Advanced analysis of sleep using multi-modal sensing

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ActiGraph

Sleep is important to our health

Sleep deficiency is associated with major health risks

Cardiovascular

- Short sleep duration is associated with a greater risk of developing or dying from coronary heart disease and stroke [1]

Accidents

- Short sleep duration is associated with an increased risk of automobile and workplace accidents [2]

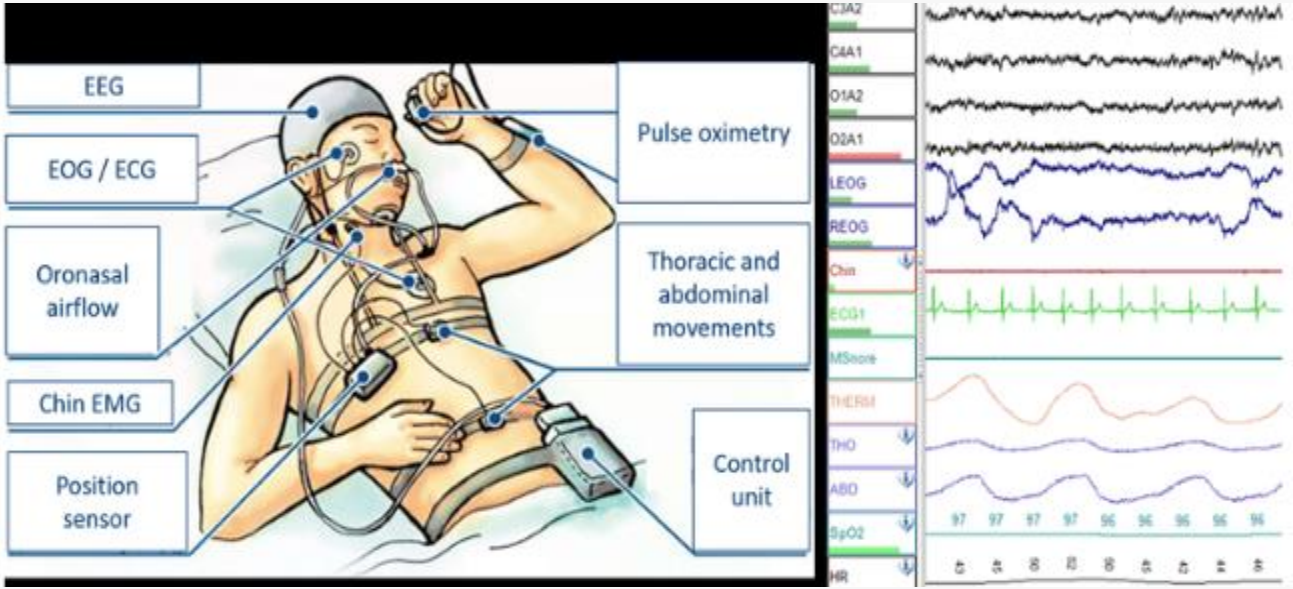
Metabolic

- Observational and longitudinal epidemiologic studies suggest that short (and possibly long) sleep duration is a risk factor for obesity and the development of type 2 diabetes [3]

Cancer

- Short sleep duration has been associated with a greater risk of developing breast cancer, colorectal cancer, and prostate cancer [4, 5]

Gold Standard of Sleep Measurement: Polysomnography



PSG Image from:

- Crivello, A., Barsocchi, P., Girolami, M., & Palumbo, F. (2019). The meaning of sleep quality: a survey of available technologies. *IEEE access*, *7*, 167374-167390.

How to understand sleep outside of the laboratory

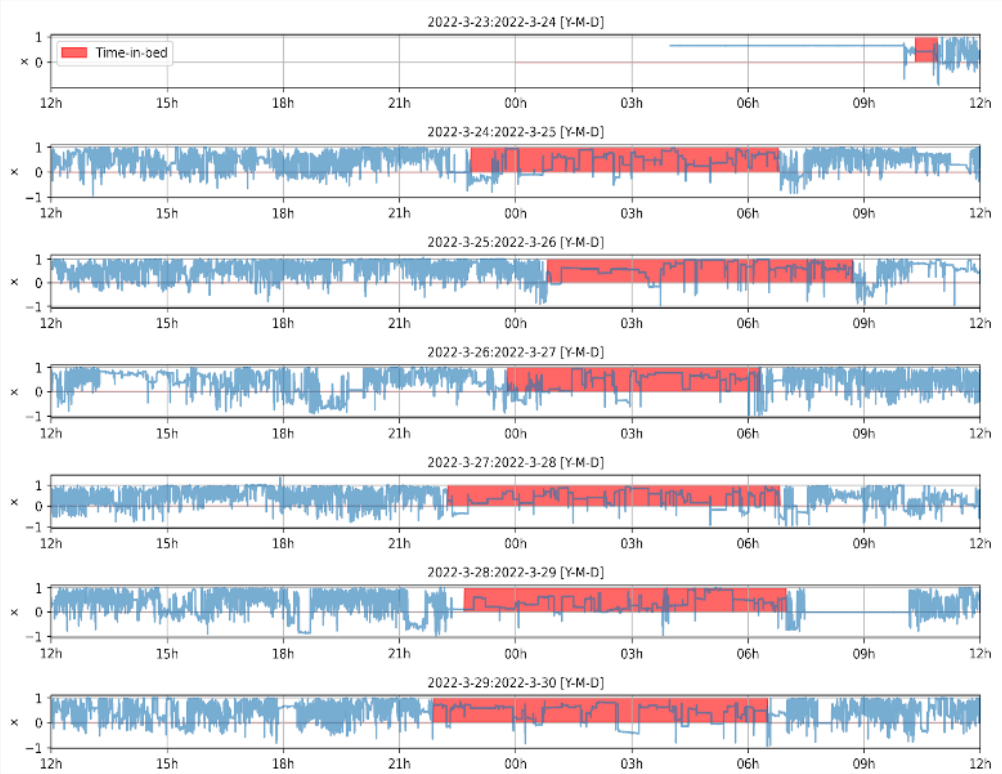
Sleep Diary

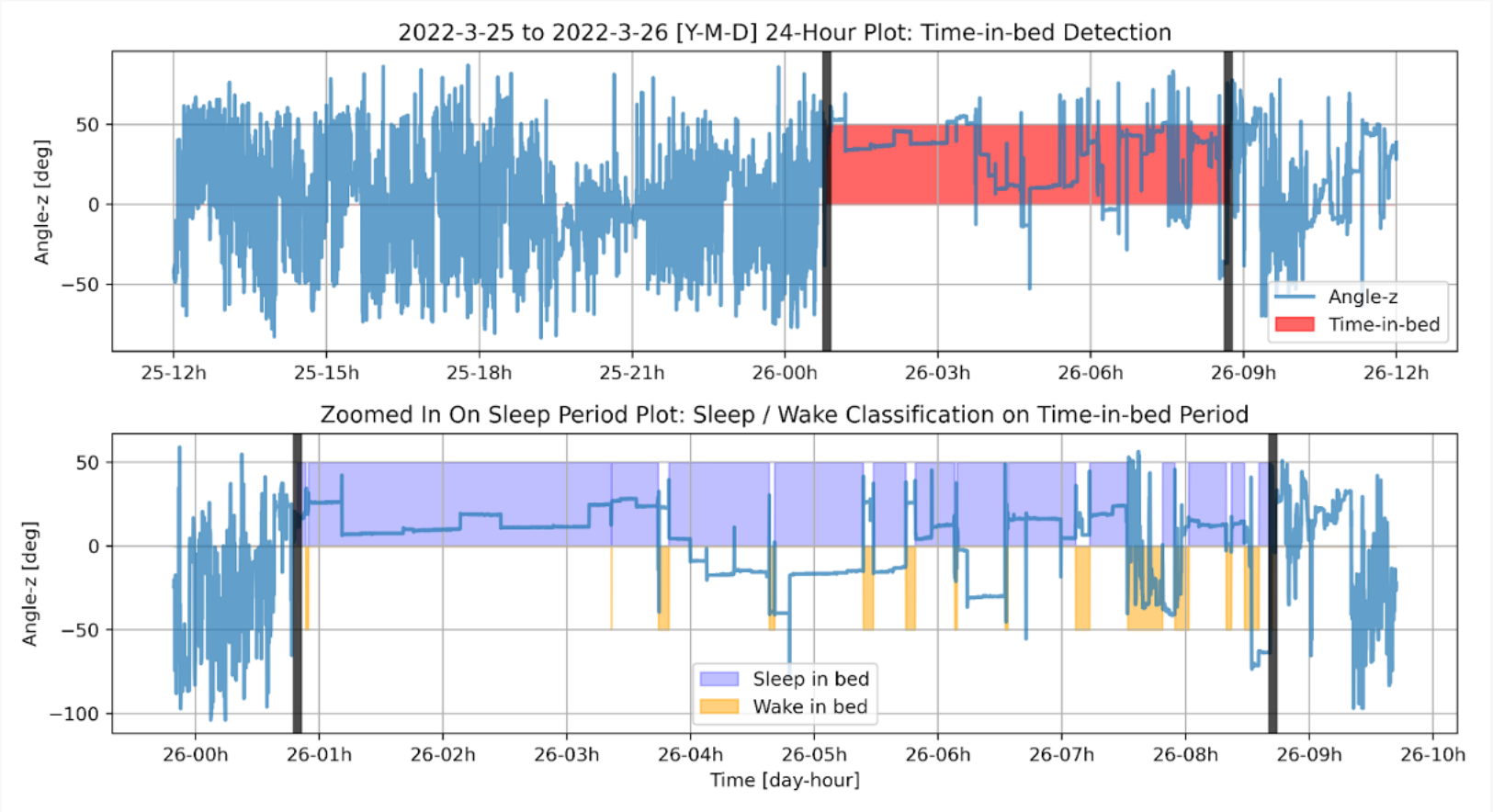
Sleep diary data has been shown to be inaccurate.

Moore, C. M., Schmiege, S. J. & Matthews, E. E. Actigraphy and Sleep Diary Measurements in Breast Cancer Survivors: Discrepancy in Selected Sleep Parameters. *Behav. Sleep Med.* **13**, 472–490 (2015).

Wearables - Accelerometer

- First study in 1980's
- Since then
  - Multi-axis sensing
  - Increased storage (save raw)
  - Transfer to cloud




2022-3-25 to 2022-3-26 [Y-M-D] 24-Hour Plot: Time-in-bed Detection
Angle-z [deg]
50
0
−50
25-12h
25-15h
25-18h
25-21h
26-00h
26-03h
26-06h
26-09h
26-12h
Angle-z
Time-in-bed
Zoomed In On Sleep Period Plot: Sleep / Wake Classification on Time-in-bed Period
Angle-z [deg]
50
0
−50
−100
26-00h
26-01h
26-02h
26-03h
26-04h
26-05h
26-06h
26-07h
26-08h
26-09h
26-10h
Time [day-hour]
Sleep in bed
Wake in bed

Add another dimension to understanding patient health

Sleep Algorithm Overview

Polysomnography

ActiGraphy (*DACNN*)

ActiGraphy + HR / HRV (*CNN*)

Raw PPG (*SleepPPGNet*)

Sleep staging using CNN

CNN architecture [1]

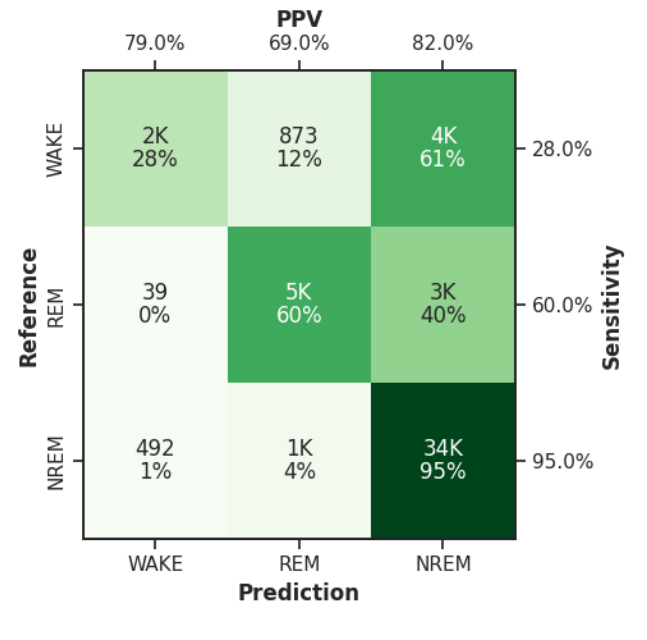
- 11 layers, IBI and activity classification at 4 Hz as input

Trained on CinC Challenge 2018 data (n=994) [2]

- Accuracy: 81% [1] (test set=10% n~99)

Evaluated on internal data (n=69) [3]

- 29 male, age=38.2±14.8 years, BMI=25.3±4.4 kg/m^2, 43 apnea
- Apneas: 53% (no), 26% (mild), 18% (moderate), 4% (severe), ~90% OSA/10% CSA
- Accuracy: 79.70 %
- Cohen's Kappa: 0.49



[1] E. Türetken, et al. in *2019 6th Swiss Conference on Data Science (SDS)*, Bern, Switzerland: IEEE, 2019, pp. 95–96. doi: 10.1109/SDS.2019.00005.

[2] https://www.physionet.org/content/challenge-2018/1.0.0/

[3] F. Braun *et al.*, in *EMBC 2020*, Montréal, Canada: IEEE, Jul. 2020, pp. 5115–5118. doi: 10.1109/EMBC44109.2020.9176081.

SleepPPGNet

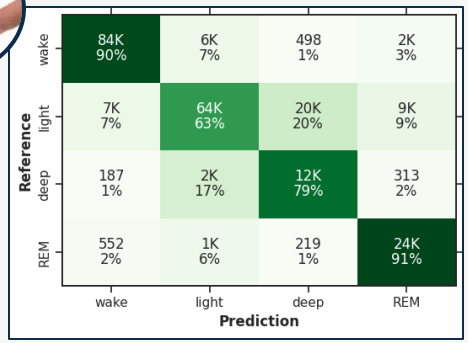
8-layer ResConv and TCN model [1][2]
- Raw PPG as input [1]

Trained on MESA dataset (n=1698) [3]

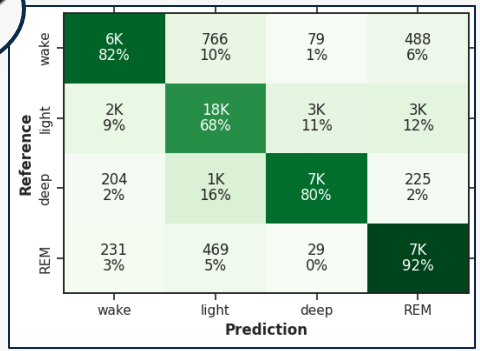
Evaluated on:
Internal data (n=69) [4]

Similar performance between train / test

Further subdivides NREM into deep / light



Accuracy: 78.6%, Kappa: 0.67 (MESA, n=1698)



Accuracy: 78.1%, Kappa: 0.68 (n=66)

[1] L. Constantin, et al., submitted to: *IEEE EMBC 2024*, Orlando, Florida, USA.

[2] K. Kotzen, et al. *IEEE Journal of Biomedical and Health Informatics* 27.2, 2022, pp. 924-932.10.1109/JBHI.2022.3225363.

[3] https://sleepdata.org/datasets/mesa

[4] F. Braun *et al.*, in *EMBC 2020*, Montréal, Canada: IEEE, Jul. 2020, pp. 5115–5118. doi: 10.1109/EMBC44109.2020.9176081.

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Thank You for Your Time.

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References

1. Cappuccio FP, Cooper D, D'Elia L, Strazzullo P, Miller MA. Sleep duration predicts cardiovascular outcomes: a systematic review and metaanalysis of prospective studies, *Eur Heart J*, 2011, vol. 32 (pg. 1484-92)
2. Williamson A, Lombardi DA, Folkard S, Stutts J, Courtney TK, Connor JL. The link between fatigue and safety, *Accid Anal Prev*, 2011, vol. 43 (pg. 498-515)
3. Luyster, F. S., Strollo Jr, P. J., Zee, P. C. & Walsh, J. K. Sleep: a health imperative. *Sleep* **35**, 727–734 (2012).
4. Wu AH, Wang R, Koh WP, Stanczyk FZ, Lee HP, Yu MC. Sleep duration, melatonin and breast cancer among Chinese women in Singapore, *Carcinogenesis*, 2008, vol. 29 (pg. 1244-8)
5. Kakizaki M, Inoue K, Kuriyama S, et al. Sleep duration and the risk of prostate cancer: the Ohsaki Cohort Study, *Br J Cancer*, 2008, vol. 99 (pg. 176-8)