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Whole brain characterization of blood flow changes during sleep/wake phases using fUS

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Background, Motivation and Objective

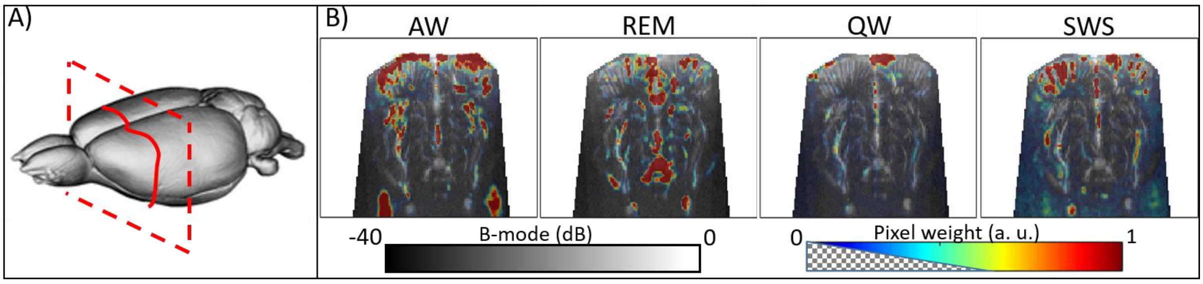
Traditional sleep scoring methods rely on multimodal analysis of signals such as electroencephalography (EEG), electromyograms (EMG), usually interpreted manually in humans or semi-automatically in animals, which is both time consuming and observer-dependent. Functional Ultrasound (fUS) imaging provides rich information about changes in blood flow tightly associated with neuronal activation occurring during periods of sleep/wake. This study aimed to train a simple artificial neural network (NN) to discriminate between sleep/wake states and provide a visualization of the spatial blood flow changes in the whole rat brain.

Statement of Contribution/Methods

fUS data was acquired for 3 adult Sprague Dawley rats on 8 coronal planes spanning the whole rat brain (1mm spacing), concurrently with extracellular recordings of local field potentials (LFP) in the dorsal hippocampus. LFP, neck EMG and head acceleration data were used to manually label frames according to their vigilance state: quiet wake (QW), active wake (AW), slow-wave sleep (SWS) or Rapid Eye Movement sleep (REM). Supervised learning was performed using a fully connected feed forward NN taking as an input the fUS pixel values, and using perceptron neurons with sigmoid activation in the hidden (3-5 neurons) and output layers (2 neurons). Each NN was trained on 500 images and tested on 160 images. Characteristic fUS patterns were extracted for each plane and each sleep/wake state by activation maximization, i.e. using backpropagation to find the input image maximizing the NN output for that state.

Results/Discussion

The NNs accurately classified more than 95% of frames for all sleep phases with a training time of 30s - 30min. Activation maximization maps for each sleep phase highlighted structures known to be particularly active during that specific phase on each coronal plane. This provided 3D maps of characteristic blood flow changes for each sleep/wake states in the whole rat brain. For example, the septum, hippocampus, dorsal thalamus and parietal cortex were strongly highlighted for REM, whereas ocular structures, and the sensory/motor cortex were highlighted for AW. We expect that this method will have a large impact on the understanding of brain activation during sleep/wake phases and potentially allow for real-time sleep scoring based solely on fUS data.



A) 3D-view of the rat brain and coronal imaging plane highlighted in red and B) B-mode (grayscale) and overlayed activation maps (color) for the coronal plane shown in (A) highlighting characteristic blood flow changes for different sleep/wake states