Novel Ultra-long Term EEG Monitoring System
A Possible Enabler of BCI Technologies

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1 OBJECTIVES

Various groups have recently sketched the future within portable EEG equipment (Brunner et al., 2015; Casson et al., 2010). They agree that small, portable and convenient systems for instant and continuous EEG monitoring are essential.

We therefore present a novel subcutaneous monitoring system developed for unobtrusive, continuous, ultra-long term EEG applications. Evidence of high signal quality is provided for two patients monitored continuously night and day for a 1 month period.

2 METHODS

The recording system is described previously in (Duun-Henriksen et al., 2015; Elsborg et al., 2011) and preliminary results based on the same dataset as the current is presented at The 15th European Congress on Clinical Neurophysiology, October 2015 (Duun-Henriksen et al., 2015).

The system consists of an implantable part and an external part, see Figure 1. The implantable part of the device consists of an insulated lead with three embedded platinum-iridium electrodes located 30mm apart. The middle electrode is the reference to each of the other electrodes, thus providing two channels. The lead is fixed to the implant housing, which contains a coil for wireless transmission of power and brain signals to an outer device. The outer device consists of a small shell containing a coil and electronic components for online data analysis. It is furthermore possible to connect a memory unit if up to 30 days of EEG recording, sampled at 207 Hz, should be stored. The implantation and explantation of the subcutaneous device is carried out under local anaesthesia and takes approximately 15 minutes. After implantation the electrodes do not move.

Data were collected from two healthy volunteers for up to 45 days. The project was approved by the regional ethical committee and the Danish Health and Medicines Authority. All subjects have given informed written consent before being enrolled in the trial. The implantable device was placed with the housing right behind the ear and the lead pointing a little posterior to vertex. Subjects wore the system day and night, except while taking a shower or doing water sports.

To investigate the signal quality longitudinally, the signal was forward and reverse filtered into standard physiological frequency bands (δ: 0-4 Hz, θ: 4-8 Hz, α: 8-13 Hz, β_{low}: 13-20 Hz, and β_{high}: 20-30 Hz). Filters were 10^{th} order IIR bandpass filters. Then the average power of each frequency band in 10 seconds, non-overlapping windows were computed. The average power values were then further split into 30 minute intervals, from which the 20^{th} percentile power for each frequency band were extracted.

For the statistical analysis, a linear model was fitted for each frequency band with time, day/night and patient as independent variables. The band power was log-transformed prior to the modelling.

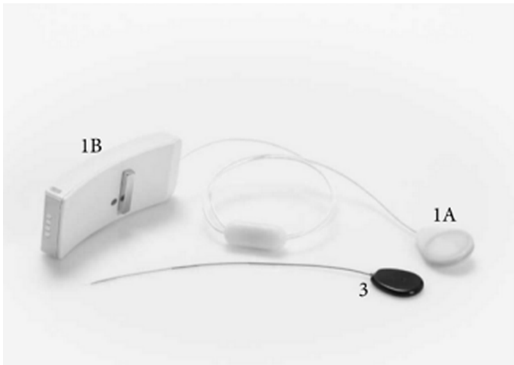

Figure 1: Experimental setup. (1A) Outer device for power and signal transmission to and from the implantable part. (1B) External memory unit to store long-term EEG recordings. (3) Implantable part with lead and implant housing.

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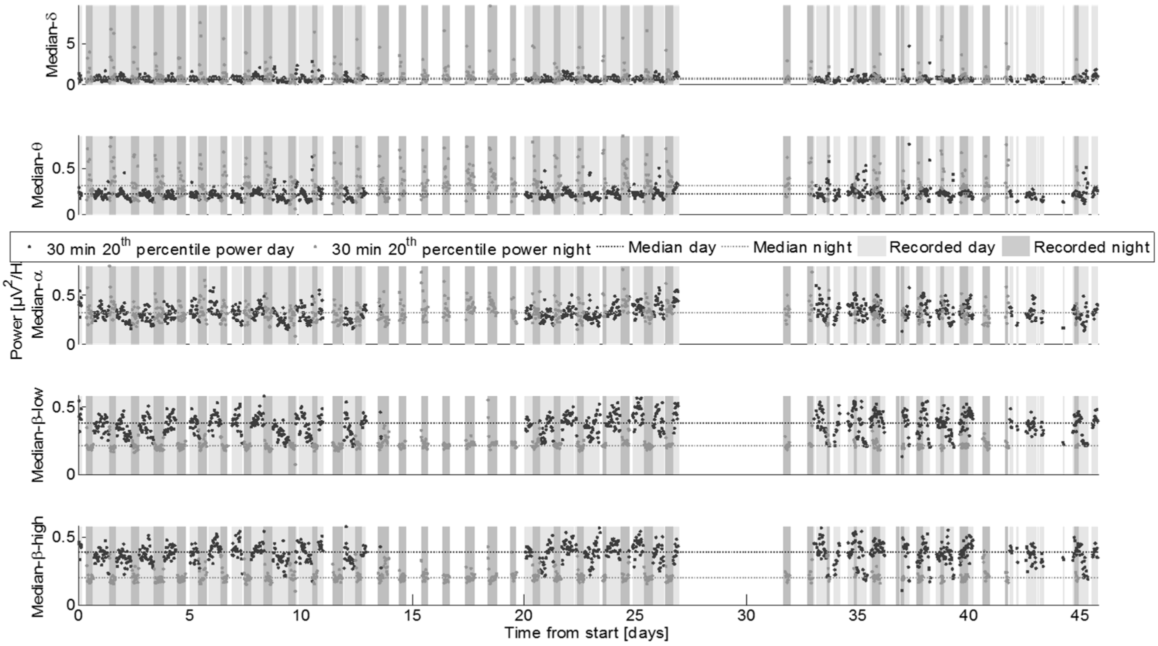

Figure 2: 20th percentile power in different frequency bands during a 45 days period for subject 1. The power does not seem to change over time for neither day nor night recordings.

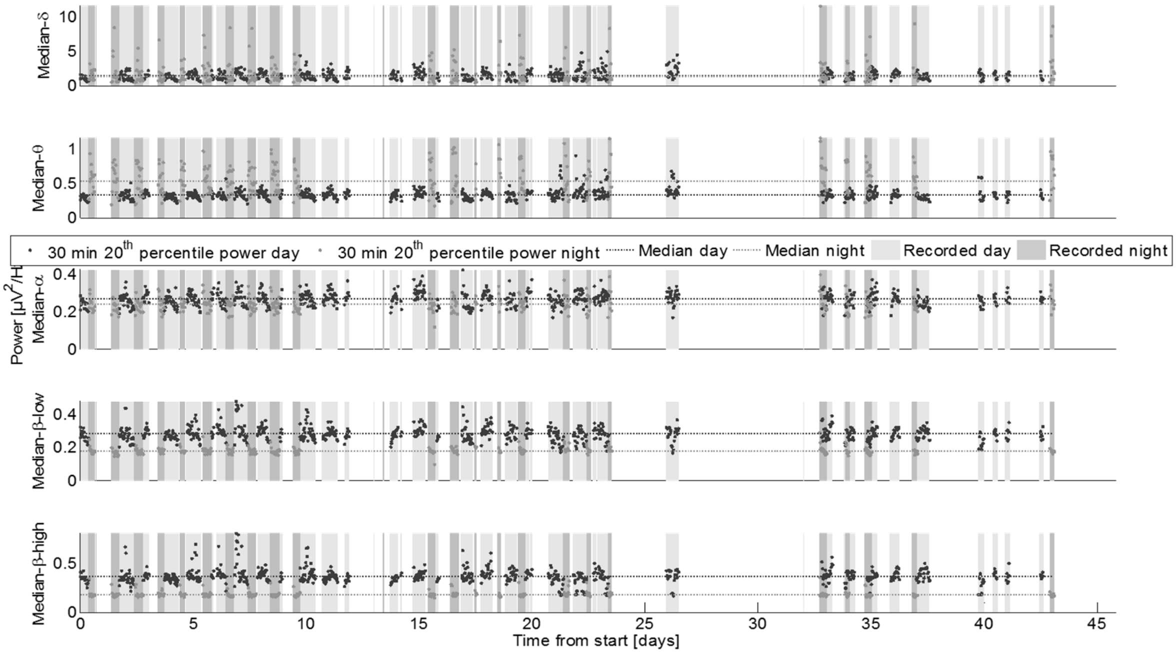

Figure 3: Same as figure 2 but for subject 2. The same tendencies regarding differences in night and day as well as no trend over time are seen for both subjects.

3 RESULTS

Figure 2 and Figure 3 show the 20_{th} percentile of the average power in the five standard physiological frequency bands as described in Methods.

The figures illustrate a difference between night and day recordings in the θ, β_{low}, and β_{high} frequency bands. This is also validated in the statistical analysis with p-values<0.001. Although a clear difference in the δ-band is not as easily seen in the figures, the statistical analysis showed a significant difference in this band too.

Looking at the data points as a function of time, there is no visual trend that implies that the distribution should change over time. For both subjects, the variance in the θ-band is higher during night recordings, but both the mean and the standard deviation are consistent over time.

4 DISCUSSION

4.1 Data Quality

In a previous publication we showed that the EEG data quality of subcutaneous measurements made 10 days after implantation of the implantable device is comparable to the data quality of standard scalp EEG (Duun-Henriksen et al., 2015). The present analysis has shown that the 20_{th} percentile of the average power in the five standard frequency bands do not change over a time course of ~ 1 month. This indicates that the good data quality documented ten days after implantation can be expected throughout the ultra-long term, subcutaneous EEG measurement.

4.1.1 20th Percentile

The use of the 20_{th} percentile as a measure of the approximate power during a 30 min long period has some advantages as well as pitfalls. The advantage is that especially during day, a decent amount of artefacts are seen. Extracting the 20_{th} percentile eliminates those artefacts. Investigating the amount of artefacts in data was out of the scope of this extended abstract, but the number is well above the 20_{th} percentile. The pitfall is that data are not stationary, thus eliminating states that are evident for less than 20% of the time. Such a state is for example the deep sleep stage 3 with pronounced high amplitudes of delta sleep. As this state only constitutes approximately 15% of the time for normal adults during sleep, this will not be included in the 20_{th} percentile. This is probably also the reason that the power in the delta-band is actually higher during day recordings than night recordings in this comparison.

4.1.2 Beta-power Declines during Night

It was seen that for both β_{low}, and β_{high} frequency bands the power was significantly lower during night recordings. Whether this is due to less β-activity during the night or simply less muscle activity during the day is impossible to say with the current analysis. Further investigation is needed.

4.2 The Use of the Device for BCI

We believe that the results support the statement that the novel device is feasible for ultra-long term EEG monitor that can be used for applications within BCI technologies where continuous and instantaneous measurements of the EEG is needed.

ACKNOWLEDGEMENTS

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DECLARATION OF INTEREST

Jonas Duun-Henriksen and Sirin W. Gangstad are full time employed at Hypo-Safe A/S developing and producing devices for unobtrusive subcutaneous EEG monitoring.

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