Case Study 2 - Sleep Study

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1 Objective

The goal of this study is to analyze the data from a pilot study conducted by a student in the Yale School of Medicine to compare two devices that measure sleeping position in degrees (0 representing sleeping on the back and -90 and 90 representing sleeping on the right and left side respectively. The study aims to investigate The devices are:

- SomnoPose: A new promising iPhone app to measure sleeping position, that records every 2 seconds
- Embletta: A customized medical device to measure sleeping postion, this will be considered as the "gold standard" in this study, that records at 10Hz frequency. It was supposed to automatically record from 10PM - 7AM (324,000 recordings).

The sensor setup is shown in Figure 1, the Embletta is silver and is strapped firmly to the torso while the iTouch is black and is clipped onto the strap next to the Embletta.

Figure 1: Both devices on the second subject, Embletta is the silver and the iTouch is the black.

The objective is to compare the data from the two devices for six nights by two subjects, and determine if SomnoPose is sufficient compared to Embletta in order to study side-dependent sleep to investigate if that might cause pressure on either eye.

The data was collected by two subjects by dates as follows:

- Subject A: November 15, 17, 18 and 19 (2011)
- Subject B: November 23 and 24 (2011)

2 Angle Processing

Some of the recorded data was outside the range $[-180; 180]$ and were considered artifacts by the sleep center expert, which reccommended to ignore those datapoints.

After exploring the data, there was a sign mismatch between the Embletta and the SomnoPose angle recordings by the second subject on November 23rd and 24th. This could have stemmed from the fact that either of the devices were turned upside down. This was corrected by reversing the sign of the SomnoPose, since the Embletta was considered as the "gold standard" of the study.

3 Time Alignment

The Embletta data was only provided as `.txt` files without any time associated with each recording. The recording started at 10PM and ended at 7AM (the next day) on Nov 17, 18 and 19 while having unknown start and end times the other days. A number was associated with each recording as seconds from 10PM to 7AM (`0, 0.1, 0.2,... 32,400`) for Nov 17, 18 and 19.

For the SomnoPose, the `Time_of_day` contained the time of each recording in a HH:MM:SS format, which was mapped to the same format as the Embletta data as seconds from 22:00:00.

The other days were handled as:

- **Nov 15**
  The Embletta file contained 579,900 recordings, being about 16 hours of recording. The `ReadMe` file associated with the data said:
  "Only the first part of the Embletta data file is needed; the second part may be daytime recording by mistake."
  So by removing recordings after 7AM, the data aligned with the SomnoPose recordings so the starting time appeared to be 10PM as for the other days while the end time did exceed 7AM.

- **Nov 23**
  This was recorded by subject 2. The Embletta file contained 252,000 recordings, missing 2 hours of recordings (compared to 324,000 from 10PM to 7AM). By shifting the start time from 10PM to 00:30AM for Embletta, the two devices seemed to align. Hence there was an observed shift of +2.5 hours in the Embletta start time.

- **Nov 24**
  This was also recorded by subject 2. The Embletta file contained 288,000 recordings, missing 1 hour of recordings. The Embletta was shifted by +1.5 hours that aligned with the SomnoPose response. This was therefore the same processing as for November 23rd, except for a smaller shift in the Embletta timesteps.

4 Comparison of Embletta and SomnoPose

The recorded response of the two devices is plotted for each of the days recorded in Figure 2.

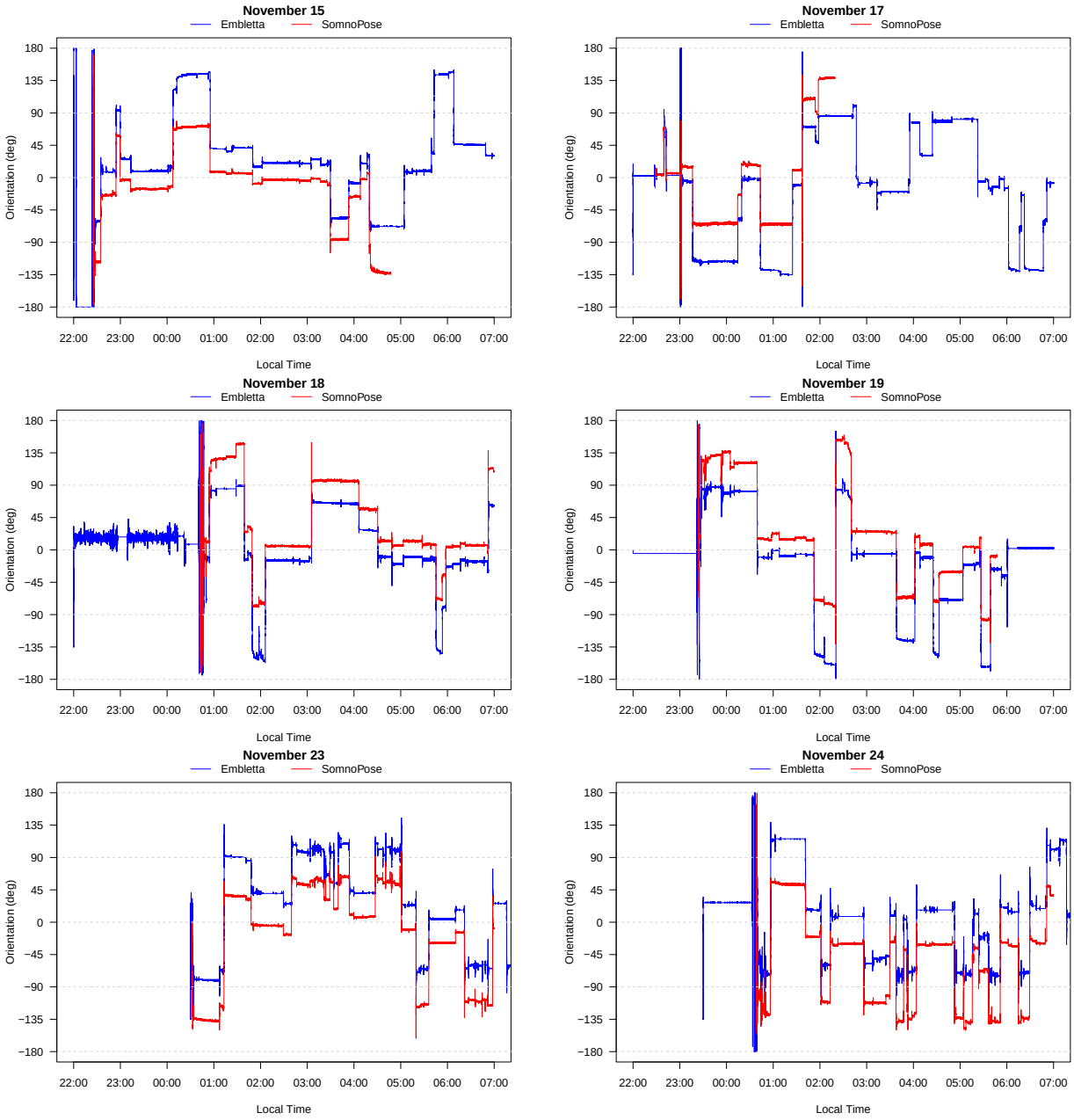

Figure 2: Comparison of the Embletta (blue) and SomnoPose (red) responses.

From the experimental setup in Figure 1, the the two devices would be expected to have a constant vertical shift in angle records, as they could never be perfectly placed similarly on a round torso. Inspecting the plots in Figure 2, the offset varies by pose (e.g., on November 17, the curves have an offset of about 50 degrees near 00:00 yet diverge by only 20 degrees at 00:30 when the subject rotated in their sleep). This pose-dependent bias is plausible: the devices were not perfectly co-located and, on a rounded torso, small lateral separations produce different effective

rotations when the subject lies on the side; minor strap slippage could have added to this. We also find that for our test subjects, none of the nights shows sustained "tummy" sleep, and angles mostly cluster around 0° (back sleep) and ±90° (left/right side sleep).

To account for this observed shift in the recordings, a linear model was fitted for

$$\theta_{SomnoPose} \sim \theta_{Embletta}$$

and the estimated intercept was used to shift the SomnoPose response to visualize the alignment and amplitudes better between the two sensors, as shown in Figure 3

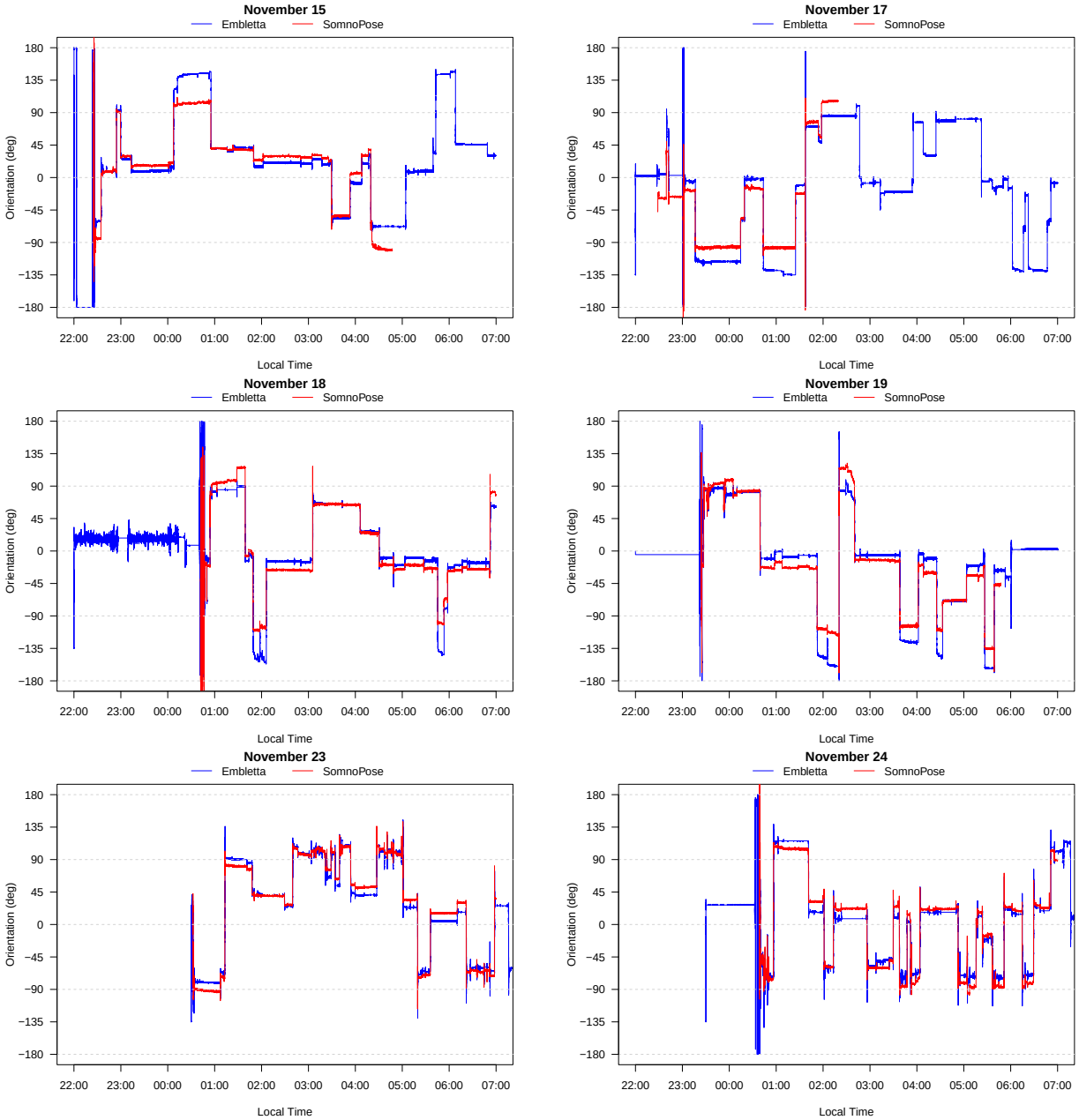

Figure 3: Comparison of the Embletta (blue) and shifted-SomnoPose (red) responses.

Considering the eye-pressure question of the study, the main point of interest is about which of the four canonical poses (back, left, right, tummy) the subject is in. From Figure 3, the SomnoPose recordings seem to provide acceptable data compared to the Embletta. However, the amplitudes of the orientation do have some modest bias (on the order of $20 - 30^\circ$ at most).

While the Embletta records at 10 Hz, the SomnoPose records roughly once every 2 seconds. This lower cadence is totally sufficient for the research question of which side the subject is mostly sleeping on, but would not suffice for other studies examining, e.g., rotations during sleep closely.

During this pilot study analyzed here, it is also important to note that both devices were used at the same time, that causes the difference in measured angles. So using the SomnoPose only, centered at the torso, would probably provide a very comparable response as the Embletta. If the analysis of the pilot study were to map each sample of the unshifted data to the nearest target angle ($0^\circ, \pm 90^\circ, \pm 180^\circ$), the two responses would likely yield stable pose labels.

In short, SomnoPose remains adequate for side-occupancy summaries, compared to the more precise and expensive Embletta sensor. However, closer assessment of a precise sleeping angle or other studies investigating how the subject turns might consider using Embletta measurements.

5 Recommendations

To conclude our findings, we believe that the SomnoPose does provide adequate data to identify if the subject has a tendency to sleep on either side rather than the other, and thus subject either of the eyes to more "pressure" during sleep. The Embletta device that has been used for such recordings, does provide more frequent measurements (at 10Hz), that is not necessary for this study and the 0.5Hz frequency of SomnoPose is sufficient for the research question.

The backing behind this claim comes from the experiment design/tools and from the visualizations in Figures 2 and 3. The first thing to note in the experimental design is that looking at Figure 1, it would be impossible to align the two devices on a rounded torso. Because of this, there will be a shift in the angles measured. This was taken into account in the analysis herein as discussed above. Beyond the difference of the angles, the Embletta takes measurements at a much higher frequency than the SomnoPose.

From Figure 2, the expected shift in the recordings was clear, since the devices were not located at the same spot on the torso. After accounting for the shift in Figure 3, the angle recordings align over long periods of time (a whole night). Thus, the SomnoPose performs just as well as the Embletta for long-term analysis, while deviating slightly for amplitudes from 0° that could be since the iTouch can move more easily on the torso than the Embletta.

From above arguments, conducting a more formal study on those two devices is recommended. Repeatability is key and a sample size larger than 6 would allow for more confidence on accepting SomnoPose as an alternative to Embletta in collecting the data for this study.