Deviance Detection: On and Off Responses, Omission Response, and Mismatch Negativity

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Introduction

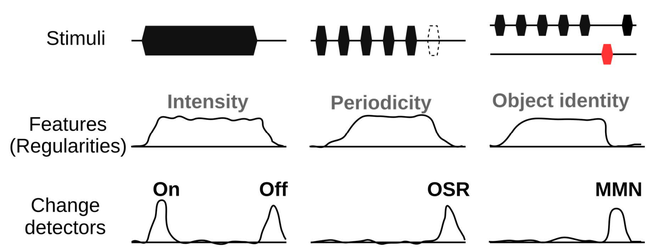
- Deviance detection is a pre-attentive mechanism that causes extra neural activities in response to unexcpected temporal stimulus patterns.

- Deviance-related responses include:
  1. On and Off responses
     – elicited by the onsets and offsets of stimuli
  2. Omitted-stimulus response (OSR)
     – elicited by an unexpected omitted stimulus
  3. Mismatch negativity (MMN)
     – elicited by an infrequent stimulus (or pattern) among regular ones

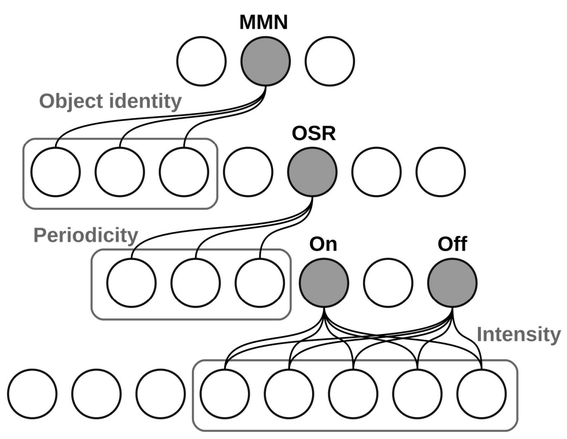
- Aim: a unifying view of cortical deviance detection.

Hypotheses

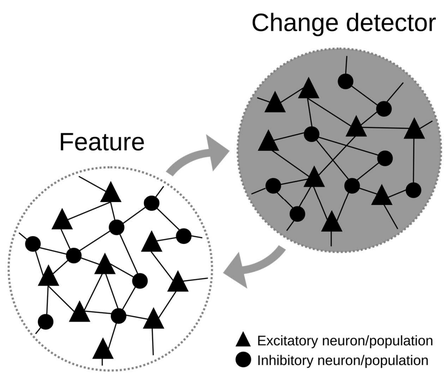
Hypothesis 1. The stimuli (e.g. prolonged or periodic) lead to steady feature representations (i.e., regularities). The deviance-related responses are the activities of change detectors.



Hypothesis 2. Features (summed activities of the white nodes) and change detectors (gray nodes) coexist in the perceptual hierarchy. The change detectors can contribute to other features as well (links not shown here for clarity).



Hypothesis 3.
A group of excitatory and inhibitory neurons (e.g., a cortical column) can potentially serve as a change detector to its neighboring feature neurons via reciprocal connections.



Discussion

Summary

- The cortical deviance-related responses (e.g. On/Off responses, OSR, and MMN) can be generated by the same mechanism, where (1) The regularities of stimuli are represented by feature nodes in a hierarchical fashion, (2) The neighboring nodes are potential change detectors that detect sudden changes of the regularities, and (3) The reciprocal connections give rise to various types of behaviors of the change detectors.

Prediction

- The NMDA-r antagonists dampen the excitatory-to-excitatory (W_{ee}) and excitatory-to-inhibitory (W_{ei}) connections, and therefore influence the profiles of all cortical deviance-related responses (not just MMN).

Methods

Network model

Cortical columns

- Each column consists of an excitatory (E) and an inhibitory (I) population.
- The intra-column connections are fixed.
- Constant background current is fed to the E population.

Inter-column connections

- The inter-column connections W (free parameters) give rise to various behaviors of the change detectors.

Inputs

- The inputs (in firing rate) represent the intensities of stimuli (or features).
- The inputs are fed to the E populations (weight=1) and the I populations (weight=0.5).

Simulations

1. Temporal profiles of On/Off responses (Fig. 2)
2. Onset- and offset-frequency receptive fields (Fig. 3)
3. Omitted-stimulus response (Fig. 4)
4. Mismatch negativity (Fig. 5)

1

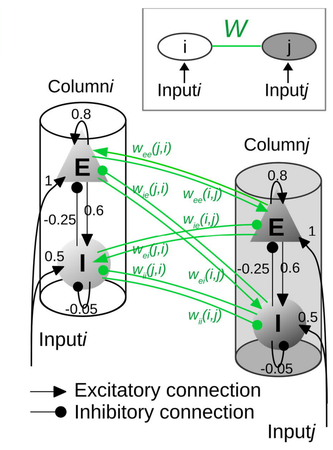
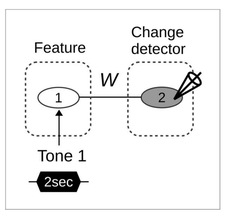


Fig. 1. Connection settings. The intra-column connections (black) are fixed throughout the simulations. The inter-column connections W (Green) are the parameters of interest.

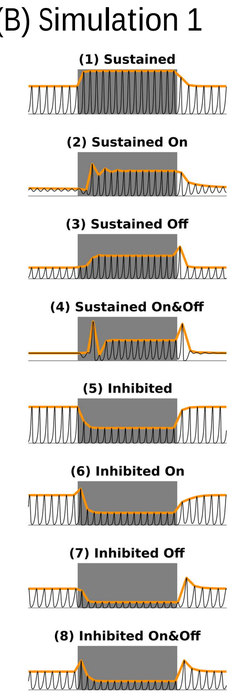
Results

2 Simulated On/Off responses are sensitive to the inter-column connections W.

(A) Model setting



(B) Simulation 1



(C) Simulation 2

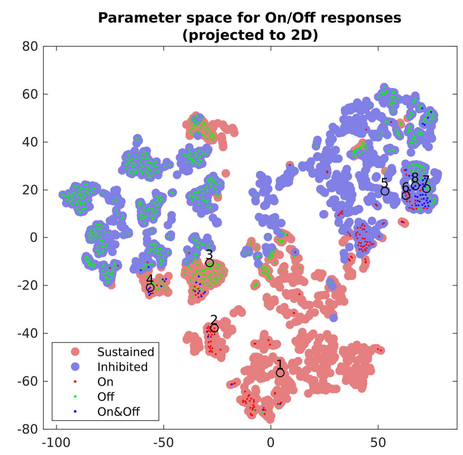
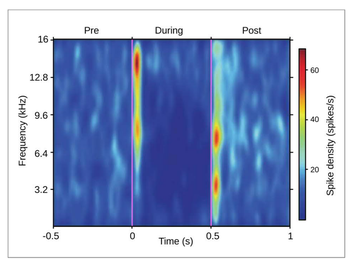


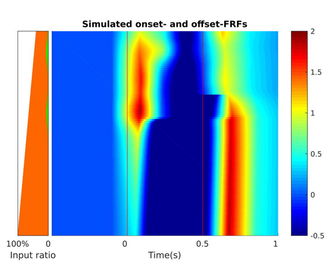
Fig. 2. (A)The prolonged tonal input is fed to column 1. By varying the W (8 parameters), various types of On/Off responses can be observed in column 2 as shown in (B). (C) The possible connection Ws that give rise to the eight On/Off types are projected to 2D for visualization (Matlab function: tsne). Neighboring dots have similar W settings. Temporal behavior of the change detector is sensitive to W.

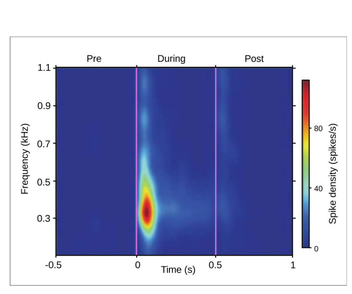
3 Distinct onset- and offset-frequency receptive fields (FRFs) can be reproduced.

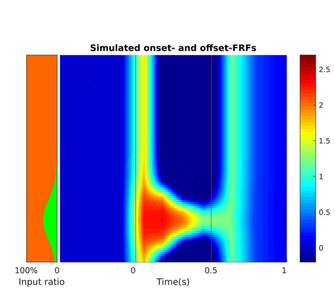
(A) Experiment



(C) Simulation







(B) Model setting

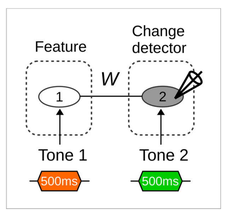
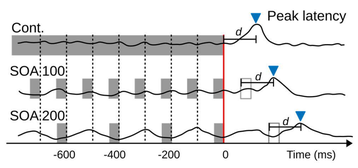


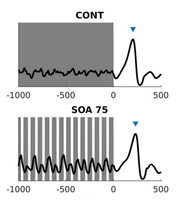
Fig. 3. (A) The onset- and offset-FRFs of examplary auditory neurons in [1]. (B) The continuum of tonal stimuli in the y-axis of FRFs is modeled as combinations of two pure tones with different proportions for simplicity. (C) The simulated FRFs are generated by choosing proper W and input ratios.

4 Temporal expectancy: simulated OSR peak latencies are linear to the periodicity.

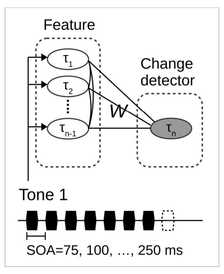
(A) Illustration



(C) Simulation 1



(B) Model setting



(D) Simulation 2

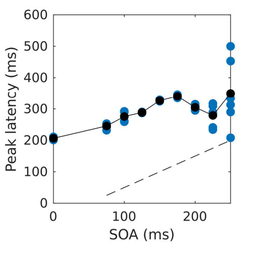
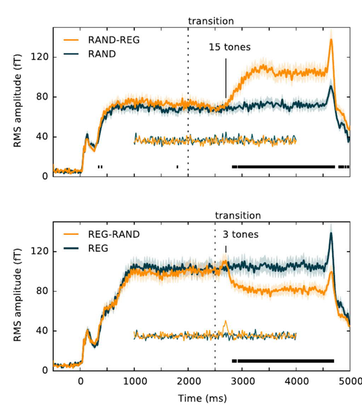


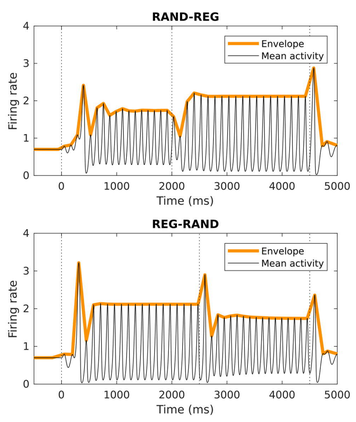
Fig. 4. (A)The OSR peak latency is a constant delay plus the SOA. (B)The feature columns have different time constants τ_i so that the periodicity (i.e. SOA of stimuli) is kept in sustained resonance. The change detector responds to a sudden change in periodicity. (C) Simulated temporal responses. (D) Simulated OSR latencies show temporal expectancy.

5 Simulated MMN at the transition between regular and random sequences.

(A) Experiment



(C) Simulation



(B) Model setting

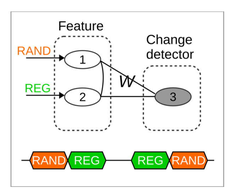


Fig. 5. (A) MEG responses to the emergence and violation of a regular pattern [2]. (B) Columns 1 & 2 receive prolonged inputs that represent object identities of random (RAND) and regular (REG) sequences.(C)Simulated responses mimic the experimental observations in (A).

References

[1] Qin, L., Chimoto, S., Sakai, M., Wang, J., Sato, Y. (2007) Comparison Between Offset and Onset Responses of Primary Auditory Cortex ON-OFF Neurons in Awake Cats. Journal of Neurophysiology, 97:3421.

[2] Barascud, N., Pearce, M. T., Griffiths, T. D., Friston, K. J., & Chait, M. (2016). Brain responses in humans reveal ideal observer-like sensitivity to complex acoustic patterns. Proceedings of the National Academy of Sciences, 113(5), E616-E625.

MMN Conference, 2018