Prediction error signalling in the auditory cortex: omission responses in anaesthetised rats

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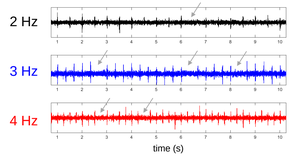
Background

Many models of cortical processing involve the signalling of the error between predictions and input, for learning or inference [1][2].
Most evidence for neural prediction errors comes from stimulus-specific adaptation, repetition suppression, and mismatch responses [3].
However, neural omission responses are arguably a closer correlate of prediction errors than responses to a mispredicted stimulus [4].
Omission responses often observed in non-invasive recordings in humans but limited evidence in invasive recordings in animal models [5,6].

Methods

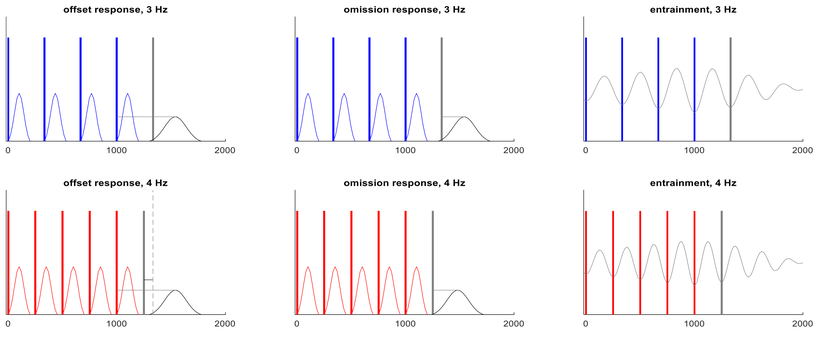
Data: local field potentials (LFP) recorded in the auditory cortex of anaesthetised female Lister Hooded rats (N = 3) using 8x8 electrode shanks across 6 experiments in total. LFP signals (1) spatially transformed to obtain 2D current source density (CSD) of low-frequency (<75 Hz) activity; (2) band-pass filtered to obtain analogue multiunit activity (AMUA; 300-6000 Hz).

Stimuli: trains of high-amplitude noise bursts presented at a range of fixed rates (2, 3, 4Hz) with a random subset of 5% bursts omitted.
Each train 40 s long; rates presented randomly.



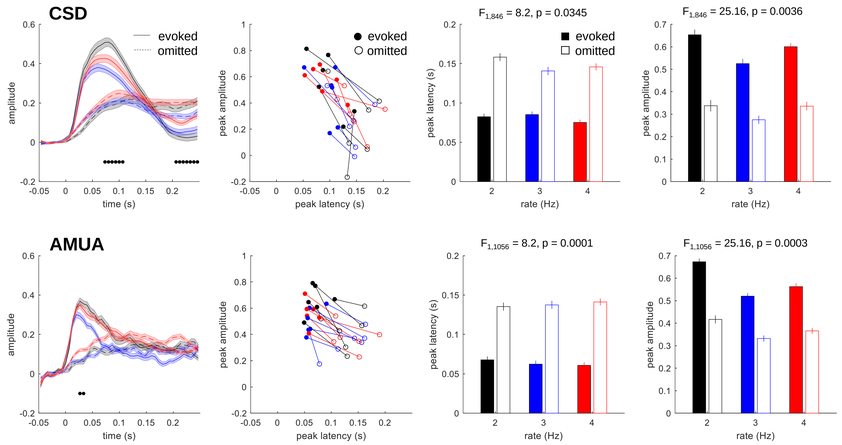
Analysis: CSD/AMUA following stimulus omissions compared to activity evoked by immediately preceding acoustic bursts. Only channels showing omission-related activity (one sample t-test of time-averaged activity, over trials; FDR-corrected across channels; CSD: 38.28%±26.33% channels; AMUA: 47.49%±20.72% channels). Per channel, peak and max amplitude used for comparisons.

Hypotheses: Neural responses to offsets of stimulus trains may be observed in the same interval as omission responses. However, offset responses should have different latencies relative to the omitted stimulus, while omission responses should have similar latencies relative to the omitted stimulus. Low-frequency entrainment of neural activity to burst rate may also be observed.

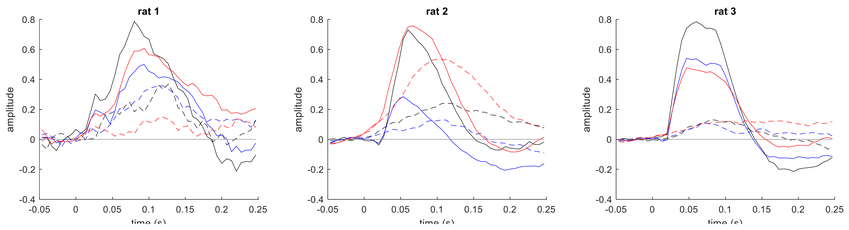


Results

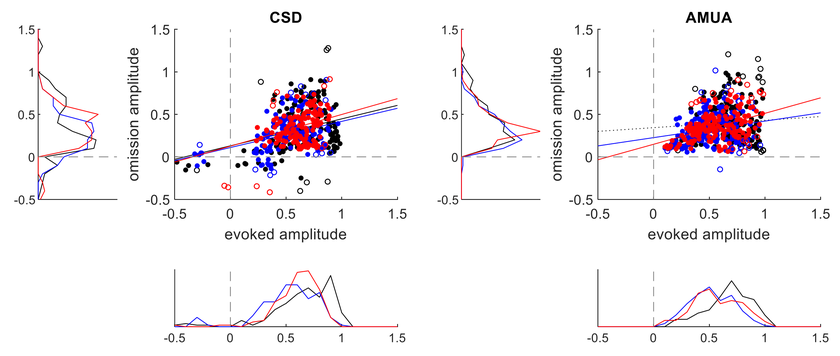
Omission responses had lower amplitudes and later latencies than stimulus-evoked responses. However, the latency of omission responses did not depend on stimulus presentation rate (no main effect of rate or interaction rate x stimulus/omission), suggesting that the observed signals do not reflect offset responses but rather true omission responses.



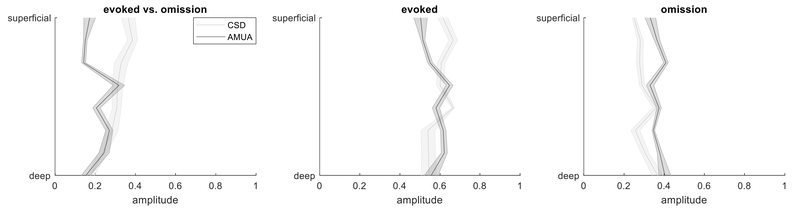
Example channels for each rat (CSD) showed consistent responses



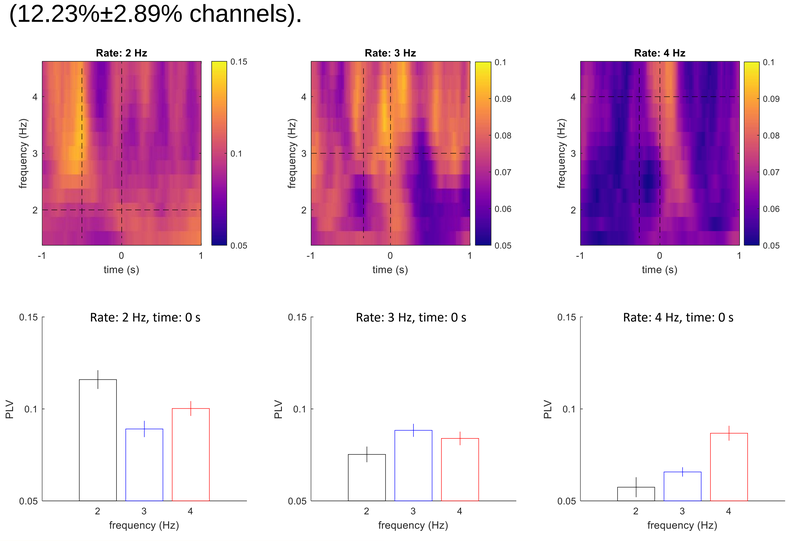
For both CSD and AMUA, peak amplitude of evoked responses correlated with peak amplitude of omission responses across channels.



Spatial distribution of omission responses shows that superficial layers differentiate between omission responses (stronger high-frequency activity / AMUA) and evoked responses (stronger low-frequency activity / CSD), possibly due to omission-related prediction error signalling from superficial layers, and stimulus-related prediction error suppression.



Stimulus-rate entrainment: LFP data were filtered using Morlet wavelets (5 cycles; time step 20 ms). Phase-locking value was calculated per frequency and time bin. Only channels showing no differences in power at omission onset (all pairwise Wilcoxon p>.05) were taken into analysis (12.23%±2.89% channels).



Conclusions

Latency of omission-evoked responses was not modulated by burst presentation rate, suggesting that they reflect error signalling.
Omission-evoked responses measurable both in higher (AMUA) and lower (CSD) frequencies, albeit with laminar asymmetries.
Stimulus-rate entrainment observed in addition to omission responses
These findings provide direct evidence for sensory prediction error signalling in auditory cortex.

References
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