

A NOVEL DEEP LEARNING AI METHOD FOR ESTIMATING WAKE, NREM, AND REM SLEEP STATES USING BREATHING AND ACTIVITY

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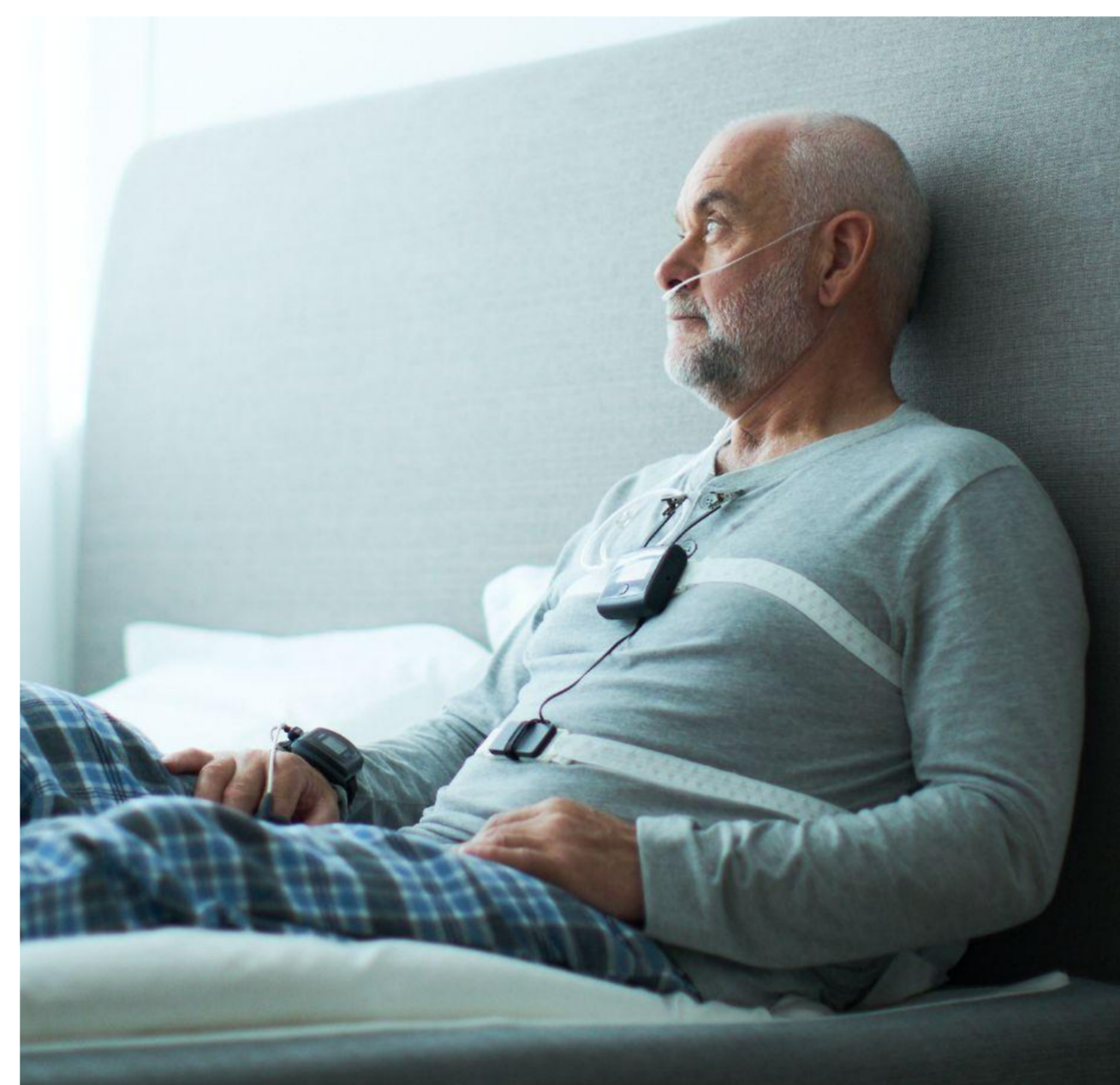
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Introduction

There is a trend toward predicting Wake, REM, and NREM sleep from other signals than EEG. Peripheral arterial tonometry (PAT) and pulse plethysmography (PPG) are commonly used. However, they may not perform well in patients with heart conditions.

The Nox BodySleep is a deep learning analysis that estimates Wake, REM, and NREM from breathing and actigraphy signals. It is inspired by physiological changes in breathing during sleep.

We compare the Nox BodySleep to a PPG-based method to estimate Wake, REM, and NREM in a general population at a sleep clinic and a population suffering from atrial fibrillation.



Methods

The Nox BodySleep is based on ResNet, a convolutional neural network (CNN) architecture that has been highly successful in image recognition tasks with an addition of temporal CNNs.

Two analyses were trained: The Nox BodySleep using respiratory inductance plethysmography (RIP) and activity signals; and a PPG-based analysis using pulse, SpO₂, and activity signals. The analyses were trained on 3185 manually scored polysomnography recordings (PSG) from sleep centers in 5 countries. The data was split into training, validation, and test datasets (70% / 15% / 15%).

External validation was done with 86 manually scored PSGs, disjoint from the training, validation, nor test datasets. This helps evaluate the analyses' performance when encountering new data from new sleep clinics. Furthermore, the performance was evaluated on 18 PSGs from patients with atrial fibrillation.

Results

The sensitivity, specificity, and accuracy were calculated using the 86 manually scored PSG recordings.

Normal population at a sleep clinic

	BodySleep RIP + Activity			PPG Oximeter + Activity		
	Sensitivity (95%CI)	Specificity (95%CI)	Accuracy (95%CI)	Sensitivity (95%CI)	Specificity (95%CI)	Accuracy (95%CI)
Wake	85% (81%, 88%)	95% (93%, 96%)	92% (91%, 94%)	74% (69%, 78%)	93% (91%, 95%)	89% (87%, 91%)
REM	75% (68%, 80%)	98% (97%, 99%)	95% (94%, 96%)	63% (56%, 69%)	97% (96%, 98%)	93% (91%, 94%)
NREM	92% (90%, 93%)	84% (80%, 86%)	89% (87%, 90%)	90% (88.0%, 91.5%)	75% (71%, 78%)	85% (83%, 86%)

Overall Agreement 88%
Cohen's Kappa 0.76

Overall Agreement 83%
Cohen's Kappa 0.66

The performance was also investigated in a separate set of 18 patients with atrial fibrillation.

Atrial fibrillation population

	BodySleep RIP + Activity			PPG Oximeter + Activity		
	Sensitivity (95%CI)	Specificity (95%CI)	Accuracy (95%CI)	Sensitivity (95%CI)	Specificity (95%CI)	Accuracy (95%CI)
Wake	92% (88%, 96%)	92% (88%, 94%)	92% (89%, 94%)	77% (68%, 85%)	90% (87%, 93%)	88% (86%, 91%)
REM	74% (68%, 80%)	97% (94%, 98%)	93% (92%, 95%)	51% (38%, 65%)	97% (95%, 98%)	90% (88%, 93%)
NREM	87% (82%, 91%)	86% (82%, 89%)	87% (83%, 89%)	86% (82%, 90%)	69% (62%, 75%)	81% (79%, 84%)

Overall Agreement 86%
Cohen's Kappa 0.70

Overall Agreement 80%
Cohen's Kappa 0.56

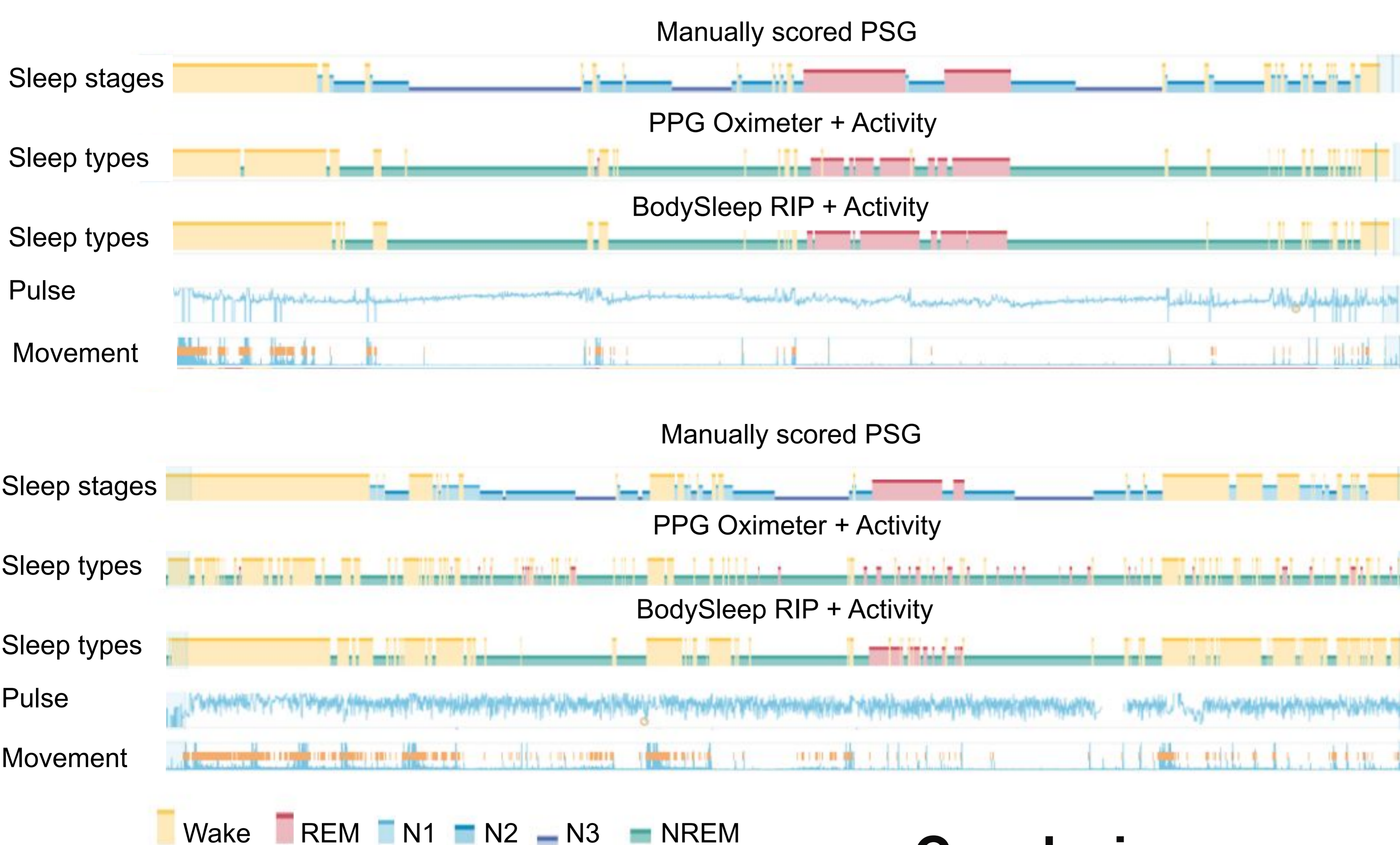


Figure 1. An example of the sleep profile in a patient with sleep apnea. The figure shows one sleep study scored using three methods. The figure shows how the two analyses capture the Wake, REM, and NREM periods in the study compared to a manual scored PSG study.

Figure 2. An example of the sleep profile in a patient with atrial fibrillation. The patient in the sleep study had atrial fibrillation for the whole study duration, which is reflected in the pulse signal. In the sleep study, the PPG-based analysis does not perform well. This is expected because the atrial fibrillation causes the pulse and SpO₂ signals to be irregular.

Conclusions

- Nox BodySleep can be used to enrich HSAT sleep studies by estimating the sleep types of wake, REM, and NREM.
- The analysis has a high agreement with manually scored PSG.
- The PPG analysis performed worse on detecting Wake and REM than the Nox BodySleep.
- The analysis outperforms a PPG-based analysis in patients with atrial fibrillation.