# Deep Convolutional and Recurrent Neural Networks for Interpretable Analysis of EEG Sleep Stage Scoring

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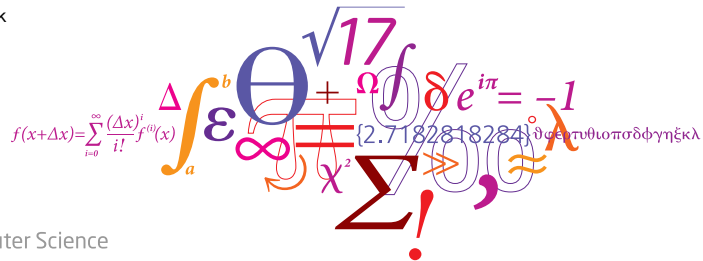


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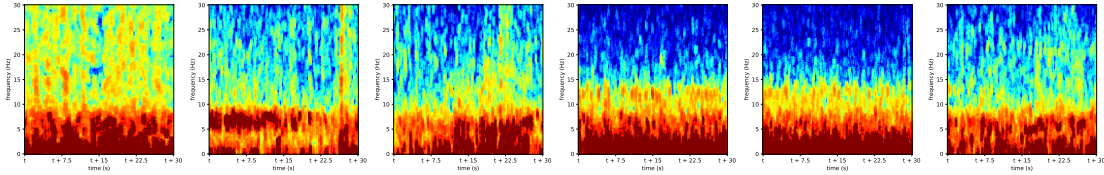
# Sleeping Stages



(a) W (b) N1 (c) N2 (d) N3 (e) N4 (f) R

Figure: This figure illustrates a random epoch of the multi-taper spectrum for each sleeping stage. There is high similarity between sleeping stage N3 and N4.

| Sleep Stage | W | N1 | N2 | N3 | N4 | R |
|---|---|---|---|---|---|---|
| Dist. (in %) | 12 | 7 | 46 | 9 | 6 | 20 |

Table: This table summerises the aggregates the distribution of the labels for all 20 Subjects. The distribution of the labels illustrates the sleep stages of subjects during the recordings.

## Confusion Matrices

| | | Predicted | | | | | | Normalized pred. (in %) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | W | N1 | N2 | N3 | N4 | R | W | N1 | N2 | N3 | N4 | R |
| CNN | W | 495 | 145 | 29 | 11 | 1 | 20 | 71 | 21 | 4 | 2 | 0 | 3 |
| | N1 | 25 | 211 | 43 | 0 | 0 | 62 | 7 | 62 | 13 | 0 | 0 | 18 |
| | N2 | 4 | 51 | 1313 | 104 | 17 | 68 | 0 | 3 | 84 | 7 | 1 | 4 |
| | N3 | 0 | 2 | 11 | 164 | 64 | 0 | 0 | 1 | 5 | 68 | 27 | 0 |
| | N4 | 0 | 0 | 0 | 54 | 91 | 0 | 0 | 0 | 0 | 37 | 63 | 0 |
| | R | 17 | 80 | 46 | 0 | 0 | 591 | 2 | 11 | 6 | 0 | 0 | 81 |
| RNN | W | 578 | 39 | 26 | 7 | 1 | 43 | 83 | 6 | 4 | 1 | 0 | 6 |
| | N1 | 38 | 107 | 64 | 0 | 0 | 132 | 11 | 31 | 19 | 0 | 0 | 39 |
| | N2 | 8 | 13 | 1314 | 102 | 28 | 92 | 1 | 1 | 84 | 7 | 2 | 6 |
| | N3 | 3 | 0 | 18 | 125 | 95 | 0 | 1 | 0 | 7 | 52 | 39 | 0 |
| | N4 | 0 | 0 | 1 | 60 | 84 | 0 | 0 | 0 | 1 | 41 | 58 | 0 |
| | R | 19 | 36 | 43 | 0 | 0 | 636 | 3 | 5 | 6 | 0 | 0 | 87 |

Table: Confusion matrices and normalized confusion matrices for the CNN and RNN network.

## Bootstrapped Performance Metrics

| Study | Precision | Sensitivity | $F_1$-score | Accuracy |
|---|---|---|---|---|
| CNN | 65-**68**-70 | 71-**71**-72 | 67-**69**-70 | 92-**92**-92 |
| RNN | 62-**65**-67 | 63-**66**-69 | 62-**64**-67 | 92-**92**-92 |

Table: **Mean** and corresponding $95\%$ confident values computed by 100.000 bootstrap iterations with replacement.

# Sensitivity Maps

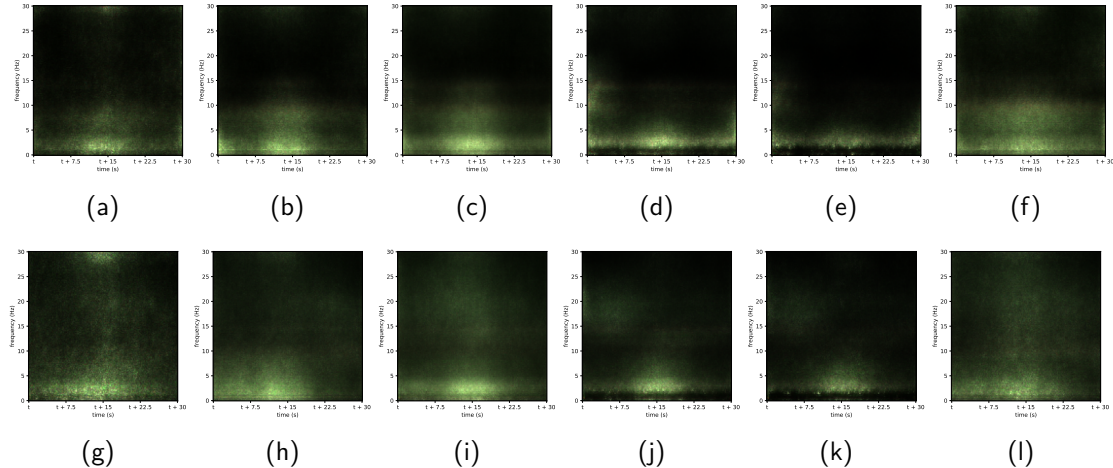



Figure: Illustration of the average sensitivity maps from the CNN (top) and the RNN (bottom) for the two validation subjects.

# Future Study

- Successfully re-produced [1] in TF which was one of the objectives, despite using few different approaches.
- Added a LSTM cell to the of the VGGNet 16 network. The of the RNN does out-perform the baseline on average (table 3), despite the RNN does archive better classification sensitivity in the following sleeping stages W and R.
- Improvements in this projects can be archived by merging sleeping stage N3 and N4, then follow the newest regulations.
- Study the effect of stacking multiple LSTM cells and applied the LSTM cells from layers with a lower-level feature representation higher and spectral variance.

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# References


A. Vilamala, K. H. Madsen, and L. K. Hansen,
"Deep Convolutional Neural Networks for Interpretable Analysis of EEG Sleep Stage Scoring,"
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