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Technical characterization of an 8 or 16 channel recording system to acquire electrocorticograms of mice

Abstract: When performing electrocorticography, reliable recordings of bioelectrical signals are essential for signal processing and analysis. The acquisition of cellular electrical activity from the brain surface of mice requires a system that is able to record small signals within a low frequency range. This work presents a recording system with self-developed software and shows the result of a technical characterization in combination with self-developed electrode arrays to measure electrocorticograms of mice.

Keywords: Recording system, characterization, electrode impedance, electrocorticogram, electrical simulation.

https://doi.org/10.1515/cdbme-2017-0124

1 Introduction

In animal experiments the acquisition of the electrical activity of brain tissue is performed in different levels of invasiveness, ranging from recordings at the head surface (electroence-phalography) to intracellular recordings within the brain. Depending on the application, different signal amplitudes and frequency bands have to be taken into consideration for signal processing and signal evaluation [1]. In recent studies, an increased use of electrocorticographical (ECoG) recordings is observed. ECoGs are acquired from the cortical brain surface with different types of electrode arrays in combination with specific recording devices. Conventional ECoG recordings in mice are in an amplitude range of ± 2 mV and in a frequency range less than 100 Hz, but also higher frequency ranges will be used to record evoked potentials for example. Here, a software for a commercial 16 channel acquisition device was produced to interface self-developed ECoG electrode arrays for mice with eight or sixteen channels (see **Figure 1A**).

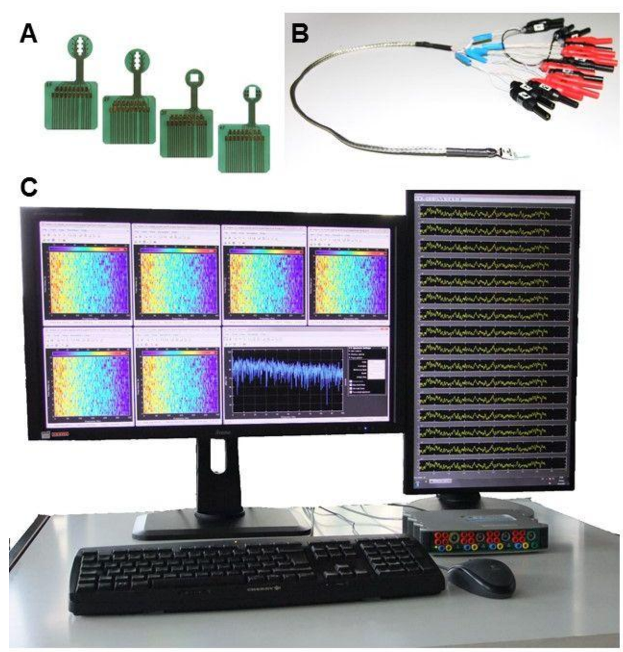

Figure 1: A) Different electrode designs with eight and sixteen channels **B)** An assembled electrode with connector cable **C)** Recording system consisting of a recording device and self-developed software showing sixteen time signals, six time-frequency plots and one spectrum**.**

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2 Materials and methods

2.1 Recording system

The recording system (see Figure 1C) consists of a 16-channel biosignal amplifier (gUSBamp, Fa. gTec) and a self-developed recording software. The recording device is connected via a USB 2.0 link and is able to acquire signals up to 4.8 kS/s. It has user-selectable input filters, which can be set individually for each channel. In addition, up to three software filters can process the signals of each channel. The software is designed to store the signals and to visualize the electrical brain activity in the time as well as the frequency domain. All time signals are displayed in one window whereas the time–frequency plots have separate windows for each channel. These can be activated and arranged by the user according to the experimental requirements. An averaging module is implemented separately and can be executed in parallel to the recording software. The software was realized through a combination of SIMULINK and MATLAB models and is run on a commercial personal computer (CPU: i7-4770HQ 3,4 GHz, main memory 8 GB RAM, hard drive: SSD SATA 6 Gb/s). Two versions of the software (one with eight and one with sixteen channels) were created. The four different electrode structures consist of electroplated gold contacts on the round-shaped array head. The heads are 3 mm or 4 mm and include an individual observation window for microscopy. The sixteen single electrode of the larger electrode arrays are 150 µm or 75 µm in diameter. The smaller arrays contain eight channels, one with round shaped electrodes of diameter 150 µm and one with rectangular-shaped contacts of 400 µm x 200 µm.

2.2 System characterization

A technical characterization of the system was carried out, showing the overall system performance and possibility to acquire signals without loss or distortion of the recorded signals. The recording device was used with a maximum sampling rate of 2.4 kS/s. This was the highest possible rate without loss of data when sixteen channels were used for recordings. Using the system with the eight channel recording setting, the full speed of 4.8 kS/s could be used. The impedance of the electrodes were measured with a potentiostat (Interface 1000, Gamry Instruments) in the frequency range from 1 Hz to 100 kHz with an signal amplitude of 10 mV. The electrode impedances were fitted with a common model [2]. The input impedance of the recording set-up was estimated by applying a step function signal with a wire to the connected microelectrode and measuring the rise time and signal amplitude of the step function response.

The response of the recording set-up to fast signals with large amplitudes (e.g. artefacts from electrical stimulation near the recording sites) was evaluated with a standard filter configuration for ECoG recordings containing a notch filter to prevent noise from mains and a bandpass with cut-off frequencies of 0.5 Hz and 200 Hz. A pulse signal was directly applied to the system (pulse width: 200 µs, amplitude: 150 mV) and the signal response was recorded by the device. The noise level of the recording set-up was estimated using electrodes with a diameter of 150 µm in saline. These measurements were carried out in a shielded room, in order to prevent electromagnetic interference.

2.3 Simulation model

To analyse the dependency of the electrical input impedance of the device and the electrode impedance to the recorded signal (U_Rec), a simulation model with LTSPICE was created (see **Figure 2**). The simulation model consists of

- a model [2] for two recording sites of one electrodes array (Ex1, Ex2) performing a bipolar recording,
- an input amplifier including the estimated input impedance (only capacitive part is expected) and a dummy resistor (R_D),
- one signal source for generating a measureable signal (V_ECoG),
- one signal source for common-mode signals (V_Com), like synchronous brain activity or noise from mains, and
- zero resistance ground connection, assuming a very large ground electrode.

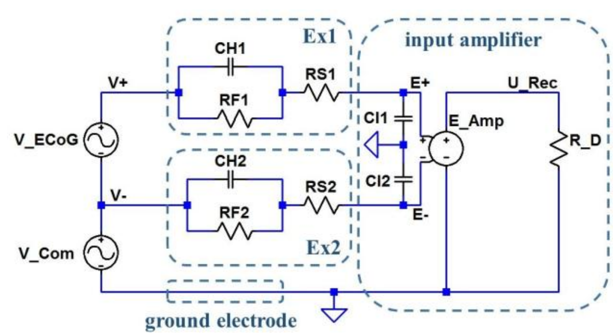

Figure 2: LTSPICE simulation model to analyze the dependency of electrode impedance and input impedance of the recording device

With simulations in the time domain, the impedance of the electrode models of Ex1 and Ex2 were changed equally according to the median impedance values of the microelectrode arrays (see **Chapter 3.1**). Due to variations in impedance values of the electrode sites of one array, simulations have been carried out varying the impedances of electrode Ex1 whereas Ex2 was permanently set to the median impedance value. For a parametric simulation the parameter "impedance factor (if)" was assigned to CH1 and RF1.

3 Results

3.1 Electrode impedance

The characterization of the gold electrodes resulted in typical impedance curves for metal electrodes [3], varying according to the electrode size. **Figure 3** shows the magnitude of the impedance for six (E1) to eight (E2, E3) single electrode contacts of one array (dots) as well as the calculated median (lines) and mean (dashed lines) values. The median and mean values were mostly identical, which indicated a homogeneous distribution of the single impedance values.

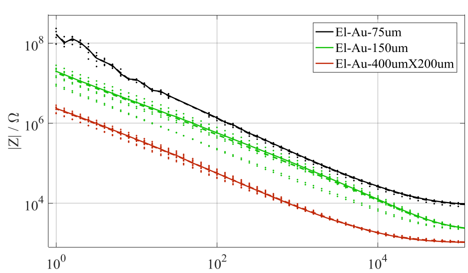

Figure 3: Measured magnitude of electrode impedances. Black: Ø 75 µm; green: Ø 150 µm; red: 400 µm X 200 µm. Dots representing single measurement points, lines represent calculated median value, dashed lines represent mean values.

The results of the single impedance measurements showed a variation in the impedance values for one electrode size. This could deviate to approximately 200 % from the lowest impedance value, although in most cases the variation was within 100%. The differences were prominent in the capacitive part (CH) and Faraday resistance (RF) of the electrode, whereas the series resistances (RS) were nearly stable. The median values were approximated by the electrode model values given in **Table 2**.

Table 1: Model parameter for mean impedance values

No.	Electrode size	RS / kΩ	CH / nF	RF / MΩ
E1	Ø 75 µm	9.1	1.1	1000
E2	Ø 150 µm	2.3	5.3	50
E3	400 µm X 200 µm	1.2	16.2	10

3.2 Input characteristics

Estimation of the input impedance of the recording system (including electrode and connector cable) resulted in a non-measurable input resistance and in an input capacitance of 172 pF. The baseline noise level measured in saline showed with broadband filtering (0.5 Hz to 1000 Hz) a time signal amplitude of ±2 µV. In the corresponding power density spectrum mainly white noise is visible as well as the upper cut-off frequency of the filter (see **Figure 4A**). The response of the system to fast, high amplitude pulse signals were estimated. For every applied filter a response was recorded, and also the response without a filter was measured as a point of reference (see **Figure 4B**). The duration of the signal was within several milliseconds, which was far greater than the pulse duration of the stimulation pulse (200 µs).

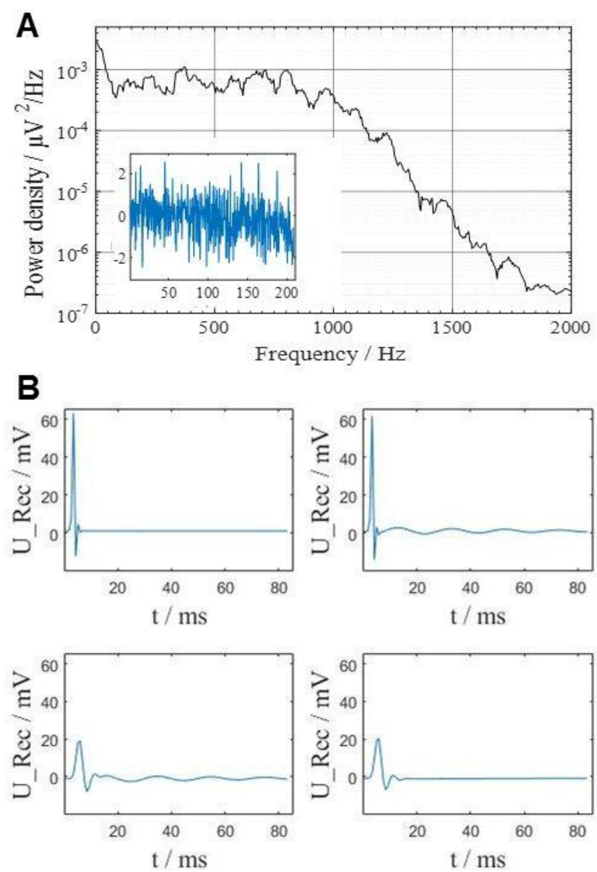

Figure 4: **A)** Noise power density spectrum for of a gold electrode with a diameter of 150 µm recorded in 0.9 % saline with assigned device filter (bandpass 0.5 Hz – 1000 Hz). Inset shows a representative section of noise time signal; scale: y-axis in µV; x-axis in ms. **B)** Recorded signals of a large fast input signal with different filtering conditions. Upper left: no input filter, upper right: 50 Hz notch filter, lower right: bandpass filter 0.5 Hz to 200 Hz, lower left: notch filter and bandpass filter.

3.3 Effect of limited input impedance

For the electrical simulations the estimated value of input capacitance (172 pF) was assigned to CI1 and CI2 (see **Figure 2**) and the impedance model values of **Table 1** were used. In addition, the voltage source V_ECoG was set to a sinusoidal signal with a frequency of 10 Hz and an amplitude of 500 µV, and the source V_Com was set to a frequency of 50 Hz and an amplitude of 5 mV. The gain of the amplifier (E_Amp) was set to 100.

The results showed, that with increasing electrode impedance the amplitude of recorded signals decreased, but the signal ECoG could be easily identified in each trace and the signal V_Com was not visible (see **Figure 5A**). When the electrode impedance values varied within a recording set-up the recorded signal could contain additional noise like parts of common-mode signals (see **Figure 5B to 5D**).

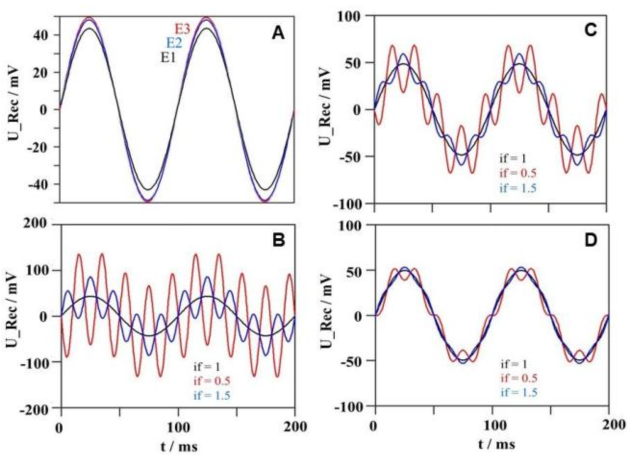

Figure 5: Simulation results; **A)** Dependency between electrode sizes (impedance) to the recorded signal. **B) – D)** Influence of impedance variances to the recorded signal, the capacitance CH2 was varied. In **B)** model values for E1, in **C)** model values for E2, and in **D)** model values for E3 were used.

4 Discussion and conclusion

The developed software for the recording system provides a comprehensive overview of the recorded time signals and calculated time frequency plots. The number and position of the single windows can be user-defined, as usual for SIMULINK applications. However, with sixteen channel recordings the sampling rate has to be carefully selected, because higher rates than 2.4 kHz will lead to a loss of signal. For conventional ECoG recordings, this sampling rate is still sufficient due to the fact that the highest frequency in a typical ECoG signal lies below 100 Hz.

The electrical input impedance was estimated and evaluated in relation to the electrode impedances in an electrical simulation. The results show the ability to use the electrodes within the set-up, but the smallest electrodes will have a measurable influence on the recorded signal. Taken the impedance variation of the electrode contacts within one array into consideration, the array with the smallest electrodes has to be used with care. A large variation of the impedance could dramatically decrease the signal quality. And moreover, the impedance variation could provoke a wrong signal interpretation if global brain activity is represented as local activity. These variations could also arise after implanting the electrode, because differences of local tissue composition (e.g. during scar tissue formation) could also impact the electrode interface. To work around this problem, the electrode impedance can be decreased by using a rough platinum coating for example [4]. The response of the system to fast signal changes has to be considered in case of electrical stimulation near the recording sites. The long lasting response of the system will prevent any reliable detection of brain activity.

In conclusion, the performance of the recording system was characterized and the usefulness for ECoG recording was shown. The systems strengths and weaknesses were investigated, which is essential to reliably acquire and evaluate signals.

Author's Statement

Research funding: The work was supported by the Trier University of Applied Sciences, the DFG SPP 1757 and the EU-H2020 MSCA_ITN EU-GliaPhD. Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent: Informed consent is not applicable. Ethical approval: The conducted research is not related to either human or animals use.

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