A Method for Studying Neural Circuits During All-Night Functional Magnetic Resonance Imaging Sleep Studies

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Advanced MRI

Introduction

The EEG signal remains the gold standard method for the study of sleep in humans due to its strong temporal resolution and minimal invasiveness. However, the spatial resolution of the EEG severely hampers its ability to precisely locate cortical activity or detect activity in brain regions deeper than the cortex. This limitation of the EEG prevents researchers from being able to study behaviors during sleep such as the initiation of sleep spindles in the thalamus or development of PGO waves during REM sleep[1, 2].

Modern imaging techniques such as functional magnetic resonance imaging (fMRI) provide the enhanced spatial resolution required to accurately locate the source of brain activity[3], but provide their own set of obstacles for collecting data during sleep. Primarily, the fMRI environment presents adverse conditions for volunteers to attain sleep. The aim of this project was to assess the feasibility of a method for achieving and measuring sleep in the MRI environment across an entire night.

Methods

Pre-Inpatient Visit:

- Extensive at-home internet screening using psychometrically validated questionnaires to increase likelihood of sleeping in MRI environment.
  - Assessments measured: risk of airway obstruction and insomnia, cluastrophobia, arousing pre-sleep thoughts, susceptibility to noise and likelihood of back discomfort.
- Volunteers maintained ~23:00-07:00 sleep schedule for 14 days prior to visit. Verified by acitgraphy (Actiwatch 2, Philips Respironics) and time-stamped voicemail call-ins.
- Volunteers were asked to listen to a recording of the MRI acoustic noise on three days prior to visit to acclimate themselves to the noise.

Adjustments to MRI:

- Volunteers slept on a clinical-grade memory foam mattress (TEMPUR-MED, Tempur-Pedic).
- Active noise cancelling headphones (Optoactive, Optoacoustics Ltd.), trained on the MRI acoustic noise were used along with standard hearing protection. This technique results in an approximately 20 dB sound reduction (from ~85 to ~65 dB).

Sleep Architecture

Estimates Based on Real-Time Corrected EEG Traces

Measures	Range from Night 2 of 12 Successful Volunteers (16 attempts)
Total Recording Time (min)	308-505
SWS (min)	40-240
REM (min)	20-120

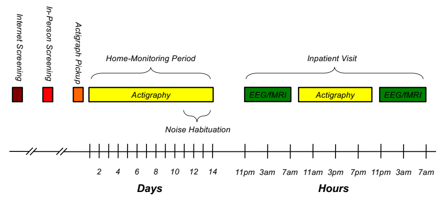
Data Scored Offline with Optimized Artifact Correction

Measures	Offline Scoring in one Volunteer
Total Recording Time (min)	369
Total Sleep Time (min)	279
SWS (min)	54
REM (min)	39
Unscored due to artifact (min)	63

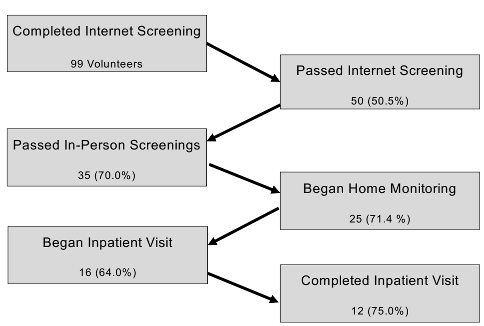
Sleep EEG scoring and estimates were made using standard AASM criteria[6]

Study Methods

Study Timeline

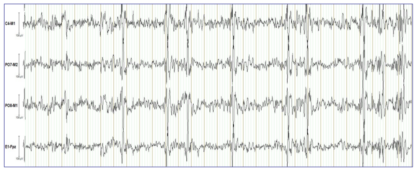


Volunteer Screening Success Rate

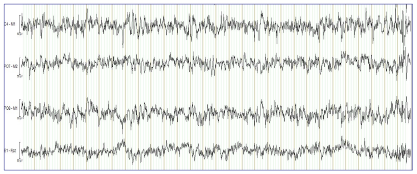


Results

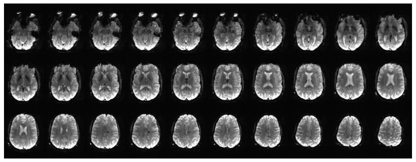
Real-Time Correction Sample



Optimized Correction Sample



Sample fMRI Images



Data Collection

- Volunteers slept in scanner on two consecutive nights with the first night being an adaptation night.
- fMRI sequence: constant slice timing, no jitter, used to reduce gradient artifact in EEG, TR= 3 s, 50 slices, resolution = 2.5 x 2.5 x 2 mm^3.
- EEG data were artifact-corrected in real-time to allow for live sleep scoring during scans
- Other peripheral signals such as variations in cardiac and respiratory cycles and eyelid position were measured
- EEG data were scored offline with optimized artifact correction algorithms
- Assessed hearing safety with baseline and post-MRI audiology examinations

Results

- No evidence of any clinically significant changes to pure tone thresholds, distortion product otoacoustic emissions, speech-in-noise recognition or early auditory evoked potentials were seen following the two night inpatient visit indicating a successful hearing protection protocol.
- SWS and REM sleep were attained by all subjects that successfully completed the both nights of the inpatient visit (12 of 16 attempts).
- Unsuccessful studies were the result of prodromal sleep apnea, inability to sleep and a stress reaction to the scanner environment

Conclusions

These findings demonstrate that our method was able to successfully promote sleep across an all-night continuous fMRI scan. The ability to scan sleeping subjects for an entire night opens up many future directions for studying neural circuits associated with sleep such as sleep state cycling[4], the mechanisms of the sleep-wake cycle and even the core functions of sleep itself[5].

References

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