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Position reconstruction of rats by the use of neural spike information from hippocampal place cells

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ABSTRACT
Place cells are pyramidal neurons that get active every time an animal moves through specific places of its environment. Such place is called firing field. These spatially modulated neurons are responsible for different locations of their environment. This attribute was used to reconstruct the position of rats just by the use of their brain waves. The reconstruction step can be divided into two steps. In the first step, the training phase, the activity of all neurons was related to the position of the animal . In the second step, the reconstruction phase, unseen parts of the recording are compared with the data of step 1 and the position was reconstructed with the Bayesian 2-step algorithm. The decoded position agreed well with the real position of the animal.

Keywords
Place cells, Bayesian 2-step; position reconstruction, Hippocampus;

1. INTRODUCTION
One of the most investigated neurons, the so-called place cells [1], are located in the Hippocampus [2], an important brain region for navigational skills. Place cell neurons have a background firing rate of about 0.1 Hz, but when the animal enters the neurons responsible location, the so-called place field, the firing rate goes up to about 10-20 Hz. These local fields can be stable of up to 150 days [3]. Recordings of place cell neurons of the hippocampus show their firing fields at different locations in space. The correlation of different neurons to different positions allows the reconstruction of the animal's position from their brain waves. The goal was to reconstruct the positions of rats in square open fields between 0.5 m x 0.5m – 1 m x 1 m.

2. METHODS
A pre-condition of neuronal decoding is the technology for single cell recordings. To be able to distinguish superimposed spikes [4] of different neurons, recordings were made with tetrodes [5]. These multiple wired electrodes dispose of four different channels with an inter-electrode distance of less than 40 µm. Every time the signal exceeds a given threshold the signals was recorded for 1 ms (200 µs before and 800 µs after the spike event) with a sampling rate of 48 kHz. Since the relative distance of each electrode-tip to the recorded cell will be different, the amplitude and spike duration differ. This allows the assignment of spike activities to specific neurons. For this purpose manual spike-sorting [4] was applied on the recordings. To be able to assign spike activities to the positions of the animal the trajectory of the rat was tracked with a video-tracking-system.

After the action potentials and position were recorded two steps are necessary to reconstruct the position: encoding and decoding (see Figure 1). In the encoding step the arena is divided by software into 64 bins in X- and 64 bins in Y-direction. Every recorded spike is then assigned to the position (bin) the rat was at the moment of activity. The results of this process are matrices including the total amount of spikes of a neuron for every bin. The amount of spikes in each bin gets then normalized with the time the animal spent in this bin. This normalization leads to the so-called firing rate map – a map which represents the firing rate of a neuron over all bins the rat has visited during the recording. The firing rate maps of all neurons were then used to train three different algorithms.

In the decoding step a time window with a length between 1 s- 8 s was moved along time of unseen recording parts in 500 ms steps. For every step the firing rates of all neurons within the this time-window was calculated and compared with the normalized spike frequencies of the firing rate maps to find the best fitting position. For the reconstruction process 'template matching', 'Bayesian 1-step' and 'Bayesian 2-step' algorithm were used [6]. The reconstruction results were calculated for unseen recording parts with cross validation of six different rats.

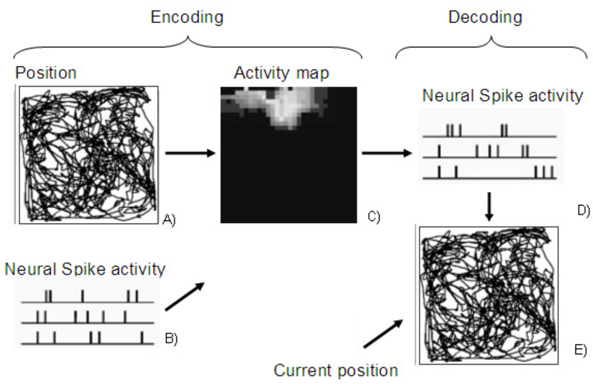

Figure 1: Encoding and Decoding. The spikes of different neurons (B) are assigned to the position (A) of the animal acquired with a video tracking system. A shows the trajectory of the rat within the recording arena. B shows the spike activity over time for three different neurons. The result is a firing rate map (C) representing the individual firing rates of

a neuron over position. Bright pixels are representing positions of high neuronal activity whereas dark pixels represent position of low or no activity. In the decoding step the firing rates within a time window of unseen recording parts (D) are compared with the positions of the firing rate maps and the position gets reconstructed (E).

3. RESULTS

The Bayesian 2-step algorithm showed the best results for all rats (Figure 2). The median error of unseen recordings were calculated with a 3 x 3 cross validation and were 9 cm in a 50 cm x 50 cm arena in best case (brain region: CA1) and 45 cm in a 100 cm x 100 cm arena in worst case (brain region: Subiculum). Window lengths of 4000 ms brought the best reconstruction results.

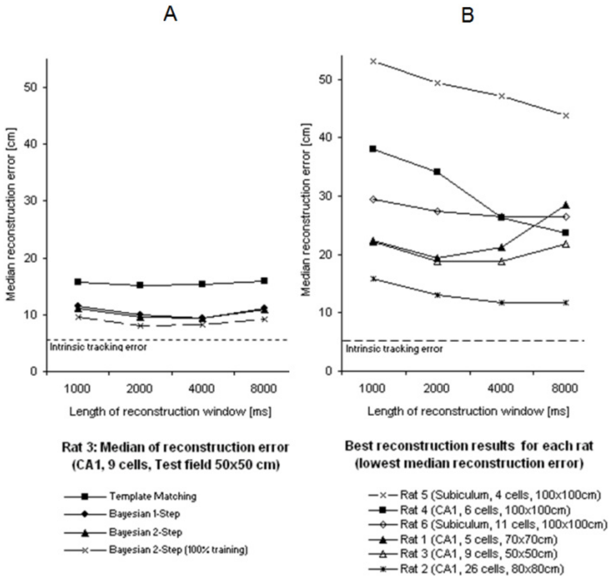

Figure 2: A shows the position reconstruction results of rat 3 for different reconstruction window sizes and all three reconstruction algorithms. B shows the best reconstruction results for each rat.

Figure 3 shows the reconstruction results of rat 3 over 160 seconds. The reconstruction error was 1 cm in the best and 35 cm in the worst case for Bayesian 2-step. The median reconstruction error was 9 cm.

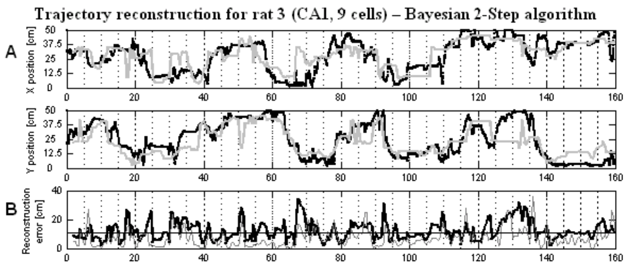

Figure 3: A shows the x- and y-position of the rat tracked with a video system (black) and the reconstructed position (grey). (B) Reconstruction error in cm (horizontal dark line shows median error)

4. DISCUSSION

The study for six different rats demonstrated that the position of rats in space can be reconstructed by the use of place cell recordings. The median error of the Bayesian 2-step algorithm was 9 cm and was achieved with only 9 neurons. In total six different rats were investigated and errors between 9 cm and 45 cm could be found. The accuracy increased significantly with the number of neurons. Furthermore different brain regions were compared. Place cells from CA1 region showed higher accuracies than cells in the subiculum. In future the position reconstruction is planned to be realized in real-time. Therefore automatic sorting algorithms instead of offline manual cluster sorting have to be implemented. However, the ability of encoding neuronal activities holds great promise for the development of neuroprosthetics that rely on control signals from single neurons.

ACKNOWLEDGEMENT

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