

Additional Material

1. **Additional File 1** - S1_Electrophysiology-Review-Table.docx

Supplementary Table 1 - **A history of electrophysiological recordings**

A table that summarizes marine mammal sleep studies, non-invasive and wild recordings in other mammals and birds, and electrophysiological recordings of wild marine mammals (ECG only) to highlight the shifts in recording methodologies over time and across vertebrate systems as well as emphasize the need for non-invasive recordings of freely moving wild marine mammals, in their natural environment. For each paper, we display the citation number (for referencing icons in Figure 1), citation, family, species, number of animals (N), recording duration (color indicates on land [tan] or in water [blue], N/A indicates evoked potential studies involving averaged responses over multiple stimulus presentations [no baseline synchronous data collected]), recording location (including restraint technique within land or water environments), animal mobility (physical restraint [P], chemical restraint [C], trained restraint [T], tethered (attached to a stationary recording device via cables), or no restraint), captive (C) versus wild (W), electrode invasiveness (non-invasive [NI]: does not pierce the skin, minimally invasive [MI]: needle electrodes, or invasive [I]: implanted in the skull [epidural] or brain [subdural]).

2. **Additional File 2** - S2_Design-Iteration-Summary.docx

Supplementary Table 2 – Design Iteration Summary

Table that summarizes features of each design iteration of the housing and frontend (including the headcap, patches, and wires) and assesses water intrusion and signal quality for each (Good vs. Scorable vs. Unscorable ECG – subjective judgment of accuracy level for automated peak detection [always accurate, not always accurate, apnea vs. eupnea not readily distinguishable]; Good vs. Scorable vs. Unscorable EEG – subjective judgment of ability to visually and quantitatively distinguish between SWS and REM [both distinguishable, visual but not quantitative, not readily distinguishable]).

3. **Additional File 3** - S3_Statistics Report.docx

Supplemental File 3 – Statistics Report for Signal Quality Analysis

Summarized stats outputs for JMP analysis (see JMP reports in <https://github.com/jmkendallbar/Eavesdropping-on-the-Brain-at-Sea/tree/main/scripts>). See S4_Statistics Report.xlsx for full data outputs.

4. **Additional File 4** - S4_Statistics Report.xlsx

Supplemental File 4 – Statistics Report Spreadsheet

Full stats outputs for JMP analysis (see JMP reports in <https://github.com/jmkendallbar/Eavesdropping-on-the-Brain-at-Sea/tree/main/scripts>). See S4_Statistics Report.xlsx for full data outputs.

5. **Additional File 5** - S5_AEP-Goldcup-Needle-Comparison.docx

Supplemental File 5 - Auditory Evoked Potentials (AEP) to compare Goldcup vs. Needle electrodes

Description and data from AEP recordings to compare electrodes.

PLEASE NOTE: The files below will also be included in a versioned Github repository upon manuscript review.

6. **Additional File 6** – 00_Sleep_Study_Metadata.csv

Metadata for all seals. All Excel Date Times are provided in the following format:

“mm/dd/yyyy hh:mm:ss”. Row descriptions:

1. **Test #:** recording # (includes test recordings between deployments)
2. **Animal:** portable logger deployment number (incorporated into Nickname)
3. **Name:** long name
4. **Nickname:** unique animal code
5. **Recording ID:** recording type including location (WILD vs. CAPTIVE), age estimate (i.e. 2mo = 2 months old), and age class (weanling, yearling, juvenile)
6. **Methods_Paper_SEALID:** recording number (to match to Table 1 in MS)
7. **Sex:** visually determined sex (M/F)
8. **Age:** estimated age interval in years
9. **Age estimate:** verbal description of age estimate
10. **Version:** tag iteration used (V1/V2/V3)
11. **Deployment:** deployment number
12. **Seal ID:** Resight Seal ID for Ano Nuevo Research database:
<https://www.anonuevoresearch.com/>
13. **Pressed Start Logger:** Excel Date Time for pressing start
14. **Logger Start:** Excel Date Time for actual logger start
15. **Start from Real Time Clock:** Excel Date Time for time derived by real time clock utility (implemented in 2021).
16. **Start for EDF Files:** start time used for EDF files.
17. **ON ANIMAL:** time heart beats first detected in ECG channel (coincides with instrument attachment)
18. **OFF ANIMAL:** time heart beats last detected in ECG channel (coincides with instrument detachment)
19. **Duration_ON_ANIMAL_h:** hours logger was attached until either was removed or device stopped recording.
20. **Logger Stop:** time logger turned off (if applicable).
21. **Device Failure:** indicates whether logger was in ON or OFF state when recovered.
22. **Standard Length:** straight length of animal in centimeters (nose to tail)
23. **Curved Length:** curved length of animal in centimeters (nose to tail along body)
24. **Ax Girth:** circumference of animal behind pectoral flippers
25. **Mass animal_kg:** mass of animal in kilograms
26. **Flipper tag 1:** ID listed on flipper tag 1 (including G to denote green color)
27. **Position:** flipper tag position 1
28. **Flipper tag 2:** ID listed on flipper tag 2 (including G to denote green color)
29. **Position:** flipper tag position 2
30. **Birth date:** verbal description of birth date estimate
31. **Animal ID:** unique animal ID for elephant seal database:
<https://www.anonuevoresearch.com/>
32. **Deploy ID:** unique deployment ID for TOPP Bird & Mammal Database: <http://lml-research-app-1.ucsc.edu/web/entryform/>

33. **TOPP ID:** unique animal ID for TOPP Bird & Mammal Database: <http://lml-research-app-1.ucsc.edu/web/entryform/>
34. **Deploy Latitude:** latitude where instrument was attached to animal
35. **Deploy Longitude:** longitude where instrument was attached to animal
36. **Hematocrit:** blood hematocrit level (if known)
37. **Ultrasound skull depth_cm:** skull depth estimated from ultrasound images
38. **Recording Duration_s:** time logger was recording in seconds
39. **Recording Duration_days:** time logger was recording in days
40. **Begin Calm in Water for ICA:** Excel Date Time for start of ICA training dataset
41. **End Calm in Water for ICA:** Excel Date Time for end of ICA training dataset
42. **Duration for ICA:** length of ICA training dataset hh:mm:ss
43. **Best EOG EMG EEG:** channels that provided best EOG, EMG, L EEG, and R EEG signals
44. **ICA Decomposition Quality:** subjective assessment of ICA decomposition
45. **ICA Component Maximal Brain:** IC# that expressed maximal brain activity
46. **ICA Component Maximal Brain:** IC# that expressed maximal brain activity
47. **Pruned with ICA Components:** ICs that were removed from EOG, EMG, and EEG signals for visual and quantitative analysis

7. **Additional File 7 – 05_Signal_Quality_Data.csv**

Signal quality data for each observation (a 30-sec time period around each comment- See Cmt Text). Column descriptions:

1. **Seconds.On.Animal:** Seconds since instrument attachment
2. **Date Time:** Excel Date Time for each observation
3. **Seal.ID:** Nickname from S5_00_Sleep_Study_Metadata.xlsx
4. **Version:** Version from S5_00_Sleep_Study_Metadata.xlsx
5. **AGE:** age from S5_00_Sleep_Study_Metadata.xlsx
6. **Wild v. Captive:** WILD or CAPTIVE
7. **Phase:** Mode of categorical location denoting current location (LAND vs. WATER) and then the phase number (i.e. LAND02 denotes second time on land).
8. **Date:** Excel date of recording
9. **Sel Start:** Start time of observation hh:mm:ss
10. **Sel End:** End time of observation hh:mm:ss
11. **Sel Duration:** selection duration (all 30s)
12. **Pressure_mean :** mean pressure for selection
13. **Pressure_SD :** standard deviation of pressure for selection
14. **REEG2_Raw_Ch7_Mean**
15. **LEEG3_Raw_Ch8_Mean**
16. **EEG_ICA5_Mean**
17. **pitch_Mean**
18. **roll_Mean**
19. **EEG_ICA_DELTA**
20. **EEG_Pruned_DELTA**
21. **EEG_Raw1_DELTA**
22. **EEG_Raw1_DELTA_SD**
23. **EEG_Raw2_DELTA**
24. **EEG_Raw2_DELTA_SD**
25. **EEG_ICA_DELTA2**
26. **EEG_ICA_DELTA_SD**
27. **BEST_EEG_DELTA**

28. BEST_EEG

29. Cmt Text: Comment placed during scoring (includes: Instrument ON Animal, SWS1, REM, SWS2, Heart Patterns Scorable, Sleep State Scorable, Eye Movement, Muscle Twitch, LS (light sleep), Animal Enters Water, Animal Exits Water)

8. Additional File 8 – 05_SignalData_binned.csv

Signal quality data summarized per day per animal. Column descriptions:

1. **Observation #**
2. **Day:** Day since instrument attachment
3. **Seal.ID:** Nickname from S5_00_Sleep_Study_Metadata.xlsx
4. **Mean:** Mean SWS $\bar{\delta}$ /REM $\bar{\delta}$ per day
5. **sd:** Standard deviation SWS $\bar{\delta}$ /REM $\bar{\delta}$ per day
6. **Max:** Maximum SWS $\bar{\delta}$ /REM $\bar{\delta}$ per day (for a single sleep cycle)
7. **Min:** Minimum SWS $\bar{\delta}$ /REM $\bar{\delta}$ per day (for a single sleep cycle)
8. **Mean_SWS:** Mean SWS $\bar{\delta}$ per day
9. **sd_SWS:** Standard deviation SWS $\bar{\delta}$ per day
10. **Mean_REM:** Mean REM $\bar{\delta}$ per day
11. **sd_REM:** Standard deviation REM $\bar{\delta}$ per day
12. **Version:** Version from S5_00_Sleep_Study_Metadata.xlsx
13. **Phase:** Mode of categorical location denoting current location (LAND vs. WATER) and then the phase number (i.e. LAND02 denotes second time on land).
14. **Percent.Obs.Water:** # of sleep cycles in water for that day / total sleep cycles that day
15. **Deployment:** deployment number from S5_00_Sleep_Study_Metadata.xlsx
16. **Seal.Number:** Methods_Paper_SEALID from S5_00_Sleep_Study_Metadata.xlsx
17. **AGE:** age from S5_00_Sleep_Study_Metadata.xlsx

9. Additional File 9 – 05_SignalData_paired.csv

Signal quality data summarized per sleep cycle. Column descriptions:

1. **Observation #**
2. **PairLabel:** Sleep cycle number (for paired SWS and REM observations)
3. **Day:** Day since instrument attachment
4. **MinSec:** Seconds on animal before first observation (SWS)
5. **MeanSec:** Mean seconds on animal between SWS and REM observations
6. **Standardized:** SWS $\bar{\delta}$ /REM $\bar{\delta}$ for each observation (paired SWS/REM sleep cycle)
7. **Seal.ID:** Nickname from S5_00_Sleep_Study_Metadata.xlsx
8. **Location:** animal location (LAND v WATER)
9. **Version:** Version from S5_00_Sleep_Study_Metadata.xlsx
10. **Phase:** Mode of categorical location denoting current location (LAND vs. WATER) and then the phase number (i.e. LAND02 denotes second time on land).
11. **AGE:** age from S5_00_Sleep_Study_Metadata.xlsx
12. **Deployment:** deployment number from S5_00_Sleep_Study_Metadata.xlsx
13. **Seal.Number:** Methods_Paper_SEALID from S5_00_Sleep_Study_Metadata.xlsx
14. **SWS:** SWS $\bar{\delta}$ for best EEG channel
15. **REM:** REM $\bar{\delta}$ for best EEG channel
16. **Days.Elapsed:** Mean days on animal between SWS and REM observations

10. **Additional File 10** – 06_Signal_Quality_Excerpts_Across_Locations.csv

1-min excerpts of raw signals in different settings. Data can be plotted using R script 06_SignalQuality_Excerpts_Plot.R in code repository. Column descriptions:

1. **SecElapsed**: seconds since logger start
2. **Date**: Excel date of recording
3. **ECG**: raw timeseries data for ECG
4. **LEOG**: raw timeseries data for left EOG
5. **REOG**: raw timeseries data for right EOG
6. **LEMG**: raw timeseries data for left EMG
7. **REMG**: raw timeseries data for right EMG
8. **LEEG1**: raw timeseries data for left EEG (frontal region)
9. **REEG2**: raw timeseries data for right EEG (frontal region)
10. **LEEG3**: raw timeseries data for left EEG (parietal region)
11. **REEG4**: raw timeseries data for right EEG (parietal region)
12. **Acc X/Acc Y/Acc Z** : unprocessed accelerometer timeseries data
13. **HeartRate**: output for automated peak detection
14. **Seconds**: seconds since start of each excerpt (0 to 60)
15. **Comment**: channel with event markers for each identified heart beat
16. **SealID**: Nickname from S5_00_Sleep_Study_Metadata.xlsx
17. **Wild v. Captive**: WILD or CAPTIVE
18. **Active v SWS v REM**: denoting whether excerpt is of active behavior (galumphing on land or swimming in water), slow-wave sleep (SWS), or rapid-eye-movement (REM) sleep
19. **Location**: LAND or SHALLOW (water)
20. **Activity**: Galumphing (land), Swimming (water), Stationary (land or on the ocean floor), or Drifting (water).

11. **Additional File 11** – 06_Signal_Quality_Excerpts_Challenges_Solutions.csv (1-minute raw data excerpts with different signal quality challenges/solutions)

1-min excerpts of challenges and solutions to signal recording obstacles. Data can be plotted using R script 06_SignalQuality_Excerpts_Plot.R in code repository. Column descriptions:

1. **SecElapsed**: seconds since logger start
2. **Date**: Excel date of recording
3. **ECG**: raw timeseries data for ECG
4. **LEOG**: raw timeseries data for left EOG
5. **REOG**: raw timeseries data for right EOG
6. **LEMG**: raw timeseries data for left EMG
7. **REMG**: raw timeseries data for right EMG
8. **LEEG1**: raw timeseries data for left EEG (frontal region)
9. **REEG2**: raw timeseries data for right EEG (frontal region)
10. **LEEG3**: raw timeseries data for left EEG (parietal region)
11. **REEG4**: raw timeseries data for right EEG (parietal region)
12. **Acc X/Acc Y/Acc Z** : unprocessed accelerometer timeseries data
13. **HeartRate**: output for automated peak detection
14. **Seconds**: seconds since start of each excerpt (0 to 60)
15. **Comment**: channel with event markers for each identified heart beat
16. **SealID**: Nickname from S5_00_Sleep_Study_Metadata.xlsx
17. **Wild v. Captive**: WILD or CAPTIVE

18. **Active v SWS v REM:** denoting whether excerpt is of active behavior (galumphing on land or swimming in water), slow-wave sleep (SWS), or rapid-eye-movement (REM) sleep
19. **Location:** LAND or SHALLOW (water)
20. **Activity:** wet (headcap had significant water intrusion), dry (headcap had no water intrusion), VHF BAD (VHF on land), VHF GOOD (VHF in water where signals were attenuated), with pings (satellite pings present), without pings (satellite pings removed), HR BAD (HR signals messier with poor wire fortification), HR GOOD (HR signals better with good wire fortification).