Sleep Staging with a Wearable Respiratory Device
Deep Transfer Learning from an Inductance Plethysmography-based Model

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INTRODUCTION

Electroencephalography (EEG) is used as the main signal to stage sleep. However, a more practical and patient-friendly assessment of sleep is in demand. Here, we assess the efficacy of a wearable respiratory device called AirGo (MyAir LLC).

Previously, a deep learning (DL) model, consisting of a CNN and LSTM, was trained to stage sleep for 30-second epochs from abdominal respiratory inductance plethysmography (RIP) signals on a dataset of more than 6000 annotated polysomnographies (PSG), recorded at the Massachusetts General Hospital sleep laboratory. The model showed good agreement with human experts on a test set of 1000 PSGs (Cohen's kappa of 0.579).

AIMS

- Build a model that can stage sleep from a wearable respiratory signal.
- Use the existing DL model based on RIP signal and adapt it to the wearable signal ('Transfer Learning').

METHODS

260 PSGs that contain the RIP and wearable respiratory signal are used to train and evaluate a model (Train: 230, Validation: 15, Test: 15 PSGs).

Wearable signal is preprocessed (detrended, filtered) and 270-second segments are used to predict the center 30-second-epoch.

Weights of the RIP DL model are used to start with. Initially, only the first and last hidden layers are free to train, followed by all of the parameters of the CNN. Finally, all LSTM parameters are optimized.

SIGNALS

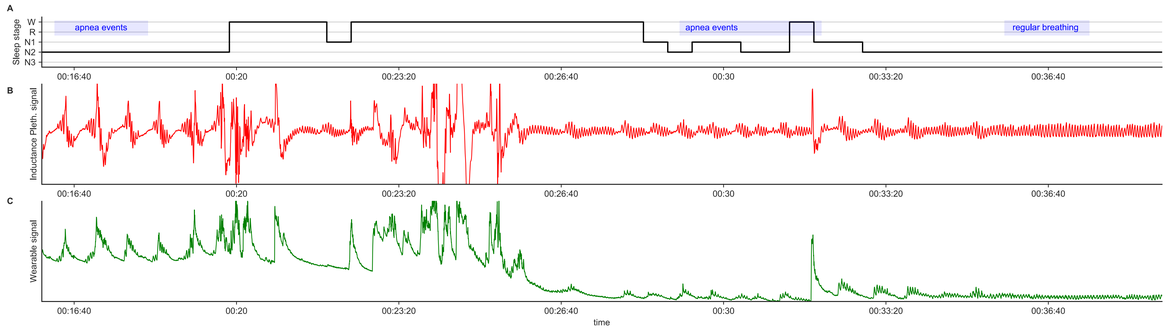

Figure 1. A 35-minute example of a PSG containing both RIP **(B)** and wearable respiratory signal **(C).** Relatedness of signals enables transfer learning.

SLEEP STAGING MODEL BUILDING

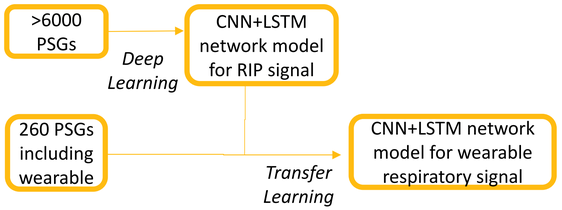

Figure 2. Scheme of model building. A deep learning model, that has been trained on RIP signals, and a PSG dataset, containing both RIP and wearable signals, are used to build a model based on the wearable respiratory signal.

RESULTS

Agreement with human expert (Cohen's kappa κ):

	κ
W, N1, N2, N3, R	0.47
W+N1, N2+N3, R	0.61
W, N1+N2+N3, R	0.62

Confusion matrix (%):

expert label \ model prediction	W	N1	N2	N3	R
W	61.6	22.3	11.7	0.9	3.6
N1	11.9	47.6	26.4	1.9	12.2
N2	1.2	13.3	58.6	14.6	12.4
N3	0.8	0.7	34.7	54.4	9.4
R	0.1	1.7	9.4	1.0	87.8

Figure 3. Cohen's kappa and the confusion matrix correspond to the model's performance on the test set (15 PSGs, 13049 30-second epochs).

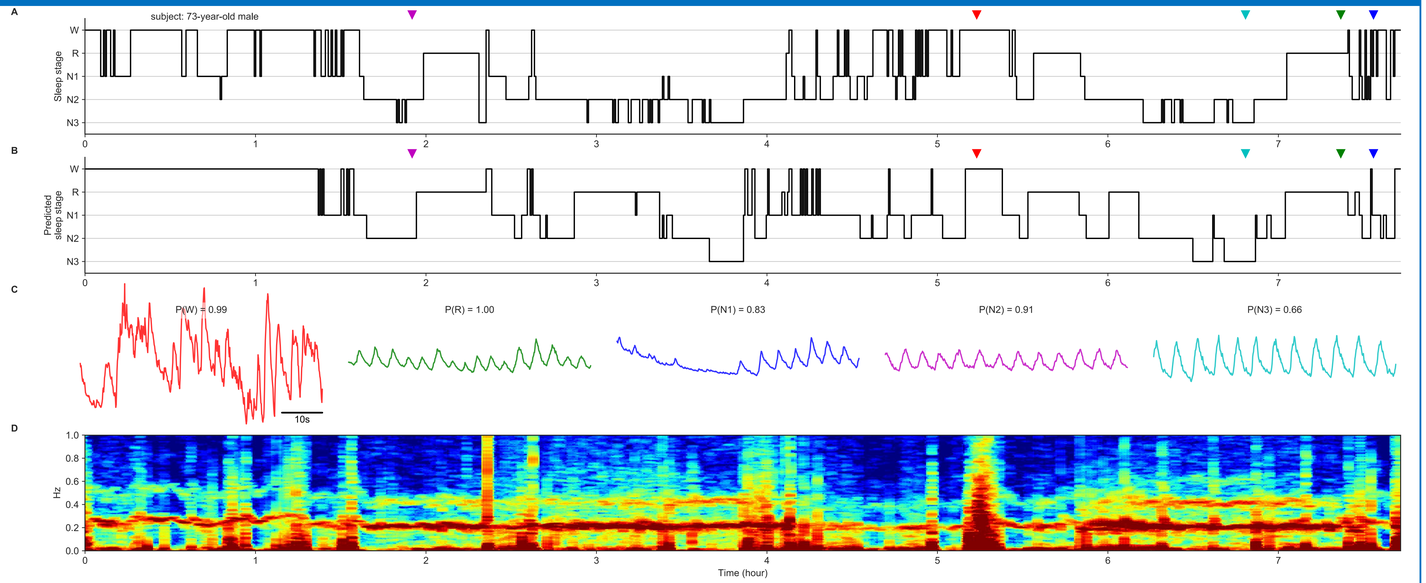

Figure 4. Example PSG file of test set. **A)** Hypnogram showing the sleep stages throughout the night as annotated by the human expert. **B)** Hypnogram based on the model's predictions. Cohen's kappa for this PSG is 0.49, comparable to the overall kappa of the test set. **C)** One-minute wearable respiratory signal segments which maximize the model's probability output for each sleep stage. The segments show a clear distinction in amplitude and regularity of breathing for the different sleep stages. **D)** Multitaper-based spectrogram of the preprocessed wearable respiratory signal.

CONCLUSION

- Transfer learning provides a model to stage sleep with a wearable respiratory device.
- The sleep stage-prediction model's performance and agreement with human expert is moderate to substantial.
- More wearable device data and hyperparameter tuning might further increase performance.
- Model can help with more practical and patient-friendly assessment of sleep.

ACKNOWLEDGMENTS

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DISCLOSURE

R.Thomas: Patent and license to MyCardio, LLC. ECG spectrogram Patent-CO2 device for central sleep apnea, Patent and license-DeVilbiss-Drive, auto CPAP algorithm, General Sleep Medicine consulting-Guidepoint Global, GLG Council.
DK is founder and CEO of MyAir LLC, inventor of AirGo platform.
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