Transformation in the Neural Code From Receptors to Cortex: Representation of Dynamic Whisker Stimuli

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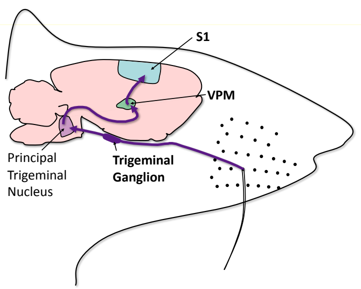
M. R. Bale, R. A. A. Ince and R. S. Petersen
Faculty of Life Sciences, The University of Manchester, UK

Background and Aims

The neural code for whisker deflections undergoes a marked transformation along the whisker lemniscal pathway (Simons and Carvell, 1989; Minnery et al., 2003; Bale and Petersen 2009).

High speed video recording of whisker motion across textures demonstrate that whiskers are dynamic (Ritt et al., 2008). High-velocity high- acceleration events that occur when a whisker **slips** have shown to be encoded by S1 population activity (Jadhav et al., 2009). White noise stimulation has been used to study ganglion (Jones et al., 2004) and VPM (Montemurro et al., 2007) but a systematic comparison across the pathway investigating how neural responses to dynamic whisker stimulation are transformed has not been performed.

Aim of the study: How is dynamic whisker stimulation represented at three key stages of the lemniscal pathway; the trigeminal ganglion, the VPM nucleus and barrel cortex?



Methods

We made single unit recordings under identical experimental conditions from the trigeminal ganglion (N=56), ventro-posterior medial thalamus (VPM, N=14) and barrel cortex (N=109; 17 in layers II-III, 14 in layer IV and 78 in layers V-VI) of urethanised adult rats.

The principal whisker of each unit was deflected with an identical low pass filtered white noise stimulus for 1 second repeated 40 times using an optically calibrated piezoelectric actuator.

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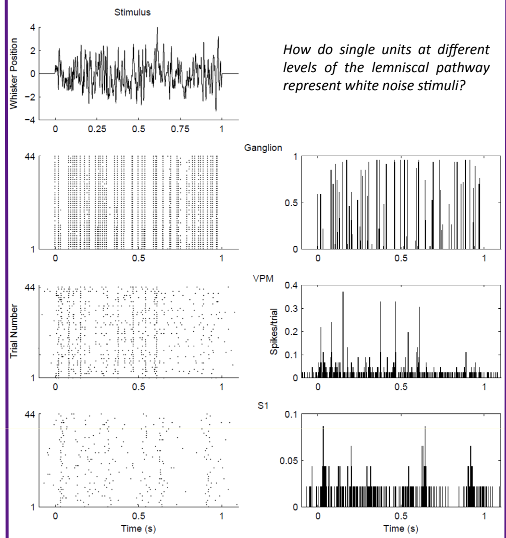
Representation of Dynamic Stimuli

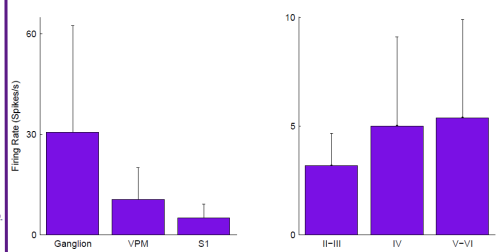
How do single units at different levels of the lemniscal pathway represent white noise stimuli?



Spikes evoked by example single units at different levels of the pathway to a white noise stimulus shown in **A**. All areas fired spikes at similar times on repeated trials forming **peaks of activity** in a units PSTH.

1. Transformation in Firing Rate

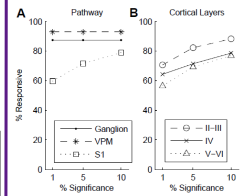
Do neuronal responses differ at each stage of the pathway?



Mean firing rate decreased significantly at subsequent stages of the pathway (Ganglion→VPM; VPM→S1). There was no statistical difference in firing rates across cortical layers.

2. Transformation in Responsiveness

Do neurons respond significantly to white noise?

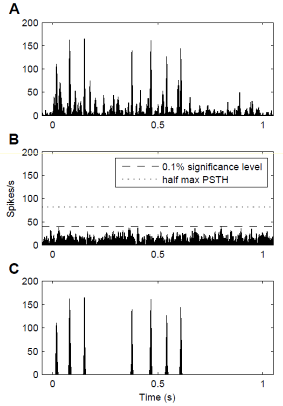


To test this, we compared a unit's stimulus evoked firing rate to its spontaneous firing rate.

Most units (80%) responded significantly to the white noise stimulus.

Significantly fewer units in S1 responded to white noise than in ganglion or VPM.

3. Transformation in PSTH Peak Frequency



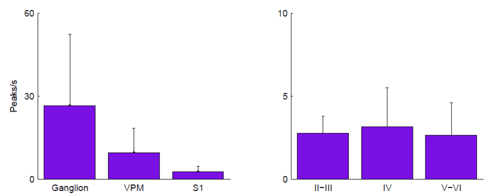
Responses consisted of isolated peaks of activity

We constructed a robust method to extract genuine peaks from all areas of the pathway. We first smoothed each unit's PSTH. We then deemed a peak as genuine if …

1. The peak was > 50% the height of the maximum peak for that unit.

2. The peak could not have occurred due to random firing (P=0.001%)

Was there a change in the number of peaks exhibited by units at different areas of the pathway?

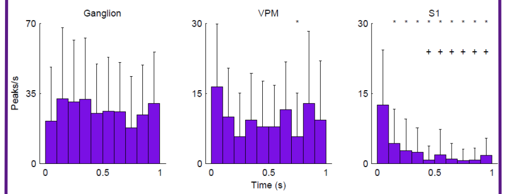


There was a significant decrease in the mean number of peaks evoked along the pathway (Ganglion → VPM, VPM→S1) but no difference between cortical layers.

The observation of decreasing peak frequency was related to the decrease in firing rate. Correlation coefficients between peak frequency and firing rates were extremely high in subcortex (ρ =0.97 in ganglion, 0.86 in VPM) yet weaker in cortex (ρ=0.24; P<0.005).

4. Transformation in Adaptation

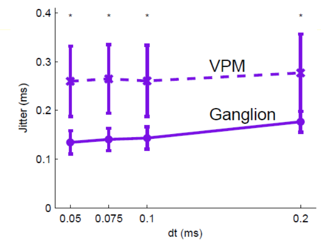
Do neurons adapt to white noise?



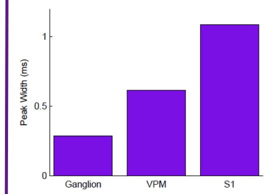
For each area, we constructed a histogram of the number of peaks occuring in 100 ms time windows. In S1, there was strong adaptation with all 100 ms windows after the first 100 ms having significantly fewer peaks. There was no significant adaptation in VPM or ganglion.

5. Transformation in Spike Timing

Does spike timing precision change along the pathway?



We estimated spike timing jitter by fitting a Gaussian to the significant PSTH peaks. Spike timing was significantly more precise in ganglion (0.13 ms) than VPM (0.26 ms).



To compare ganglion, VPM and S1 we pooled all peaks from all recorded units to create an average PSTH peak for each area. From this peak we estimated jitter as the width at half height. Using this approach we found an increase in jitter along the pathway from 0.29 ms in ganglion to 1.09 ms in S1, with VPM intermediate (0.61 ms)

Conclusions

- Most neurons (80%) respond to dynamic (white noise) whisker stimulation
- However, there are distinct transformations along the pathway; firing rate decreases, peak frequency decreases, precise spike timing decreases and adaptation occurs in S1.