DIRAC

Detection and Identification of Rare Audiovisual Cues

Insperata accident magis saepe quam quae speres.
(Things you do not expect happen more often than things you do expect) Plautus (ca 200(B.C.)

Project no: 027787

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Detection and Identification of Rare Audio-visual Cues

Integrated Project
IST - Priority 2

DELIVERABLE NO: D2.2
Recording of Spectrotemporal Receptive fields (STRFs) from Gerbil Auditory Cortex

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PP	Restricted to other program participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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D2.2 Recording of Spectrotemporal Receptive Fields (STRFs) from Gerbil Auditory Cortex

Leibniz Institute for Neurobiology (LIN)
Carl von Ossietzky Universität Oldenburg (OL)

Abstract:
An experimental setup was developed to record spectro-temporal receptive fields (STRFs) from the auditory cortex in an anaesthetized and an in an awake animal preparation. Several of the usually employed methods to estimate STRFs have been compared. A new stimulus set, consisting of short, fixed duration, frequency-modulated (FM) tone components was created that provided sufficient spectrotemporal detail for predicting unit responses to FM stimuli used in our previous studies.

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1. Introduction

The spectrotemporal receptive (STRF) of a neuron is a (linear) kernel function expressed in the dimensions of time and frequency which, when convolved with a stimulus, predicts (the linear aspects of) that neuron's response to that stimulus. The aim of present deliverable was to build an experimental setup that (1) allows recording of STRFs from neurons in auditory cortex of Mongolian gerbils (*Meriones unguiculatus*) to study how predictability depends on the way the kernel function was estimated from data and (2) will allow pharmacological manipulations of the cortex to identify neuronal mechanisms of excitation and inhibition that give rise to the spectrotemporal sensitivities of the neuron. The present deliverable also represents a necessary precondition for deliverable D-4-3, the investigation of learning-induced changes in cortical receptive fields.

2. Background

The characterization of neuronal response properties by spectrotemporal receptive fields (STRFs) historically derives from the family of reverse-correlation techniques having a long tradition in physiology for characterizing the linear and nonlinear relationships between spectrotemporal properties of stimuli and suitable features of evoked neuronal responses. In that respect, these methods are more or less straightforward applications of Volterra series expansions as used in general systems theory (Schetzen 1980). In sensory systems physiology, STRFs were first introduced for analyses in the auditory system around 1980, (e.g. Aertsen and Johannesma 1981), and were then used to estimate the spectrotemporal features of sound signals that are linearly related to the occurrence of action potentials of the neuron under study[1]. I.e., the STRF is considered a linear kernel function expressed in the dimensions of time and frequency which, when convolved with a stimulus s(t,f) predicts the neuronal response r(t)

$$r(t) = \iint_{t'\,f} dt'\,df \quad STRF(t', f) \cdot s(t - t', f)$$

While in most physiological situations white noise stimuli are typically used to estimate the kernel (Glaser and Ruchkin 1976), noise sounds are in fact poorly effective in driving action potential generation in auditory cortex neurons. Therefore, subsequent development of experimental techniques in this field has featured several groups elaborating suitable stimulus sets for the estimation problem, e.g. random chord stimuli (e.g. DeCharms et al. 1988, Valentine and Eggermont 2004), dynamic ripple noise (e.g. Kowalski et al. 1996), temporally orthogonal ripple combinations (TORCs) (Klein et al. 2000), natural vocalizations (e.g. Theunissen et al. 2000) and others. On the theoretical side, a deterministic and analytical

[1] Although using "spike-triggered averages" to reverse-correlate stimulus features to the occurrence of action potentials is by far the most common practise in characterizing auditory cortical neurons, the method, in principle, can be used for any suited physiological observable. Our current research (although not part of the current deliverable) shows that certain features of the cortical current source density (CSD) distribution can be used as "response" to construct STRFs in stimulus space (Jeschke et al. 2007). As the cortical CSD is mainly due to extracellular currents evoked by input synaptic activity to the cortex' principal neurons, and the spike response can be considered the "output" of the cortical signal transformation, measuring both types of STRFs assists in constructing a generalized "cortical transfer function". This is envisaged for the future, as it helps to bridge the explanatory gap between microscopic and mesoscopic descriptions of auditory cortical functions (cf. Ohl et al. 2001)

reformulation of the spectrotemporal reverse correlation has been suggested (Klein et al. 2000) which also provides information about nonlinear aspects of the stimulus-response relationship (Gill et al. 2006) and the "mechanics of the STRF" with any given stimulus (Klein et al. 2006).

3. The Experimental Setup

The experimental setup was build into an electrically shielded and sound-proof acoustic experimental chamber (80 dB SPL attenuation for frequencies > 500 Hz) (Fig. 1).

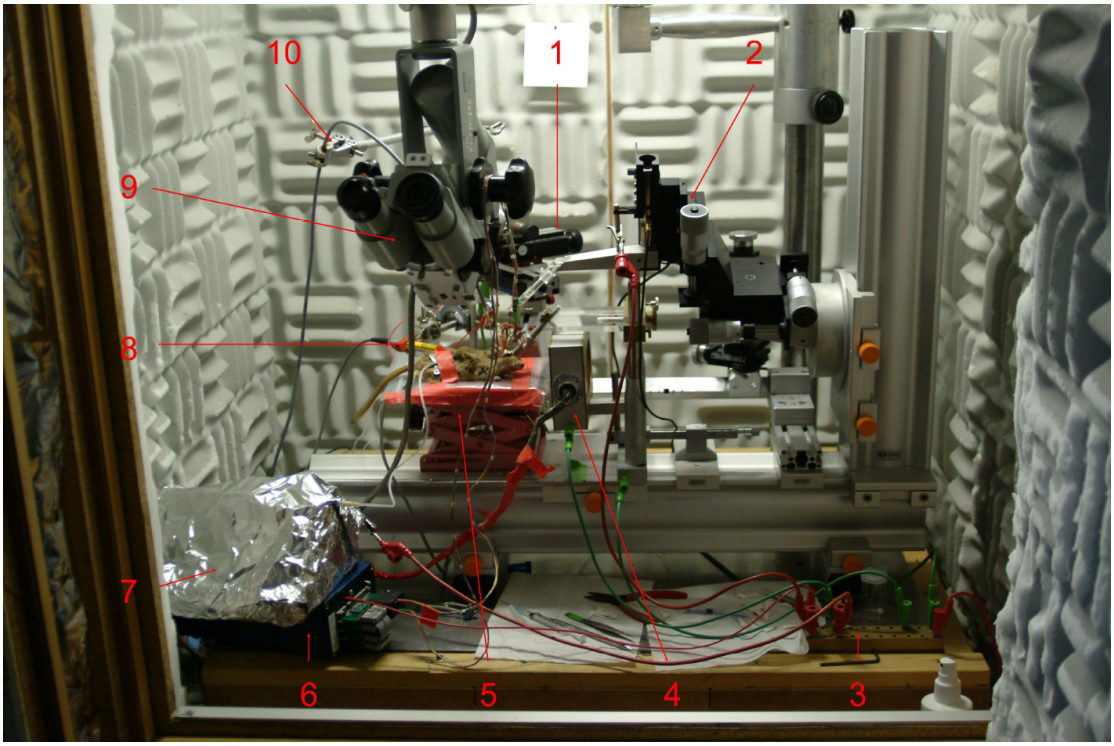


Figure 1. Overview over experimental setup to record STRFs from gerbil auditory cortex (shown as set up for acute recording). (1) micromanipulator and holder for electrodes and micropipettes, (2) piezo-controlled micromanipulator for remote electrode positioning, (3) electrical grounding block, (4) free field loudspeaker, (5) animal placement table with controlled heating equipment, (6) 32 channel preamplifier, (7) shielded pump for controlled anaesthetic supply, (8) probe microphone for controlling sound pressure level, (9) binocular optics for initial electrode positioning, (10) for electrode cables and micropipette tubes. Note that an anaesthetized animal is placed on the table.

It allows the recording of unit activity from auditory cortex in both anaesthetized and awake preparations, and as well in a fixated preparation as in a freely-moving preparation The latter condition is necessary for the work done in work package WP4, for which this deliverable has been planned as a precondition. In addition the setup allows pharmacological manipulation compatible with the electrophysiological recording of the recording site which will be important for later project phases but required taking care of during construction of our apparatuses.

Recordings were done using either shaft tungsten or stainless steel electrodes (1 Mohm) or implanted microwires (25 µm diameter platinum-iridium wires with Teflon coating, 500 kohm) (Fig. 2).

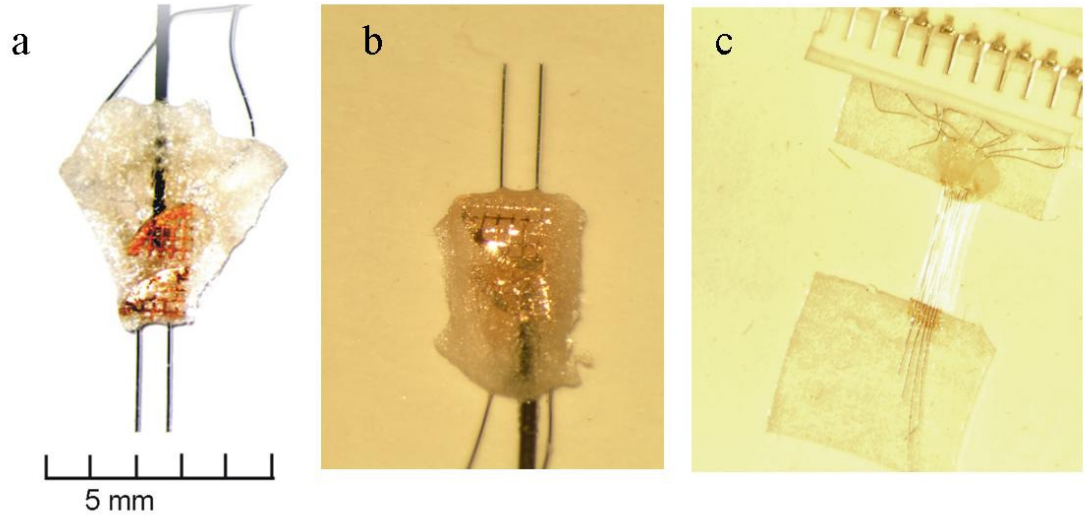


Figure 2. Examples of the main microelectrode configurations used for this deliverable. (a) Tungsten microneedles (1 µm tip diameter, 1 Mohm impedance at 1 kHz). (b) Stainless steel microneedles (2 µm tip diameter, 0.75 Mohm) (c) Bundle of 8 Teflon-insulated platinum-iridium microwires (25 µm diameter, 1-2 Mohm).

The Tungsten electrodes proved to be optimal for the acute anaesthetized operation, the platinum-iridium wires for chronic recording in awake behaving animals. While have not used parallel recordings from more than 8 implanted microwires, the setup is designed to handle up 32 channels. Increasing the number of channels provides higher yield in number of recorded neurons and allows to study correlations between neuronal firing. On the other hand increased numbers of inserted electrodes do also increase histological damage, such that optimal channel numbers for efficient recording have to be determined.

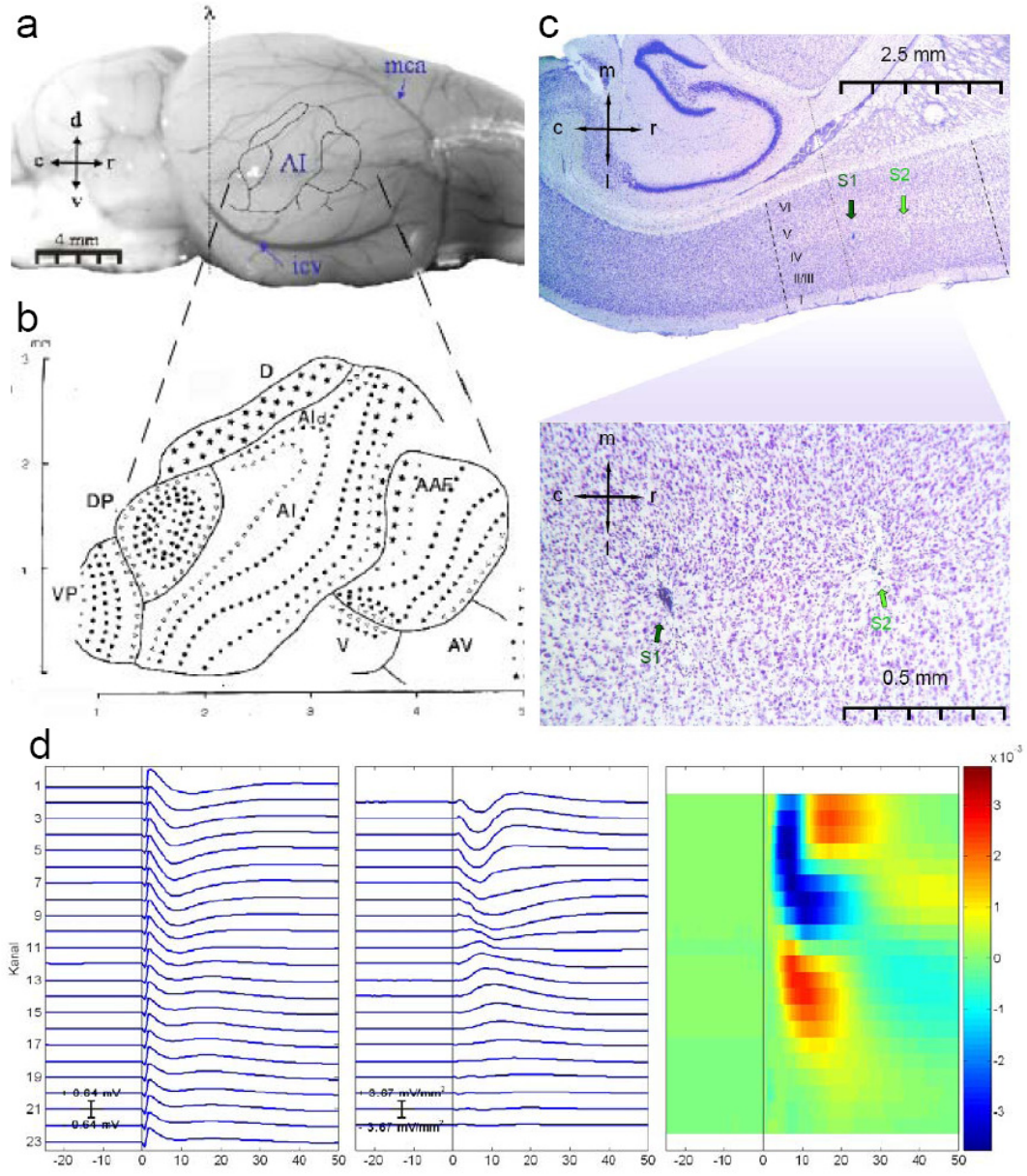


Figure 3. Electrode placement verification during and after STRF measurements. (a) gross anatomy of the gerbil brain showing anatomical landmarks and localization of the auditory cortex on the temporal pole (taken from Ohl et al. 2001) and an indication of the different fields of auditory cortex. (b) Field structure of auditory cortex in detail. (c) Histological verification of a pair of recording sites using Prussian Blue labels in a Nissl stained horizontal section of the auditory cortex. (d) Field potential recording (left) and calculated current source density (CSD) distribution (middle, right) to localize the prominent current source-sink-source triplet (red-blue-red) in the laminar CSD profile.

During each experiment, the correct positioning of electrodes within cortex is determined with respect to the tonotopic structure of the primary auditory field AI using best frequency mapping (Fig. 3a,b) and with respect to the cortical layer (where best frequencies do not vary) with reference to the laminar current source density profile which allows precise determination of the regions of the pyramidal cell cluster corresponding to apical dendrites, somata and axons (Fig. 3d). After the experiment electrode localization could be determined using histological analysis (Fig. 3c).

4. STRFs from Gerbil Auditory Cortex

We first followed the "historic track" and used static and dynamic "ripple stimuli" as have been introduced by the Shamma group (Fig. 4).

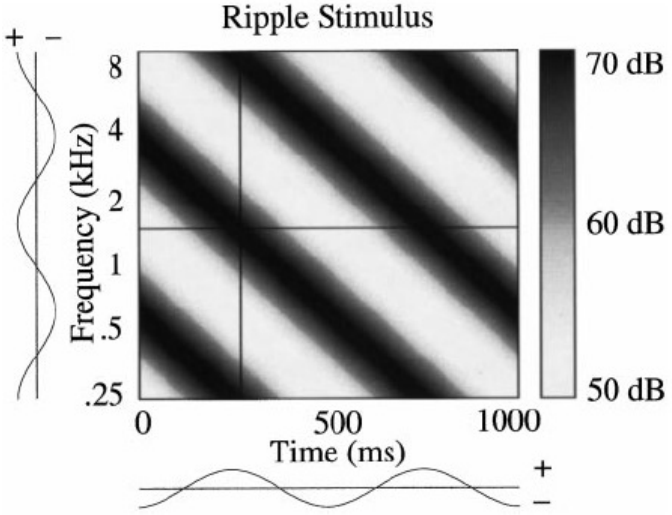
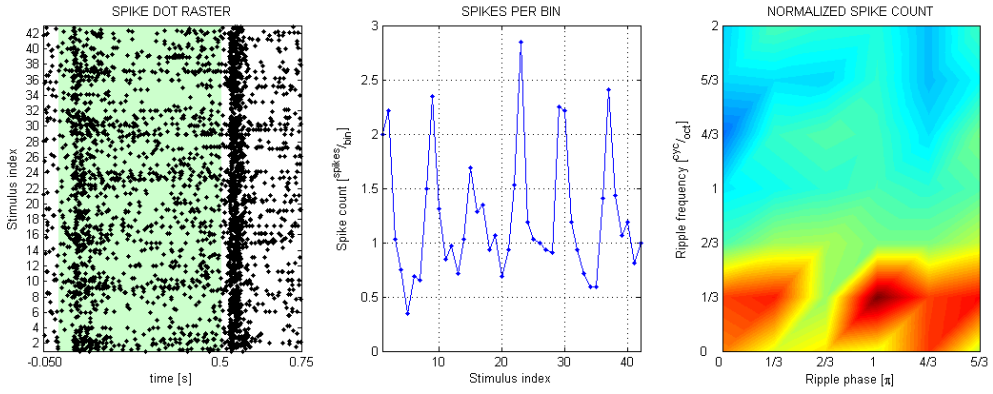


Figure 4. Scheme of a moving ripple stimulus. The ripple density Ω is defined as the number of ripple peaks at a given point in time t. The ripple velocity ω can be understood as the number of ripple peaks that occur at a given frequency f in a certain amount of time (ordinate and abscissa projections, respectively). The ripple phase π is given by the sine phase of the ripple density at the basis of the ripple at time zero. Static ripples differ from moving ripples in that the ripple velocity ω is zero (after Klein et al. 2000)

Static ripple stimuli are spectrally complex stimuli that can be characterized by their ripple density Ω and their ripple phase π. Moving ripple stimuli fulfil all necessary criteria to estimate STRF of auditory neurons.

We did initial experiments with static and moving ripples to confirm the basic results of the Shamma group and test whether the experimental procedures can be transferred to the gerbil. We found that neurons in the field AI of gerbil auditory cortex are sensitive to the variation of ripple parameters and that they exhibit a structured tuning to the ripple density as well as the ripple phase in the case of static ripples and a structured tuning to the ripple velocity and ripple density in the case of moving ripple.



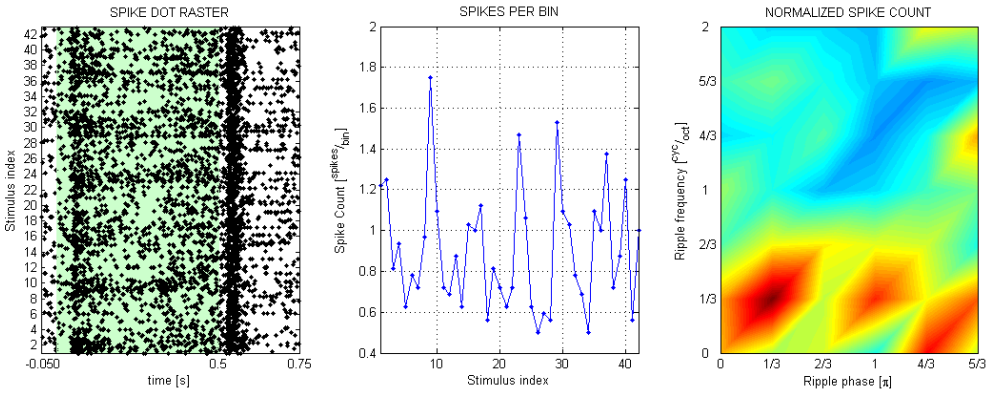
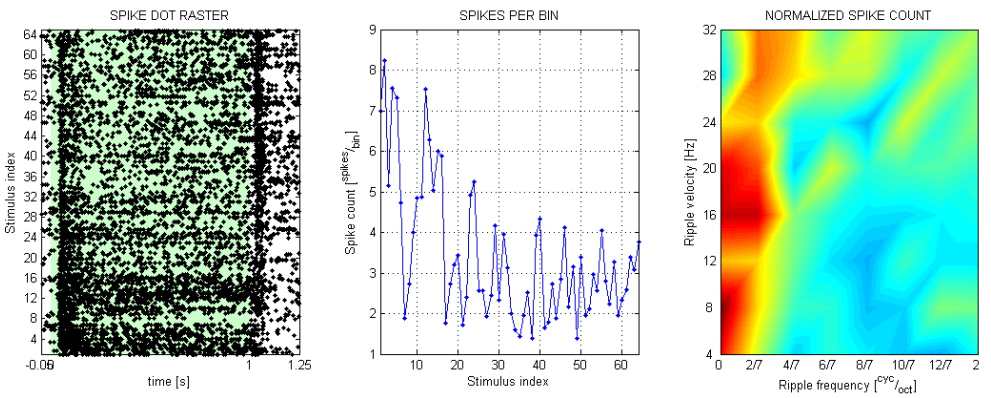


Figure 5. Example of the responses of two nearby cortical units to static ripples, (left) spike raster diagrams, (middle) spike count diagram, (right) ripple response portrait.

Figures 5 and 6 display the response of 2 a pair of nearby units in primary auditory cortex, field AI, to a set of static ripple stimuli and a set of dynamic ripple stimuli, respectively. These responses (like those shown in Fig. 6) were recorded in the unanaesthetized preparation. It is apparent that both units respond to the static ripple stimuli in a very similar fashion each time that becomes evident from both the spike raster plot (allowing observation of the time structure of the spike train) and the ripple response portrait (allowing an overall view of the response specificity to the ripple parameters). Stimulated with the dynamic ripple stimuli, however, this particular pair of units showed very different temporal structure in their evoked spike trains, while maintaining the overall similarity in their ripple response portraits. Such dissociation between responses to static and dynamic ripples among pairs of nearby neurons was found in approximately 40% of the units.

As our previous work has shown (e.g. Schulze et al. 1997, Ohl et al. 2000) that the prediction of neuronal responses to frequency-modulated (FM) tones and stimulus components depends in a very sensitive fashion on the knowledge of temporal structure of the spike train, the above examples suggest that the moving ripple stimulus set as it is currently used does not provide kernel estimates with sufficient spectrotemporal detail to predict neuronal responses to all FM features. We have therefore begun to experiment with a stimulus set of short (but fixed) duration FM tone elements with randomized spectral and temporal localization in a complex stimulus. We hypothesize that this stimulus set combines the virtues of the multifrequency stimuli (e.g. gamma tone set used by the Eggermont group), as the strong driving of cortical neurons, and those of the dynamic ripple stimuli, as the convenient parameterization of spectrotemporal stimulus parameters.



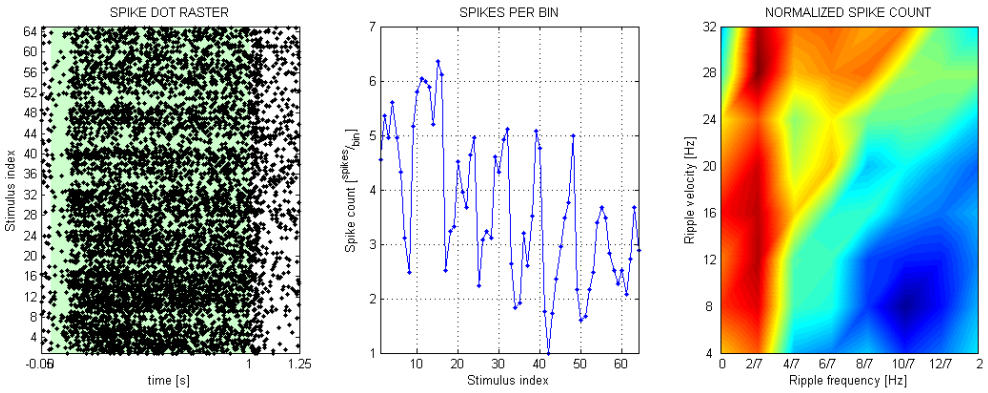


Figure 6. Example of the responses of the same two cortical units shown in Fig. 5. to moving ripples. Ripple density and velocity were systematically varied while the ripple phase was held constant. Note the strong dissimilarities of the temporal firing pattern in the spike raster dots.

Figure 7 shows a comparison of the STRF of a unit recorded from field AI of the auditory cortex of an awake gerbil using the gamma tone stimulus set and our FM tone set. It is apparent that the latter gives a clearer representation not only of the inhibitory (suppressive) surroundings of the central excitatory response peak, but also of the oblique structures, i.e. sensitivities to FM components.

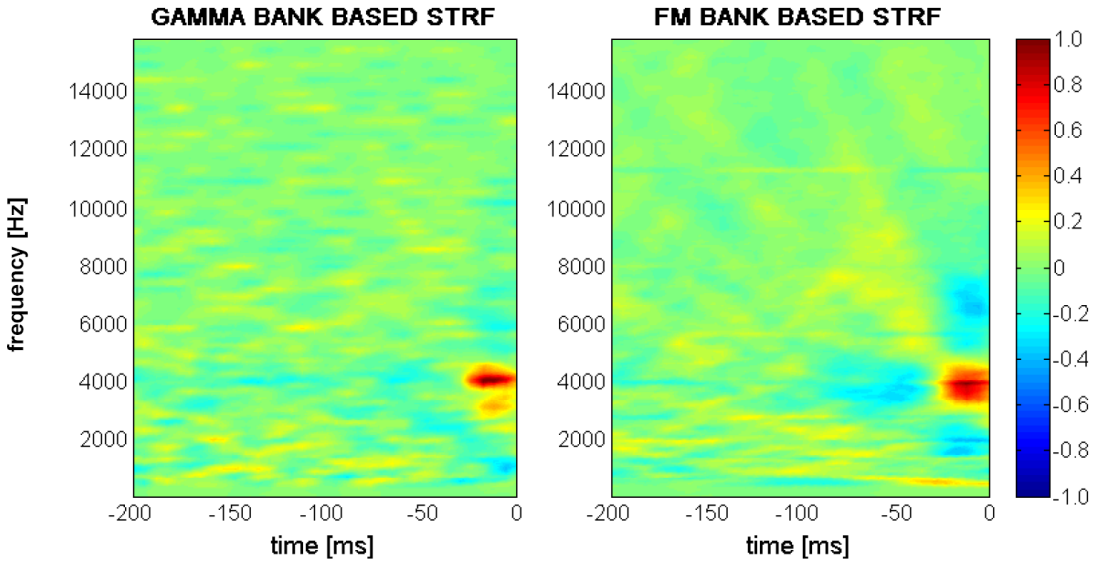


Figure 7. Normalized STRFs of a unit in gerbil auditory cortex, field AI, derived from measurements using the gamma tone stimulus set (Valentine and Eggermont 2004) (left) or the FM tone stimulus set (right), respectively.

5. Conclusion

We have been able to build an experimental setup which will allow us to perform detailed investigation of STRFs recorded from auditory cortex of anaesthetized and awake gerbils. Preliminary studies comparing some of the usually employed stimulus sets for STRF estimation have shown that those might be unsufficient to resolve the spectrotemporal detail necessary to predict neuronal responses to FM stimulus components. We have therefore developed a new stimulus set based on short duration FM components with randomized localization in temporal and spectral coordinates. As the next step we will perform a more rigorous treatment of the comparative performance of differently derived STRFs in predicting responses to FM stimulus components. This will include the use of the Oldenburg Logatome (OLLO) database as human language logatomes are sufficiently rich in formant transitions to provide a suitable test bed for testing performance of prediction of responses to natural complex stimuli.
Furthermore, to transfer the simple mapping concept from a stimulus set to a response set (inherent in the transfer function approach) to a biophysically motivated mechanistic understanding of neuronal response generation, we have begun to make use of selective pharmacological manipulation of neuronal behaviour (i.e. differentially modulating excitatory and inhibitory interactions) (Kurt et al. 2006) while recording STRFs.

6. Reference

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