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A Novel Deep Learning AI Method for Estimating Wake, NREM, and REM Sleep from Breathing and Activity.

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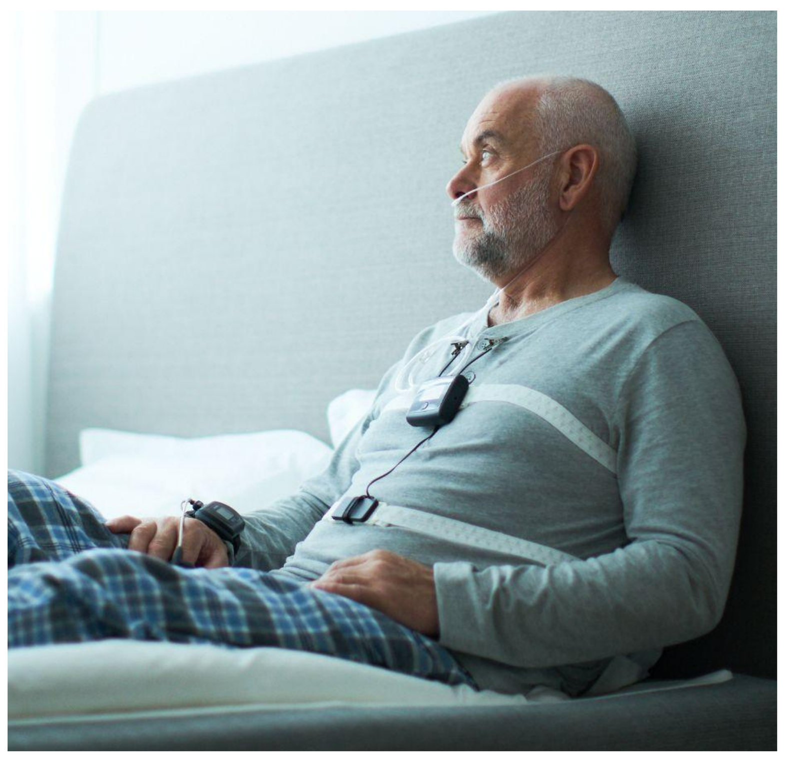
Introduction

The Nox BodySleep is a deep learning algorithm that estimates the sleep types: Wake, REM, and NREM from breathing and actigraphy signals. The model is inspired by known physiological changes in the breathing patterns between the three sleep types.

The algorithm uses raw Respiratory Inductance Plethysmography (RIP) and activity signals as inputs and outputs an estimated sleep type for each 30 second epoch.



The algorithm is based around breathing and activity signals, and is not negatively affected by common arrhythmias, such as atrial fibrillation, and pacemakers.

Methods

The Nox BodySleep is based on the ideas in ResNet [1], a convolutional neural network architecture which has been highly successful in image recognition tasks. The algorithm has the characteristic residual blocks to which we add a temporal component to increase the temporal receptive field of the model.

The algorithm was trained using 3185 manually scored sleep recordings (PSG) with EEG/EOG, from sleep centers in 5 countries. The data was split into training, validation, and test datasets.

External validation was done with 159 manually scored PSGs not present in the training, validation or test datasets. This helps evaluate the performance of the model when it encounters new data from new sleep clinics. Furthermore, the performance was evaluated on 22 PSGs from patients with atrial fibrillation.

Results

The positive percentage agreement (PPA), negative percentage agreement (NPA), and overall percentage agreement (OPA) was calculated using the 159 manually scored PSG recordings.

	PPA	NPA	OPA
Wake	75%	96%	91%
REM	73%	98%	95%
NREM	93%	75%	87%

Cohen's kappa was 0.72 (95% CI 0.70-0.75) and overall accuracy 86.5% (95% CI 85.4%-87.5%).

		Nox BodySleep			
		Wake	**REM**	**NREM**	**Total**
Manually scored PSG	**Wake**	22,701	293	7,451	**30,445**
	REM	174	10,418	3,662	**14,254**
	NREM	3,979	1,758	77,775	**83,512**
	Total	**26,854**	**12,469**	**88,888**	**128,211**

A confusion matrix showing the number of epochs in each cell. The matrix shows how many epochs were correctly classified and what kinds of misclassifications occurred.

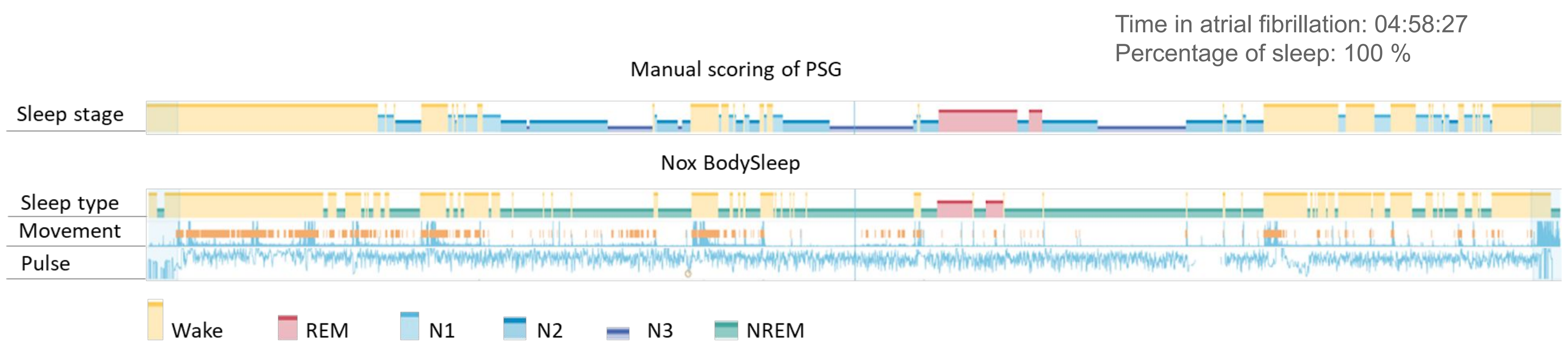
	PPA	NPA	OPA
AHI ≥ 5	98%	99%	98%
AHI ≥ 15	97%	99%	99%
REM-AHI ≥ 5	99%	95%	97%
REM-AHI ≥ 15	93%	94%	94%

The agreement of AHI severity classification when the sleep was scored manually in a PSG compared to when sleep was estimated using the Nox BodySleep.

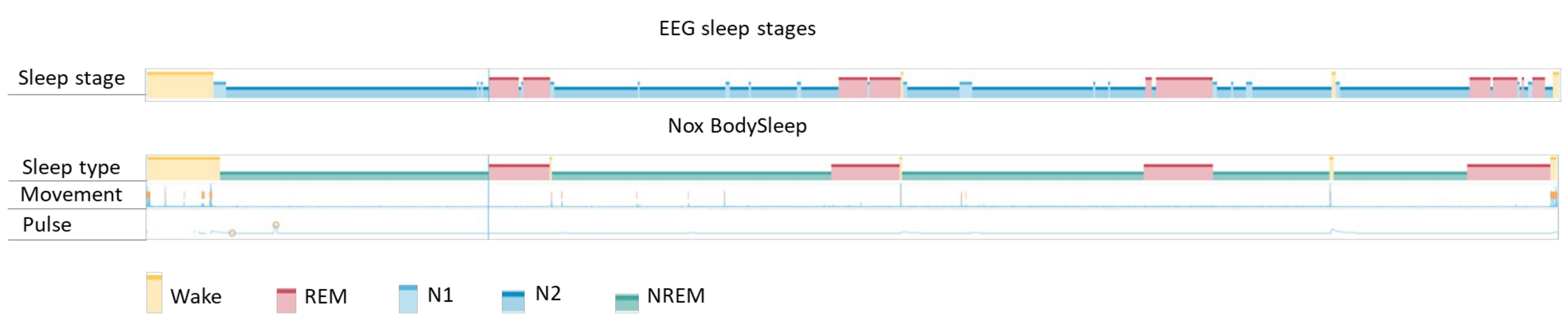
The performance was also investigated in a separate set of 22 patients with atrial fibrillation.

	PPA	NPA	OPA
Wake	81%	94%	92%
REM	69%	98%	94%
NREM	91%	76%	86%

Cohen's kappa was 0.70 (95% CI 0.66-0.74) and overall accuracy 86.0% (95% CI 83.6%-88.2%).



An example of the sleep profile from manual scoring of a PSG and the Nox BodySleep in a patient with atrial fibrillation.



An example showing the comparison of the sleep type estimation of the Nox BodySleep and sleep stage scoring from EEG in a patient with a pacemaker where the pulse is stable around 50 BPM.

Conclusions

Nox BodySleep can be used to enrich HSAT sleep studies by estimating the sleep types of: wake, REM and NREM.

The algorithm has high agreement with manual scoring of PSG.

The algorithm has been shown to perform well in patients with atrial fibrillation and a patient using a pacemaker.

1. Kaiming He, Xiangyu Zhang, Shaoqing Ren, Jian Sun, "Deep Residual Learning for Image Recognition", arXiv:1512.03385