FREQUENCY DEPENDENT TOPOGRAPHY OF 400-600 HZ OSCILLATIONS IN THE RAT WHISKER BARREL

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Dansereau R.P., Rojas M.J., Carter K.M., Rector D.M.
Washington State University, VCAPP Department, Pullman WA 99164

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Introduction: Local field potentials from the rat whisker barrel cortex are typically comprised of four major component waveforms; N1, P1, N2, and P2. By over-sampling the evoked response at high rates (10-20 kHz) and filtering between 200 and 1000 Hz (Fig 1), we and several investigators have observed a high frequency 200-600 Hz oscillatory burst of action potentials that begin before the N1 response (Jones and Barth, 1999). This oscillatory burst may originate from feedback loops involving thalamo-cortical pathways, or local feedback loops. Evidence from the bat and turtle sensory cortex shows a loop circuit may not be necessary to generate these oscillations. Units fire action potential bursts in a similar frequency range determined primarily by the postsynaptic potential and RC constant of the cell (Ricci et al., 2000). Additionally, cells in the bat and turtle cortex show a topographical burst frequency arrangement depending on the rostral-caudal location of the stimulated sensory column.

Methods: To test the hypothesis that high frequency oscillation organizational features may be also present in the rat, we placed a 25-electrode array on the surface of the whisker barrel cortex from 5 rats, and recorded local field potentials during 0.2 ms single whisker twitches. We have successfully recorded fast optical changes using scattered light imaging techniques, and mapped the electrical evoked responses with a 25 channel surface electrode array (Fig 2).

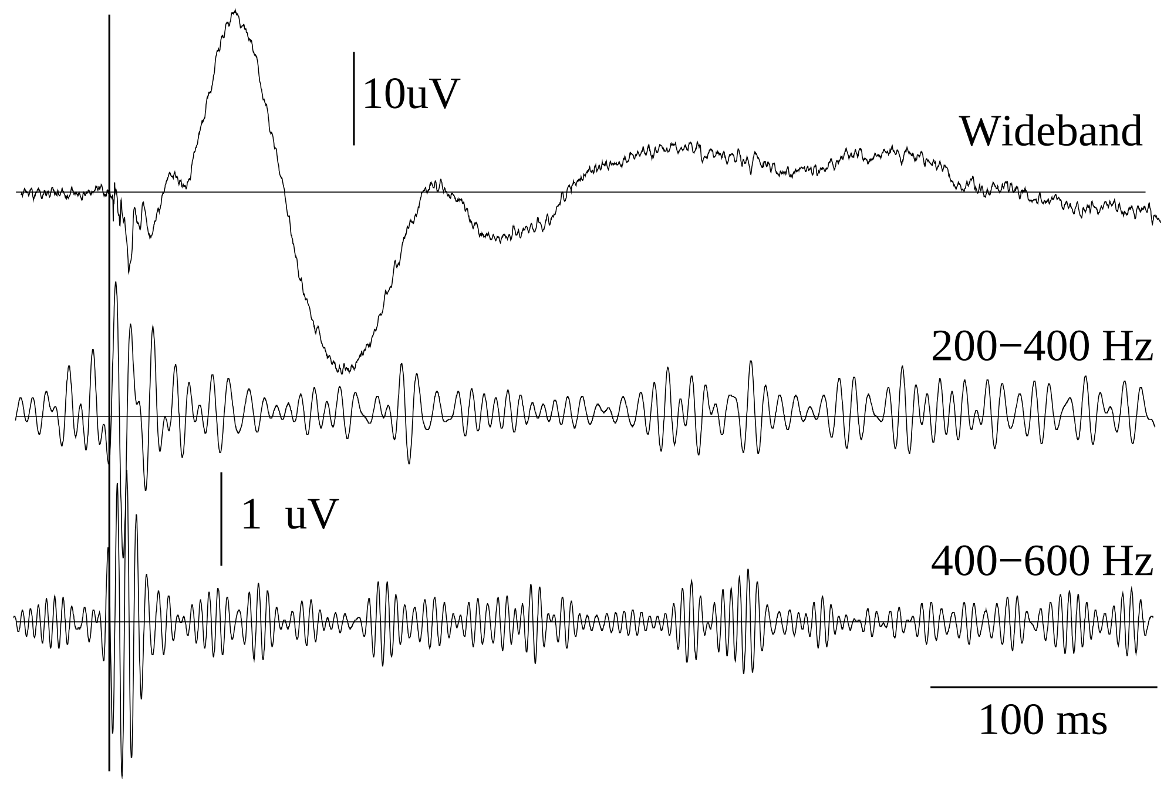

Figure 1: An evoked response from the somatosensory cortex of a rat generated by twitching a whisker shows good signal-to-noise when recorded by a prototype flexible electrode array inserted through a slot in the skull between the bone and dura. With as few as 20 averages in this example, the wideband response as well as the 200-400 and 400-600 Hz components are clearly visible.

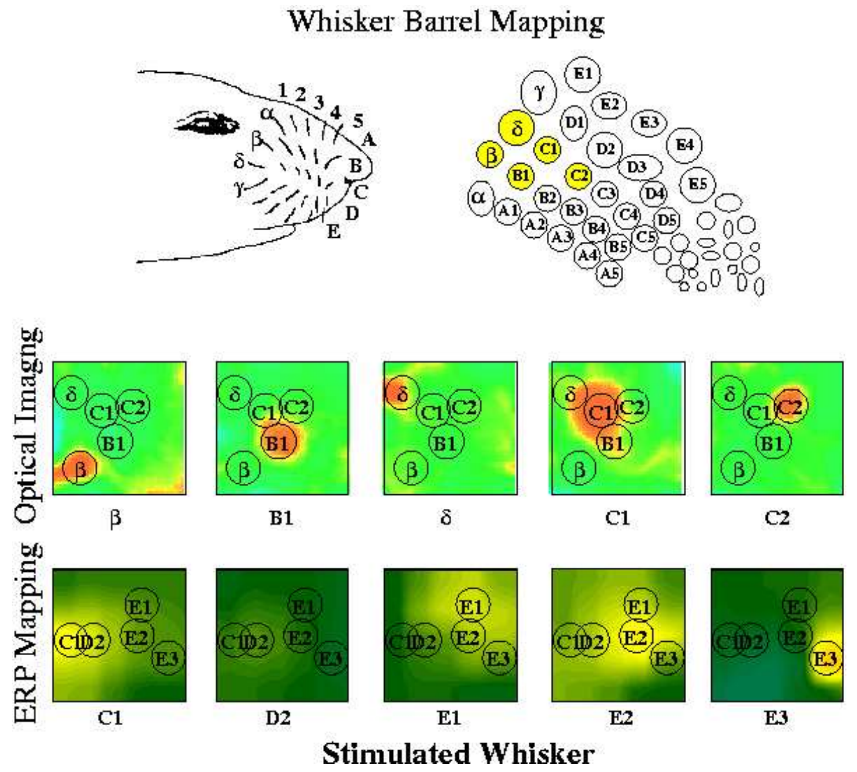

***Figure 2:** Stimulating particular whiskers produced early response images using optical and electrical techniques with discrete regions that were localized in space to regions corresponding to cortical columns. The five images were collected after stimulating the whisker indicated below the image. For spatial comparison, circles that show the activated regions were drawn on all images.*

We are currently developing a flexible plastic electrode array (Fig 4) that can be inserted through a slot in the bone between the skull and dura. The new array will reduce tissue trauma associated with removing large portions of the skull. Electrode placement was verified post-hoc by iron deposition and a ferro-cyanide stain (Fig 5). During the experiment, each whisker A0 – A4, B0 – B5, C0 – C5, D0 – D5, and E1 – E5 was twitched using a solenoid driven hook, and time triggered averages obtained for 25 to 50 trials. Each channel of the array was digitized at 20 kHz, and digitally filtered at either 0.1 – 200 Hz, 200 – 400 Hz, or 400 – 600 Hz. Each whisker barrel was localized by creating a surface potential map for each whisker, and the electrode closest to the barrel was used for subsequent analysis for the identified whisker. Using FFT procedures, the peak frequency between 400 and 600 Hz was measured for each of the whiskers and plotted on a whisker map.

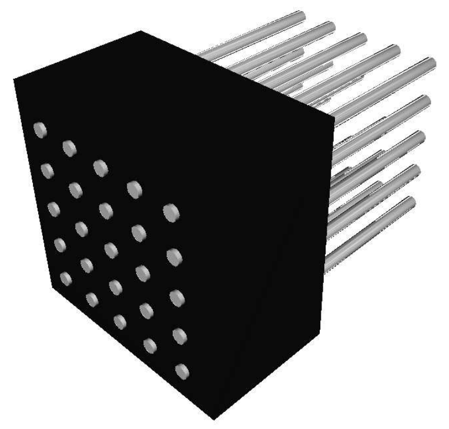

***Figure 3:** A 5 x 5 electrode array was constructed on a computer controlled mill. Holes for the individual electrodes were made using a wire drill,. After insertion of either silver or stainless steel wires, the block is glued with epoxy, and the wires cut and polished using diamond lapping techniques.*

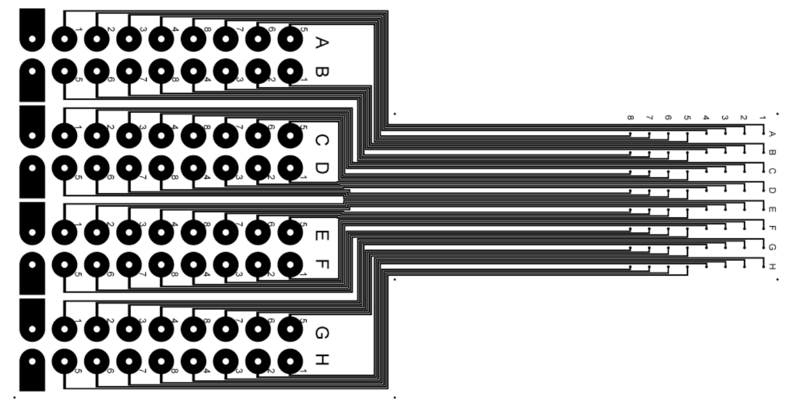

***Figure 4:** We developed miniature implantable surface electrode arrays, which will greatly enhance our ability to record electrical activity from cortical surfaces. The 5x5 mm electrode array can contain 64 or more channels for high-resolution mapping of evoked responses from the brain surface. Prototypes of the array have been inserted through a slot in the bone between the skull and dura, which greatly reduces the trauma associated with typical electrode arrays.*

***Figure 5:** Wires in our electrode array can be constructed from stainless steel, thus allowing iron to be deposited onto the brain surface. A subsequent ferro-cyanide stain during perfusion can mark the location of the electrodes.*

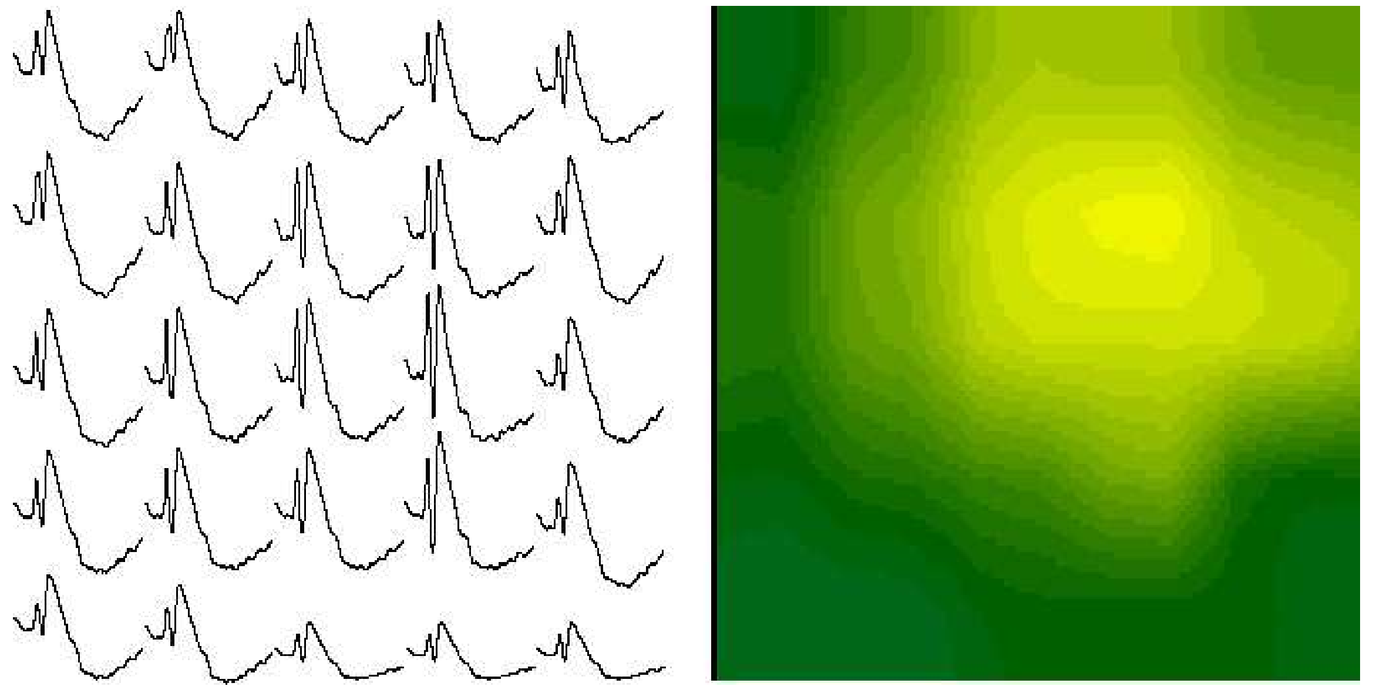

***Figure 6:** Evoked responses and corresponding graphical image at the peak of N1 from the 25 electrode field potential array after twitching whisker D1. We have implemented 25 and 64 channel electrode arrays in chronic rat preparations for mapping the somatosensory cortex of the rat and have successfully trained rats to tolerate restraint and whisker twitching, which is a critical step in the behavioral component of this proposal.*

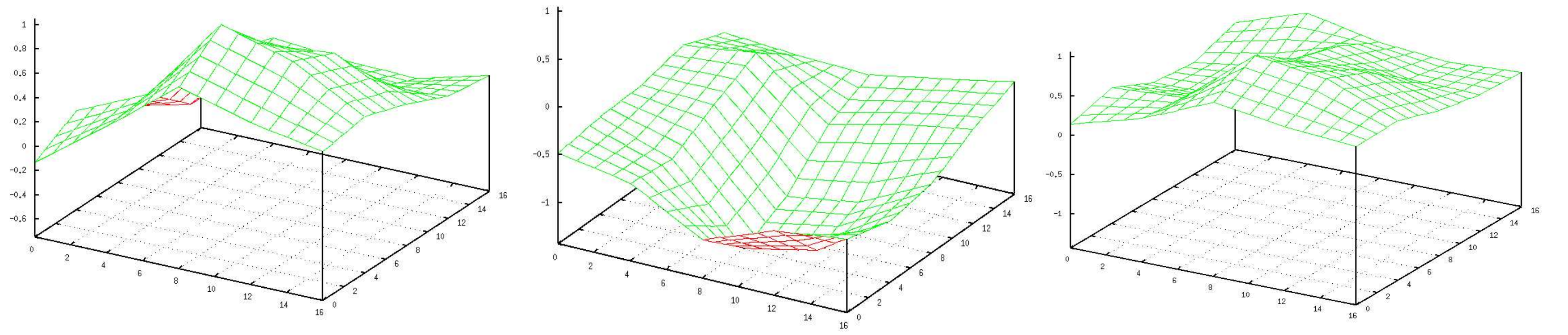

***Figure 7:** Time lapse movies of surface potential maps show clear localization of the barrel during a single whisker twitch. Three frames of the movie separated by 1 ms illustrate a typical high and low phase of one oscillation.*

Results: Time triggered averages show a clear topographical distribution of local field potentials and high frequency bursts that center over the barrel responding to the whisker being twitched (Fig 6). Four dimensional plots of the electrical potential across time show slow evoked responses and superimposed high frequency oscillatory patterns across space and time (Fig 7). Frequency analysis of the bursts show a topographical arrangement of frequencies with the caudo-ventral (whisker A0) column responding with the lowest frequency (400 Hz) and the rostro-dorsal columns (whisker E5) bursting with a higher frequency (600 Hz) (Fig 8). The 200 – 400 Hz frequency range did not show a topographical arrangement. Bursts from all barrels appeared to display classic damped RC oscillator characteristics as in Figure 1.

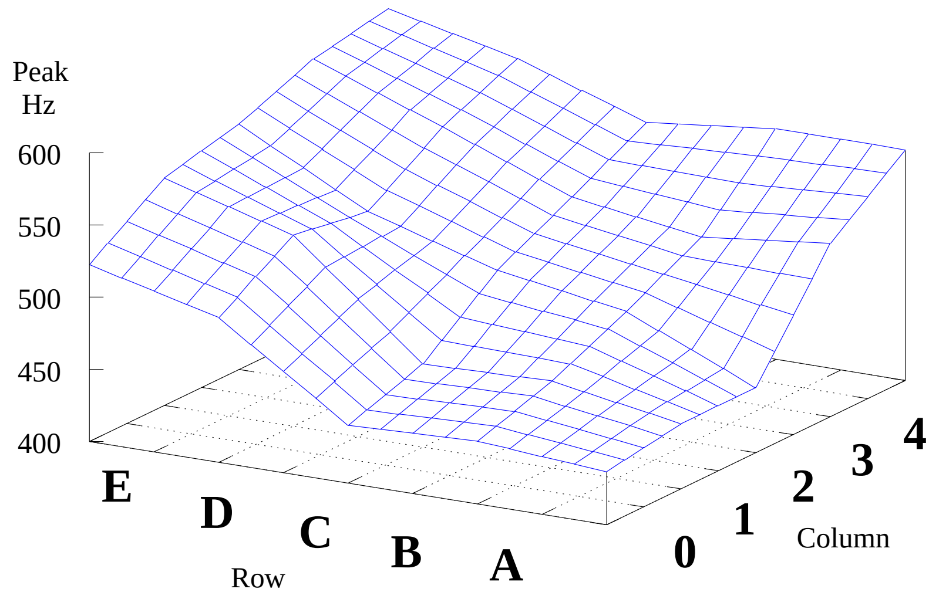

***Figure 8:** Peak frequency for each whisker A0-A4, B0-b4, C0-C4, D0-D4 and E1-E5 plotted on a mesh grid shows the spatial frequency distribution across the barrel field.*

Conclusions: The RC constant of the cell and burst frequency may be determined during development through the characteristics of calcium and potassium channels produced by the cell (Ricci et al., 2000). Since barrel diameter has a similar topographical distribution, burst frequencies could also depend on barrel size rather than position. Recent evidence also shows that whiskers are tuned to resonate at particular frequencies, depending on their size (Neimark et al., 2003), and that whiskers can transmit high frequency information from the environment (Deschenes et al., 2003).

References:
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