$ )] and 3 wild-derived [CAST/EIJ ( $n=8$ ), PWK/PHJ ( $n=8$ ), WSB/EIJ ( $n=6$ )] inbred founders. A sleep definition of  $\geq 40$  seconds of continuous inactivity using infrared beams was utilized to quantify sleep/wake amounts and bout characteristics in light and dark phases. Latency to sleep (vigilance), multiple sleep latency test (MSLT), response to sleep deprivation, and circadian period (using wheel running) were also estimated. Reproducibility was calculated using Intraclass Correlation Coefficients (ICCs) from repeated assessments. Narrow-sense heritability ( $h^2$ ) was calculated as the proportion of variability explained by additive genetic effects using genotype data in DO mice, and broad-sense heritability ( $H^2$ ) calculated as the proportion of variability explained by genotype in founders.

**Results:** Most phenotypes were reproducible within individual mice, with  $ICC \geq 0.60$ . Sleep and wake phenotypes using alternative definitions of  $\geq 20$ ,  $\geq 60$  or  $\geq 80$  seconds of inactivity were highly correlated ( $\rho > 0.85$ ) with primary measures ( $\geq 40$  seconds), demonstrating the robustness of the sleep definition. Differences in all traits were seen between founder strains and there was moderate-high heritability for most phenotypes; sleep/wake characteristics during lights-off and circadian period were the most heritable ( $H^2=54-60\%$ ). There was large phenotypic variability among DO mice; values covered and extended beyond the range across founders. Estimates of heritability were lower in DO mice than in founders, with circadian period the most heritable ( $h^2=36\%$ ). This may reflect unmeasured non-additive genetic effects.

**Conclusion:** A high-throughput phenotyping strategy based on monitoring of activity patterns in mice provides reproducible estimates of sleep and circadian characteristics with evidence of heritability. This paradigm is suitable for use in DO mice, where genetic factors explain some proportion of phenotypic variability.

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### 0326

#### IDENTIFICATION OF OBJECTIVE AND SUBJECTIVE MARKERS OF SLEEP HEALTH

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**Introduction:** While the concept of 'sleep health' has only recently been defined, how it relates to both subjective and objective sleep parameters has yet to be determined. The current study aimed to identify potential sleep (subjective and objective) markers of sleep health in a sample of healthy adults.

**Methods:** A cross-sectional study with both a questionnaire-based and an in-lab component was conducted with eighty-three 'normal sleepers' (aged 18–65). All participants reported no history of insomnia, any other sleep disorders or chronic physical or psychiatric illnesses. A selection of questions from various psychometric scales were used to determine sleep health status. Measures of psychological distress, perceived stress, stressful life events, sleep beliefs, sleep preoccupation and insomnia vulnerability were also administered. Subjective sleep continuity was assessed by two-week sleep diary. Objective measures comprised 14 days of actigraphy and two-nights of in-lab polysomnography (PSG).

**Results:** Significant correlations were found between sleep health status and subjective Sleep Efficiency (diary) and Sleep Latency (from both diary and actigraphy). Independent samples t-tests between high and low sleep health groups reflected this. No relationships between

sleep health and PSG parameters were not observed. Regression analyses indicated SOL (diary) and SOL (actigraphy) were significant predictors of sleep health, explaining 24.9% of the variance in scores.

**Conclusion:** Sleep health is likely to be a largely subjective and multidimensional concept, which may be predicted by perceived sleep latency and sleep efficiency. However, it is suggested that PSG sleep parameters cannot reliably infer sleep health status in normal sleepers. Future research is warranted to determine the dimensionality of the concept, and the physical and psychological correlates of sleep health in larger samples.

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### 0327

#### DISTINCT PATTERNS OF EEG-EMG-COHERENCE IN VARIOUS STAGES OF DISEASE SEVERITY IN PATIENTS WITH SLEEP-DISORDERED BREATHING

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**Introduction:** We investigated whether using EEG-EMG-coherence (EEC) as a feature fed to a support vector machine (SVM) algorithm may allow staging of disease severity among sleep-disordered-breathing (SDB) patients.

**Methods:** EEG-EMG-coherence data resulted by applying a multi-taper processing for estimating the power spectrums separately and calculating the coherence on raw C3-/C4-EEG- and EMG- chin data of polysomnographic (PSG) recordings of 102 SDB patients (33 female; age: 53,  $\pm 12.4$  yrs) acquired on two consecutive nights in each patient. Four epochs (30 seconds each, classified manually by AASM 2012-criteria) of each sleep stage were marked (in total 1632 epochs / night) and were included in the analysis. After multitaper processing, EEC values were fed to a SVM algorithm to classify SDB disease severity based on respiratory disturbance index (RDI). Twenty patients had a mild ( $RDI \geq 10 / h$  and  $< 15 / h$ ), 30 patients had a moderate ( $RDI \geq 15 / h$  and  $< 30 / h$ ) and 27 patients had a severe OSA ( $RDI \geq 30 / h$ ). Twenty five patients had a  $RDI < 10 / h$ . The AUC (area under the curve) value was calculated for each receiver operator characteristic (ROC) curve.

**Results:** EEG-EMG coherence values could distinguish between SDB-patients without OSA and OSA patients of the above three severity groups using an SVM algorithm. Using PSG data of the first night the AUC for mild OSA was 0.602 ( $p = 0.032$ ), in moderate OSA the AUC was 0.6319 ( $p = 0.021$ ), and in severe OSA the AUC was 0.823 ( $p < 0.001$ ). On the second night, in mild OSA the AUC was 0.616 ( $p = 0.024$ ), in moderate OSA the AUC was 0.659 ( $p = 0.003$ ), and in severe OSA the AUC was 0.823 ( $p < 0.001$ ).

**Conclusion:** Grading disease severity in SDB patients can be performed using PSG-based multitaper-processed EEC values processed with a SVM algorithm. No clinically relevant first night- effect was shown in EEC values. EEG-EMG-coherence appears to be a robust marker for SDB severity classification.

### 0328

#### AUTOMATIC DETECTION OF RESPIRATORY EVENTS DURING SLEEP USING BIDIRECTIONAL LSTM NETWORKS

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**Introduction:** Sleep apnea is a common sleep disorder, which involves cessation of breathing due to obstruction of the upper airway (obstructive) or due to suspension of ventilatory effort (central) during sleep. Currently, sleep apnea is diagnosed using polysomnography (PSG). Breathing events are manually scored by trained sleep technicians, however this is time-consuming, expensive, and prone to subjective interpretation. Thus, the aim of this study was to develop a fully automatic algorithm to detect respiratory events in sleep.

**Methods:** Oxygen saturation, nasal pressure (transducer), oral airflow (thermistor), respiratory effort (RIP belts), and snoring signals were extracted from 2,366 PSGs from the Wisconsin Sleep Cohort (age:  $59.7 \pm 8.4$ , BMI:  $31.6 \pm 7.2$  (mean $\pm$ SD)). After filtering, sixteen features (time and frequency domain) were extracted from each signal using a sliding window of ten seconds with eight seconds overlap. Two models were developed based on bidirectional long short-term memory (bLSTM) neural networks: 1) a two-class model for classification of windows as “normal” or “event”, and 2) a four-class model for classification as “normal”, “obstructive”, “central”, or “mixed”. 1882 subjects were used for training; 249 subjects were used for validation. Preliminary results were obtained for a test set of 235 subjects.

**Results:** With respect to the total number of events, the two-class model obtained precision of 0.740 and recall of 0.769. The four-class model obtained precision of 0.787, 0.205, and 0.100, and recall of 0.685, 0.190, and 0.0985, for obstructive, central, and mixed events, respectively. The Pearson correlation coefficient between annotated and predicted apnea hypopnea index (AHI) were 0.844 and 0.861 for the two-class and the four-class model, respectively.

**Conclusion:** These results indicate that obstructive events can be reliably detected with a bLSTM network. However, the models had difficulties detecting central and mixed events correctly, which were present in a very limited number (1.5 % and 0.21 % of events). Future work includes improving the models for central and mixed event detection.

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### 0329

#### RECORDING OF RESPIRATION BY ANALYSIS OF HIGH RESOLUTION ACTIGRAPHY FOR SLEEP APNEA DIAGNOSIS IN FIELD STUDIES

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**Introduction:** Large field studies now check for the prevalence of sleep apnea using simplified low cost recording technologies. A national field study on 200,000 persons investigates a subset of 40,000 persons with actigraphy and single-lead 24-hour ECG to check for arrhythmias and sleep apnea.

**Methods:** In order to validate the actigraphy and 24-hour ECG recording 500 patients referred to polysomnography in a sleep center are equipped in parallel with actigraphy (one on the wrist and one on

the hip) and a single-lead 24-hour ECG. For actigraphy on the wrist a Somnowatch plus (128 Hz sampling) with 3D acceleration was used. For actigraphy on the hip a GT3X+, primarily applied for estimating energy consumption, was used. ECG was analyzed for heart rate variability and electrocardiographic derived respiration (EDR) for all sleep stages. Actigraphy was analyzed for threshold passing and in addition with spectral analysis in 30-second epochs in parallel with PSG sleep scorings.

**Results:** The validation study has now completed 155 patients. Mean age of subjects is 45.7 years. Mean AHI in this sleep center population was 12 /hour. Analysis of cyclical variation of heart rate and EDR allows to detect sleep apnea events from single-lead ECG recordings. In addition, it was possible to detect respiration from high resolution actigraphy both from wrist and hip placed devices by applying a frequency analysis on 30-second epochs. Detection of respiration is best for stage N3.

**Conclusion:** The surprising result showed that actigraphy allowed to detect respiration with high accuracy during sleep and during periods with low activity. With this it appears possible to detect apnea events as well. To validate apnea recognition more subjects with apnea are needed. If successful this will allow to improve ECG based apnea detection and will allow to apply simple recording technology on really large epidemiological cohort studies to check prevalence in unselected groups of subjects.

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### 0330

#### DEVELOPMENT AND VALIDATION OF AN ALGORITHM TO QUANTIFY OBSTRUCTIVE SLEEP APNEA SEVERITY FROM THE ELECTRONIC MEDICAL RECORD.

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**Introduction:** Electronic medical record (EMR) data can be helpful in understanding the role of obstructive sleep apnea (OSA) as a risk factor for cardiovascular disease and other adverse outcomes. Unfortunately, billing-code based identification of OSA does not allow for evaluation of OSA severity. We aimed to develop and validate a program to identify patients with OSA and quantify disease severity by extracting data from sleep study results in a large healthcare system EMR.

**Methods:** The study population included patients  $\geq 18$  years old who had an in-laboratory or home sleep study conducted at one of six sleep laboratories within the University of Pittsburgh Medical Center system between 1999 and 2015. We identified reports generated from the Medical Archival System (MARS) and employed Python to parse the text reports and Structured Query Language (SQL) scripts to further process the data. The program extracted study type, apnea hypopnea index (AHI), sleep stages, oxygen saturation levels and total sleep time (TST). Algorithm results were validated in a sample of 467 patients by manual review of records.

**Results:** We identified 42,329 adult patients (mean age 51.4 yrs, 48% female) who underwent a sleep study during the study period. Of these, 27,208 patients (64.3%) were identified as having OSA, with 39.2% mild OSA, 25.5% moderate OSA, and 35.3% severe OSA. Accuracy in identifying AHI was 99.8%, time in N3 sleep was 99.5%, time in REM sleep was 99.5%, TST 100%, and percent time with O<sub>2</sub> saturation  $< 90\%$  was 100%. The program correctly classified OSA severity (none, mild, moderate, severe) in 466/467 (99.8%) of cases.

**Conclusion:** Our EMR-based algorithm had a high level of accuracy in identifying sleep study diagnosed OSA, OSA severity and other key