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Supplemental Information

Sleep pressure causes birds to trade asymmetric sleep for symmetric sleep

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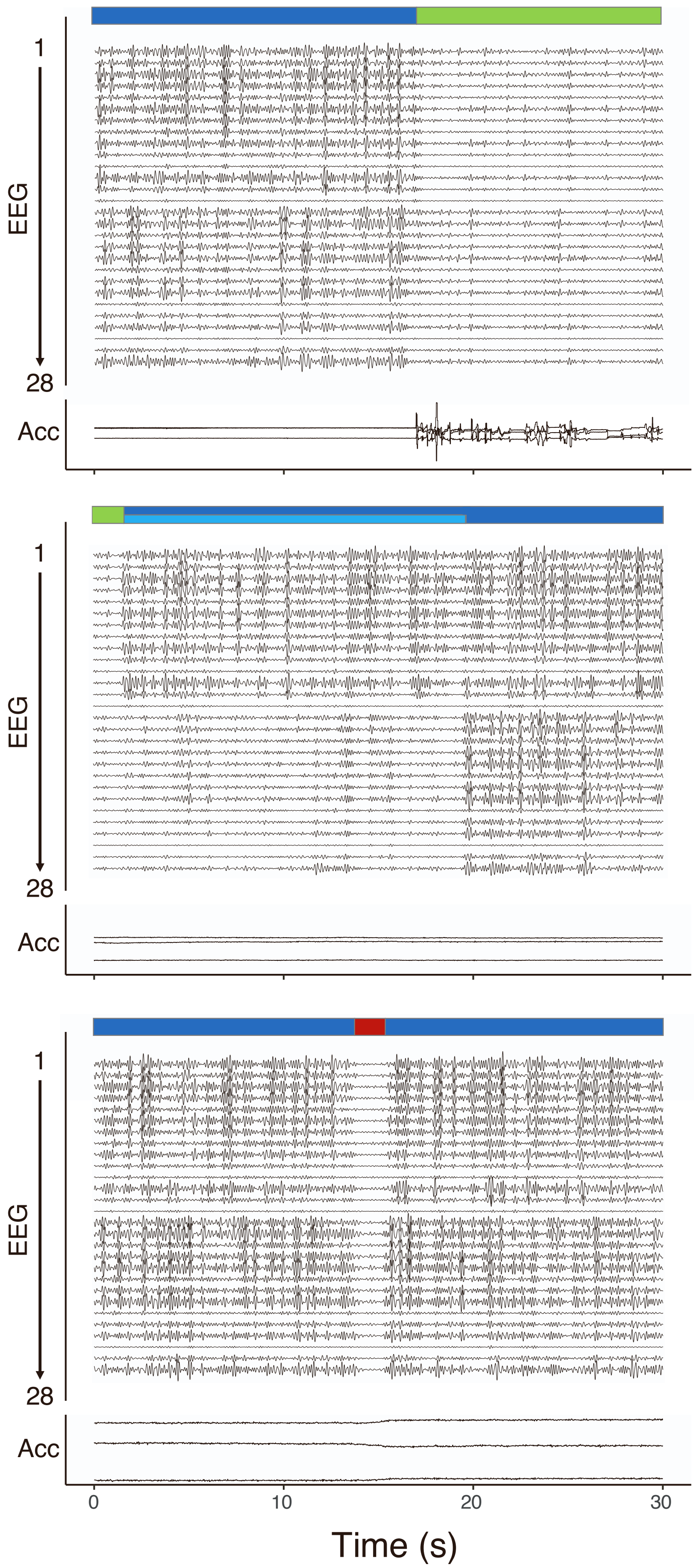


1
EEG
28
Acc
1
EEG
28
Acc
1
EEG
28
Acc
0
10
20
30
Time (s)

Figure S1. Filtered EEG recordings showing prominent 7 Hz oscillation during NREM sleep, Related to Figure 1B.

Three representative 30 s recordings from Figure 1B showing all 28 EEG channels and head acceleration (sway, surge and heave) during episodes of wake (green), symmetric NREM sleep (dark blue), asymmetric NREM sleep (dark + light blue), and REM sleep (red). The raw EEG is filtered using a one-pass, zero-phase, non-causal band-pass filter 5 – 9 Hz (-6 dB cut-off frequencies 4 – 10.12 Hz, 53 dB stop band attenuation, 'firwin' method, Hamming window) in MNE 83, version 0.23.3. The electrodes are arranged 1 (top) – 28 (bottom) according to their position on the brain in Figure 1A. Abbreviations: Acc (acceleration); EEG, electroencephalogram.

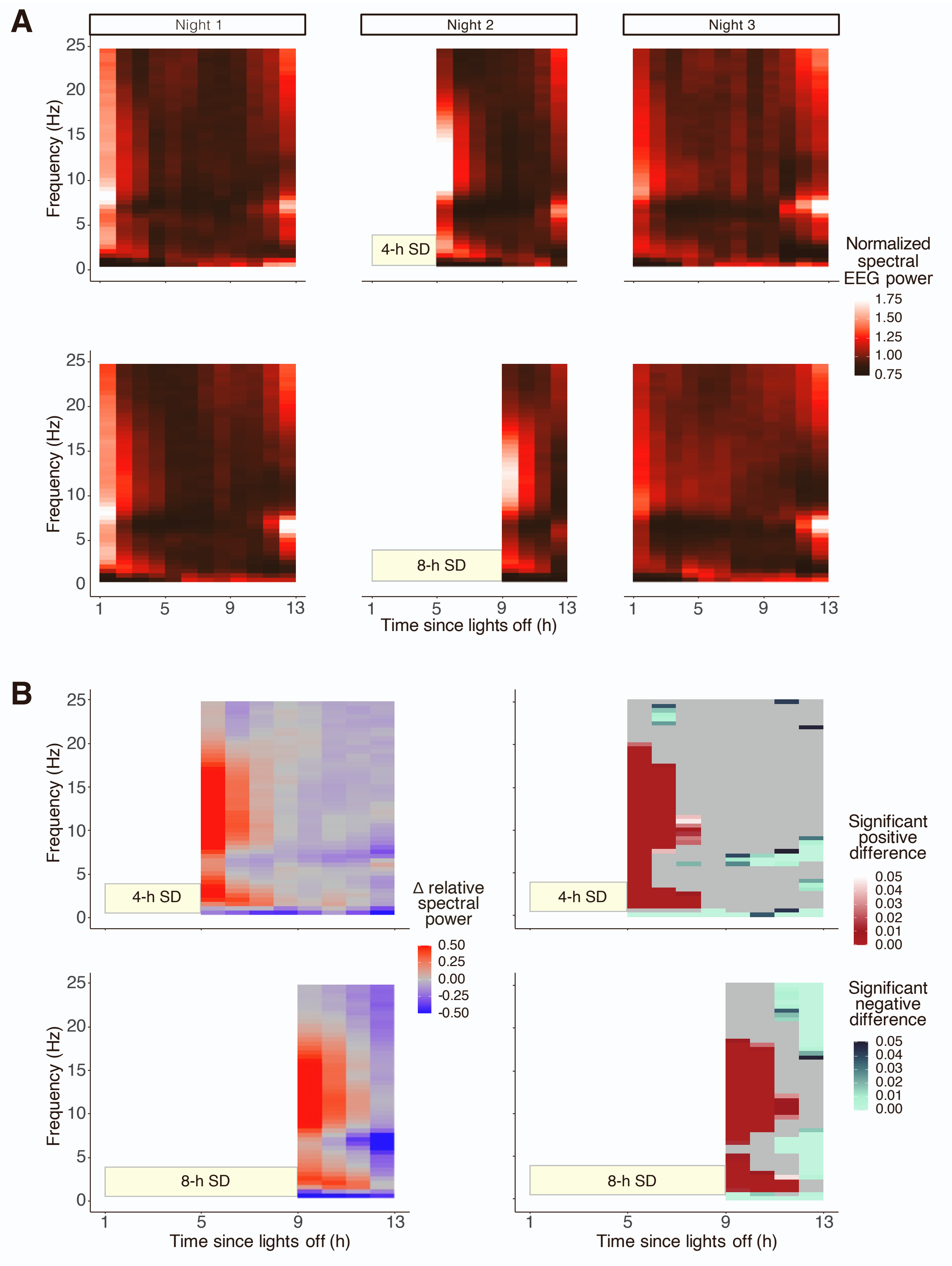
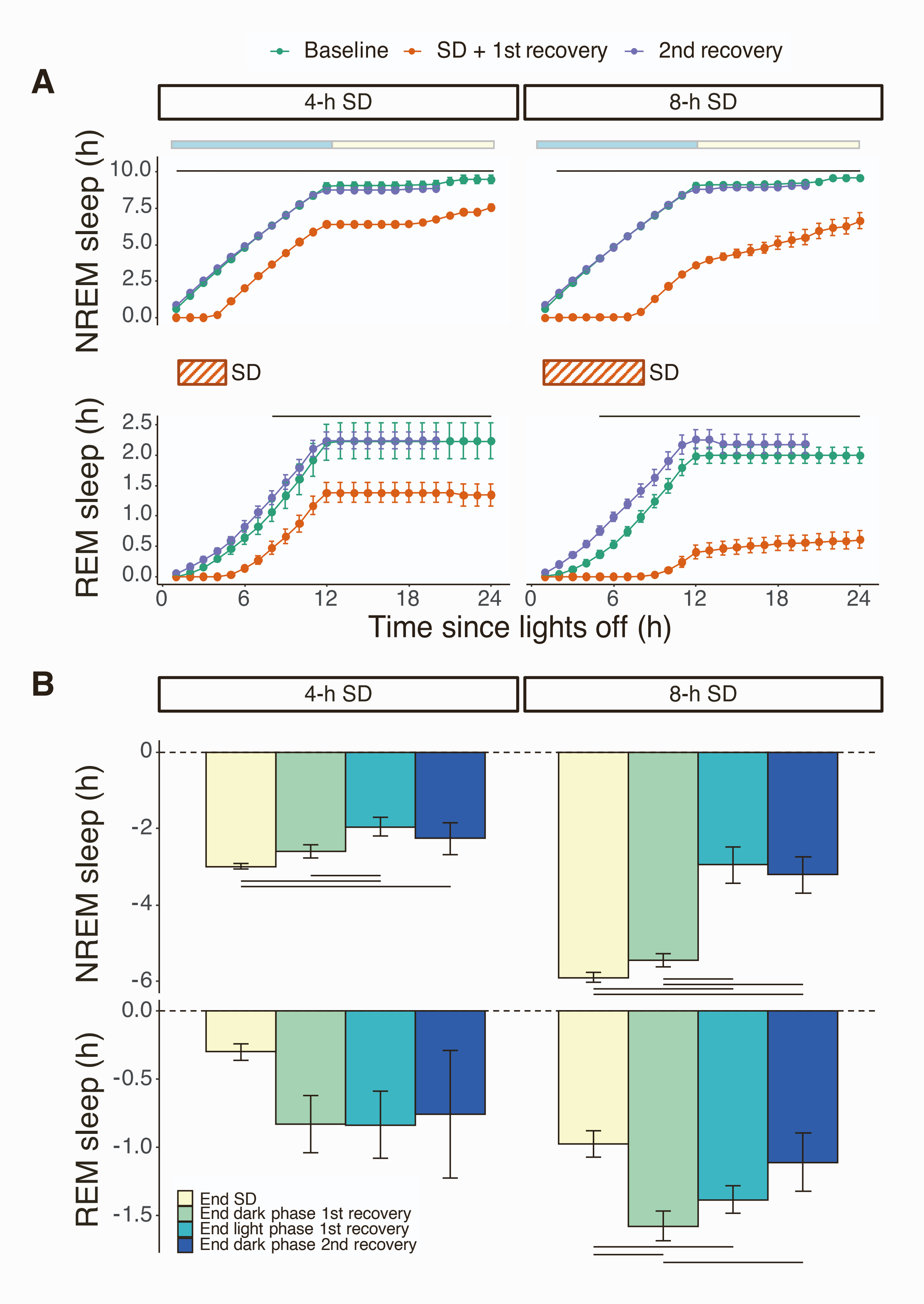

A
Night 1
Night 2
Night 3
Frequency (Hz)
4-h SD
8-h SD
Normalized spectral EEG power
1.75
1.50
1.25
1.00
0.75
Time since lights off (h)
B
Δ relative spectral power
0.50
0.25
0.00
-0.25
-0.50
Significant positive difference
Significant negative difference
0.05
0.04
0.03
0.02
0.01
0.00

Figure S2. EEG spectral power across baseline and recovery nights, Related to Figure 1 and 3.

(A) Heatmaps of the NREM sleep EEG spectral power expressed relative to the mean of the baseline night for 0.5 – 25 Hz with a bin width of 0.5 Hz. During the baseline nights, NREM sleep EEG power in many frequency bins decreased in the first hours of the night and, in some bins, slightly rose again during the last hour. After 4- and 8-h SD, the spectral power increased between approximately 1.5 – 5.5 Hz and 7.5 – 18 Hz. The two lowest frequency bins between 0.5 – 1 Hz, decreased after SD. (B) Heatmaps of NREM sleep EEG spectral (0.5 – 25 Hz) power during the 1st recovery night after 4- and 8-h SD expressed relative to the power in the same frequencies and at the same circadian time during the baseline night. Red values denote higher power compared to baseline and blue denotes lower power compared to baseline. Statistically significant differences are shown in the right panels (red and green gradient for significant positive and negative differences, respectively; $p < 0.05$, post hoc test after lmer; grey indicates non-significant changes).



Baseline
SD + 1st recovery
2nd recovery
A
4-h SD
8-h SD
NREM sleep (h)
10.0
7.5
5.0
2.5
0.0
SD
SD
REM sleep (h)
2.5
2.0
1.5
1.0
0.5
0.0
0
6
12
18
24
Time since lights off (h)
B
4-h SD
8-h SD
NREM sleep (h)
0
-2
-4
-6
REM sleep (h)
0.0
-0.5
-1.0
-1.5
End SD
End dark phase 1st recovery
End light phase 1st recovery
End dark phase 2nd recovery

Figure S3. Jackdaws do not fully recover lost sleep, Related to Figure 2.

(A) The cumulative sum of NREM sleep (top panels) and REM sleep (bottom panels) for the 4-h (left) and 8-h (right) SD experiments during the baseline day (green), experimental day with sleep deprivation and 1st recovery day (orange), and 2nd recovery day (purple). The light:dark cycle is denoted by the yellow and blue bars on top, respectively. The orange bars in the middle of the graph denote the sleep deprivation period (4- and 8-h). The compensation of NREM and REM sleep time after sleep loss was incomplete. After 24 h there remained a net sleep loss between the baseline and 1st recovery. REM sleep time showed a delayed increase into the 2nd recovery night after 8-h SD. The black horizontal lines at the top of each panel denote significant differences between the baseline day and the experimental day with sleep deprivation and the 1st recovery day ($p < 0.05$, post hoc test after lmer). Data are plotted as mean ± SEM. (B) The difference in the amount of NREM and REM sleep between the baseline day and the recovery days at four different time points: the end of the sleep deprivation (yellow), the end of the dark phase of the 1st recovery day (green), the end of the light phase of the 1st recovery day (light blue), and the end of the dark phase of the 2nd recovery day (dark blue). For both 4- and 8-h SD, the loss of NREM sleep due to sleep deprivation was partly compensated during the subsequent light phase. For REM sleep, after 8-h SD, the recovery was delayed to the 2nd recovery phase (dark blue). Statistical differences are denoted by the horizontal black lines ($p < 0.05$, post hoc test after lmer). Data are plotted as mean ± SEM.

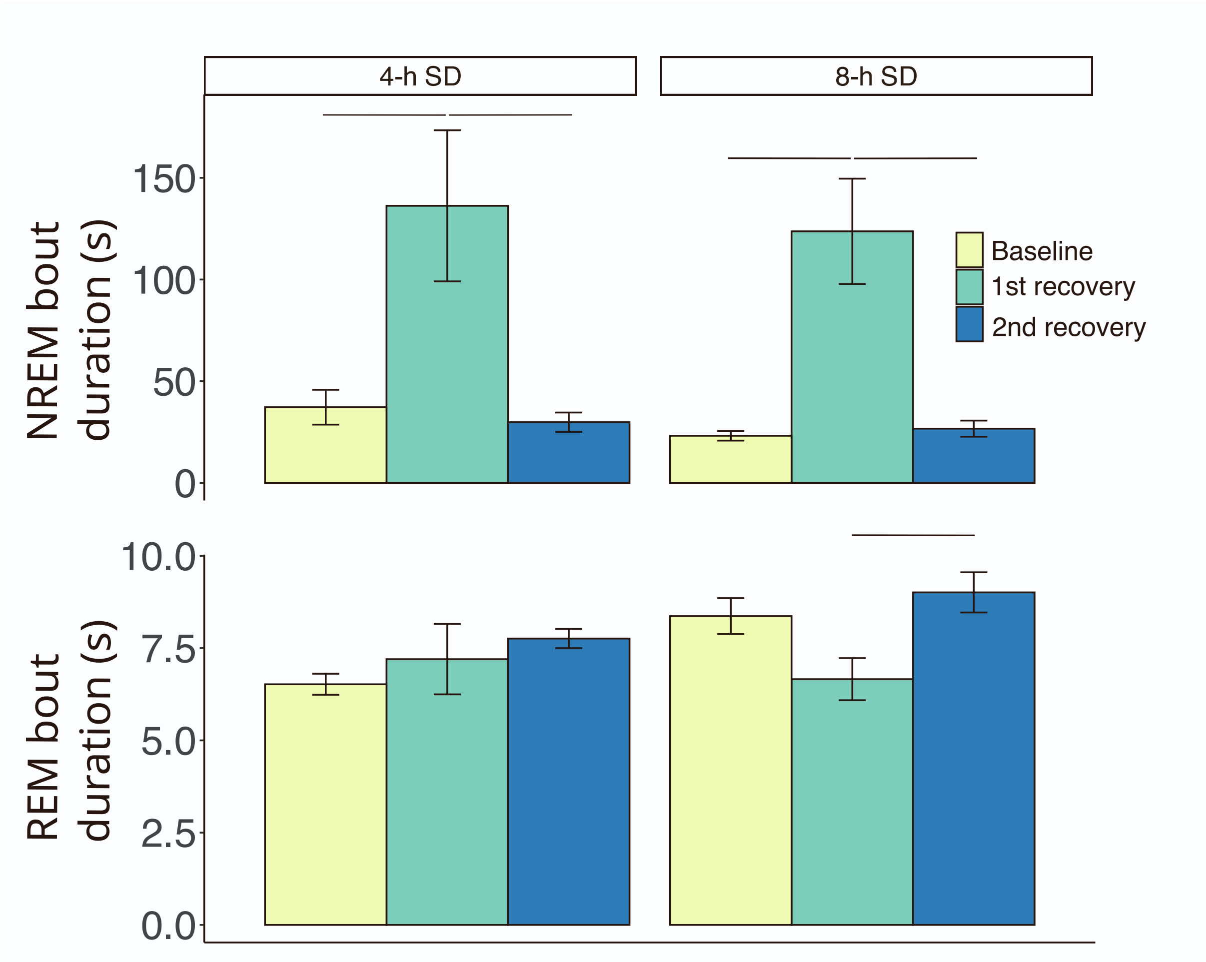


Figure S4. NREM and REM sleep bout durations, Related to Figure 2.

Nighttime NREM sleep bout durations increased during the 1st recovery night following 4- and 8-h SD, and returned to baseline values on the 2nd recovery night. Nighttime REM sleep bout durations only showed a significant increase from the 1st recovery night to the 2nd recovery night following 8-h SD. Statistical differences are denoted by the horizontal black lines ($p < 0.05$, post hoc test after lmer). Data are plotted as mean ± SEM.

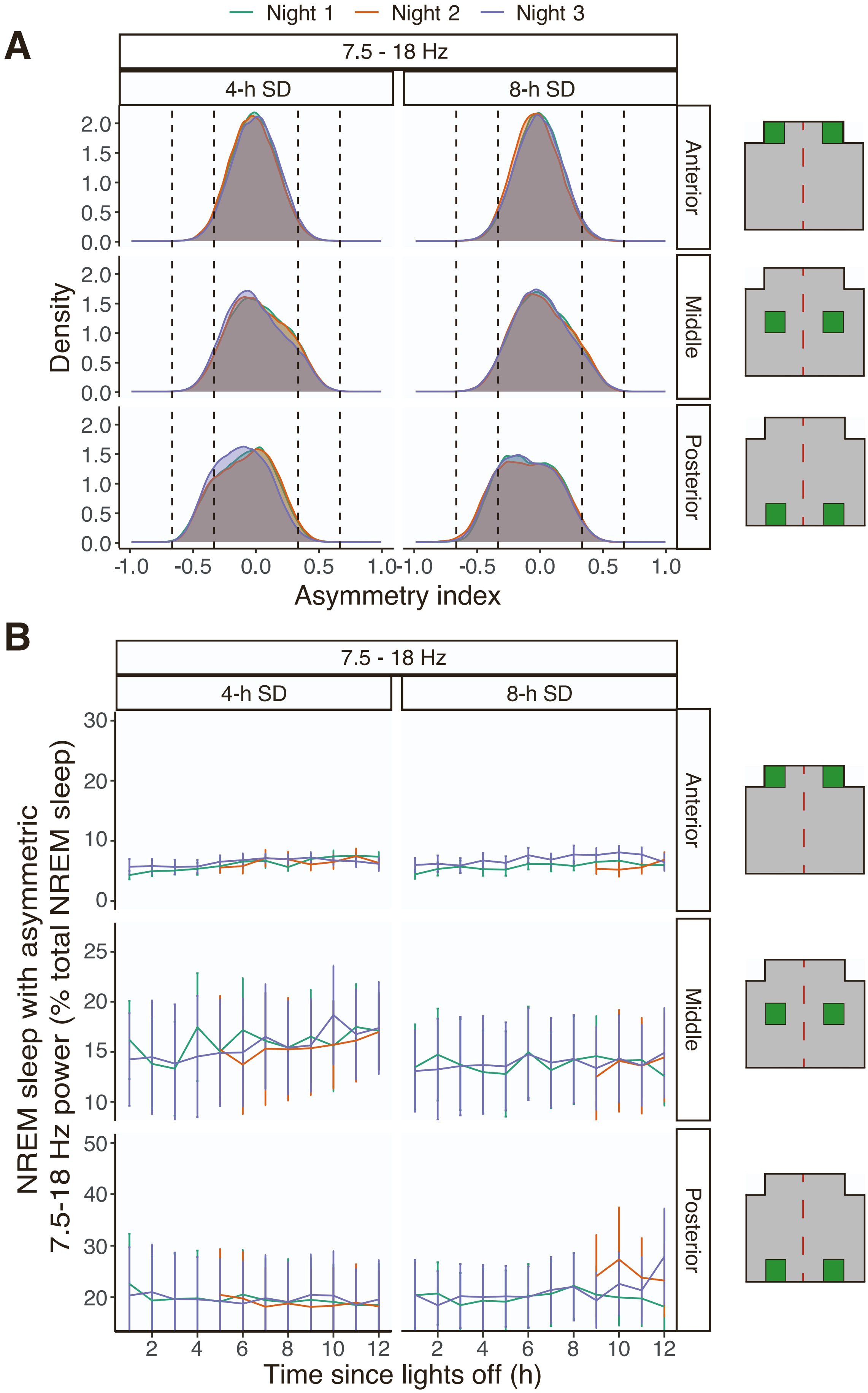

Night 1
Night 2
Night 3
A
7.5 - 18 Hz
4-h SD
8-h SD
Anterior
Middle
Posterior
Density
Asymmetry index
B
7.5 - 18 Hz
4-h SD
8-h SD
Anterior
Middle
Posterior
NREM sleep with asymmetric
7.5-18 Hz power (% total NREM sleep)
Time since lights off (h)

Figure S5. Asymmetry in NREM sleep 7.5 – 18 Hz EEG power, Related to Figure 4.

(A) Distribution of the asymmetry index (AI) values for 7.5 – 18 Hz relative power, for three electrode pairs (green in right electrode plot), and all NREM sleep episodes, during the baseline night (Night 1, green), the 1st recovery night (Night 2, orange), and the 2nd recovery night (Night 3, purple) following 4- and 8-h SD. The dashed vertical lines indicate the thresholds for classifying NREM sleep as symmetric ($-0.33 < AI < 0.33$), asymmetric ($0.33 < AI < 0.67$ or $-0.33 > AI > -0.67$), and unihemispheric ($-0.67 > AI > 0.67$) based on 1.5 – 5.5 Hz SWA. We used these same thresholds to categorize asymmetry in 7.5 – 18 Hz relative power. As with SWA, most values for 7.5 – 18 Hz were symmetric, followed by asymmetric, with only a small (< 0.1%) proportion being unihemispheric. (B) The hourly proportion of NREM sleep with asymmetric 7.5 – 18 Hz relative power during the baseline night (Night 1, green), the 1st recovery night (Night 2, orange), and the 2nd recovery night (Night 3, purple) following 4- and 8-h SD. Because the amount of unihemispheric values was minimal, for this plot, unihemispheric and asymmetric epochs were grouped together as ‘asymmetric’. Unlike 1.5 – 5.5 Hz SWA, the proportion of NREM sleep with 7.5 – 18 Hz asymmetry values above or below 0.33 and -0.33, respectively, were not influence by time of night or SD.