Introduction

Carskadon and Dement (2011) describe sleep as a reversible behavioral state of perceptual disengagement from and unresponsiveness to the environment. Sleep is generally divided into two states: rapid eye movement (REM) sleep and non-rapid eye movement (NREM) sleep. Based on EEG changes, NREM is divided into four stages (stage 1, stage 2, stage 3, stage 4). NREM and REM occur in alternating cycles, each lasting approximately 90-100 minutes, with a total of 4-6 cycles. In general, in the healthy young adult NREM sleep accounts for 75-90% of sleep time (3-5% stage 1, 50-60% stage 2, and 10-20% stages 3 and 4). REM sleep accounts for 10-25% of sleep time.

How does the amount of time spent in each sleep stage change between the well-rested night and the sleep-deprived night?

The aim of this study was to investigate the amount of time spent in each sleep stage in the well-rested night and the recovery night following sleep deprivation. We posit the time spent in each sleep stage of a recovery night following sleep deprivation will differ from the time spent in each sleep stage of a well-rested night. Specifically, we expect stage 3 and stage 4 NREM to increase during the sleep deprived condition.

With data from the laboratory of Dr. Mary Carskadon, we analyzed a full night of data (including multiple channels of EEG, EOG, and EMG) gathered both before and after sleep deprivation from four subjects.

Methods

Sleep data was analyzed in four subjects during one baseline night (BSL) of rested sleep and a recovery night following sleep deprivation (REC). Sleep stages were recorded during the sleep episodes with nine channels of electrodes; four electroencephalography (EEG), two electrooculogram (EOG), and three electromyography (EMG) channels.

Electrode placement

The EEG was recorded at four scalp electrode pairs (C3/A2, O2/A1, C4/A1, O1/A2), according to the international 10-20 system. Central C3 and C4 electrodes were placed to record sleep spindles, and occipital electrodes O1 and O2 were placed to observe alpha waves (Carskadon & Dement, 2011). Reference electrodes A1 and A2 on the left and right earlobes were placed to help remove noise from the recordings. The EOG electrodes (ROC/A2 and LOC/A1), used to monitor eye movements, were placed on the outer corner of the right and left eye, with reference electrodes on the earlobes. Three EMG Channels (Channel 5: Chin EMG 1, Channel 6: Chin EMG 2, Channel 7: Chin EMG 3) were placed on the subjects chin to monitor electrical activity of muscles. EOG and EMG were used to identify rapid eye movement (REM) sleep and periods of wakefulness.

Sleep stage classification

Researchers of Dr. Mary Carskadon's sleep lab at Brown University, classified stages for each 30s epoch in the data set. The classification scheme is as follows: 7 - Unscored (typically before lights out or after lights on, not analyzed); 0 - Awake; 1 - NREM Stage 1; 2 - NREM Stage 2; 3 - NREM Stage 3; 4 - NREM Stage 4; 5 - REM Sleep; 6 - Movement Time.

Data Inconsistency

Two discrepancies in the EEG sleep data provided by the Carskadon group lead us to drop the raw eeg/eog/emg data.

1) Channel 8(C4/A1) of all REC samples has a pronounced electrocardiogram signal. See epoch of one REC sample below (Appendix A).

2) The number of columns in each sample data matrix ('DATA') is not a factor of epoch length (srate * 30s). Thus we cannot merge the raw data and the stage classification data (Table 1).

Table 1. Difference and remainder of sample and stage data size

Sample	*Raw data size*	*Stage data size*	*Difference (Raw data size - (Stage data size * srate * 30))*	*Remainder (Raw data size % (Stage data size * srate)*
S3_REC	6481920	2219	-2039040	233216
S3_BSL	4856832	1269	-16128	146304
S2_REC	8506368	2215	768	768
S2_BSL	4819968	1255	768	768
S1_BSL	4860928	1265	3328	3328
S1_REC	8002048	2083	3328	3328

Results

Fig. 1 shows the mean percentage of time spent in each sleep stage across four subjects. Yellow bars show the baseline night of rested sleep. Red bars show the recovery night following sleep deprivation. Participant's sleep stages were recorded through the night. No significant difference is observed between the baseline and sleep deprived conditions.

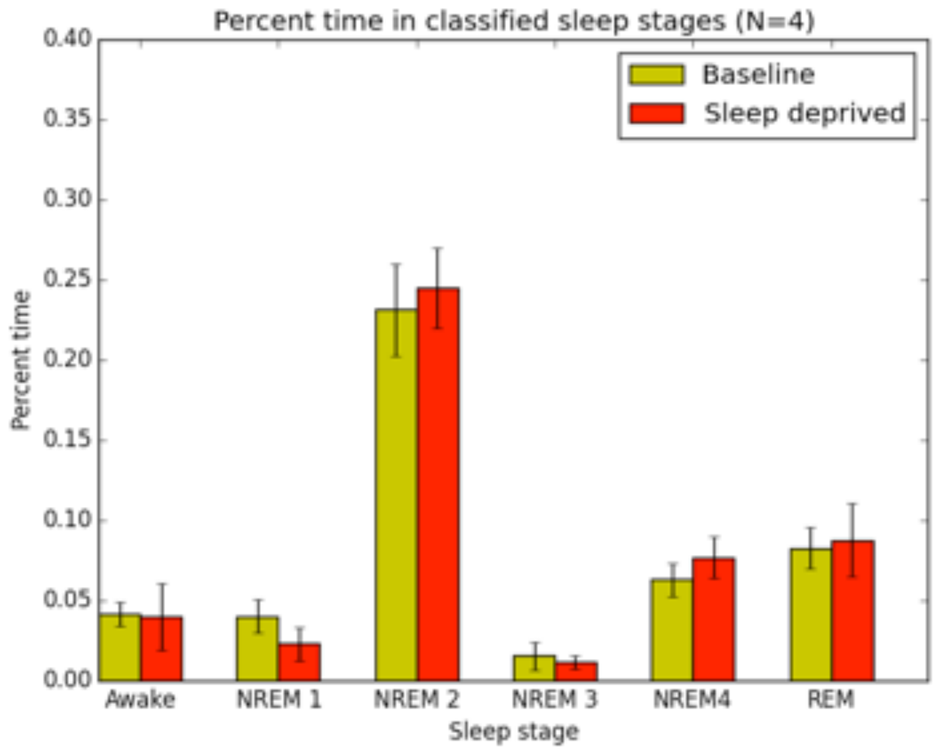


Figure 1.

Mean and SE of percent time in classified sleep stages: Baseline condition shown in yellow bars (n = 4); Sleep deprived condition shown in red bars (n = 4). Time in movement and unscored time are not show. Error bars represent the standard error.

Analysis of the sleep stage classification data shows there was no significant difference between the baseline and sleep deprived conditions in time spent in any of the sleep stages. The small sample size limits our statistical power. For instance, each subject was measured only once in each conditions. Thus we choose to examine the mean across subjects (N=4). However, difference in individual sleep stage frequency profiles may overwhelm any trend between conditions.

Discussion

Follow-up analysis

Future studies should include more nightly recordings per subject, as well as more subjects. Given more data and thus statistical power we may find subtle differences in the sleep patterns of the two conditions. Future studies could include additional conditions, such as sleep after exercise. Finally, further machine learning of sleep stage classification could be carried out on a larger data set.

Programming Trick

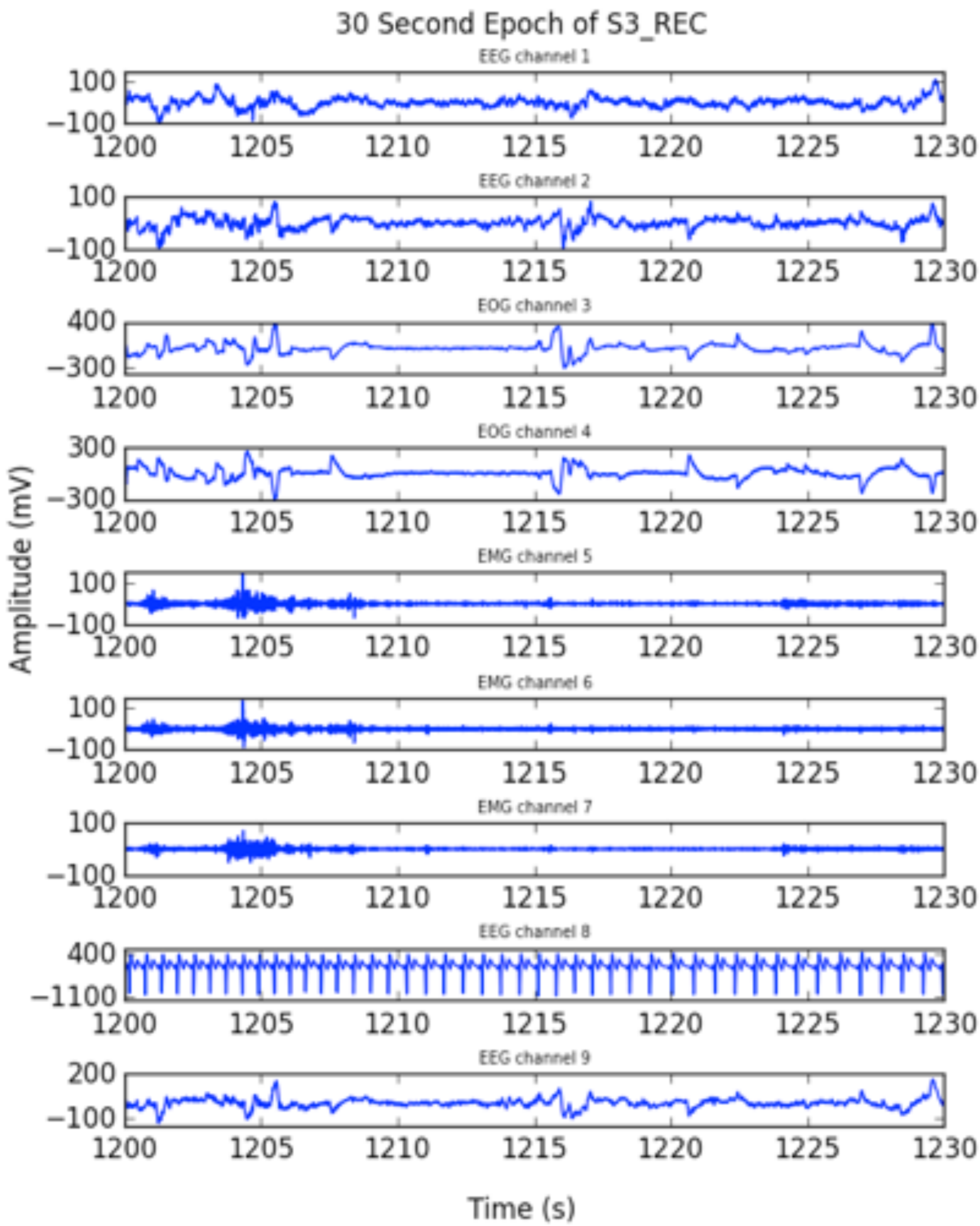
We used a nice programming trick to calculate the standard error of percent time in sleep stages for each condition across four subjects. The programming trick copies data from one structure to a more convenient data structure for statistical analysis. To do this we utilize numpy's matrix object. The starting data structure is a dictionary of 1d arrays, keyed by sample name. The data structure for statistical analysis is a matrix of N-stages by M-subjects instantiated with zeros. The trick is to fill the columns of the matrix with transposed, by-sample arrays. String comparisons of the sample name are made in order to distinguish between conditions.

```
N, M = 8, 4
rec_stderr, bsl_stderr = np.matrix([np.zeros(M) for x in range(N)]),
                         np.matrix([np.zeros(M) for x in range(N)])
i, j = 0, 0
for sample_name, stage_frequency_array in stage_frequency_dict.items():
        if sample_name.find('BSL') > -1:
                bsl_stderr[:, j] =
                np.transpose(np.matrix(stage_frequency_array))
                j += 1
        elif sample_name.find('REC') > -1:
                rec_stderr[:, i] =
                np.transpose(np.matrix(stage_frequency_array))
                i += 1
        rec_stderr = [rec_stderr[i, :].std()/np.sqrt(rec_stderr.shape[1])
                for i in range(rec_stderr.shape[0])]
        bsl_stderr = [bsl_stderr[i, :].std()/np.sqrt(bsl_stderr.shape[1])
                for i in range(bsl_stderr.shape[0])]
```

Works Cited

Carskadon, M.A., & Dement, W.C. (2011). Monitoring and staging human sleep. In M.H. Kryger, T. Roth, & W.C. Dement (Eds.), Principles and practice of sleep medicine, 5th edition, (pp 16-26). St. Louis: Elsevier Saunders.

Appendix A


30 Second Epoch of S3_REC
EEG channel 1
EEG channel 2
EOG channel 3
EOG channel 4
EMG channel 5
EMG channel 6
EMG channel 7
EEG channel 8
EEG channel 9
Amplitude (mV)
Time (s)