How Do Local Neural Populations Know About the Predictability of Sound Sequences

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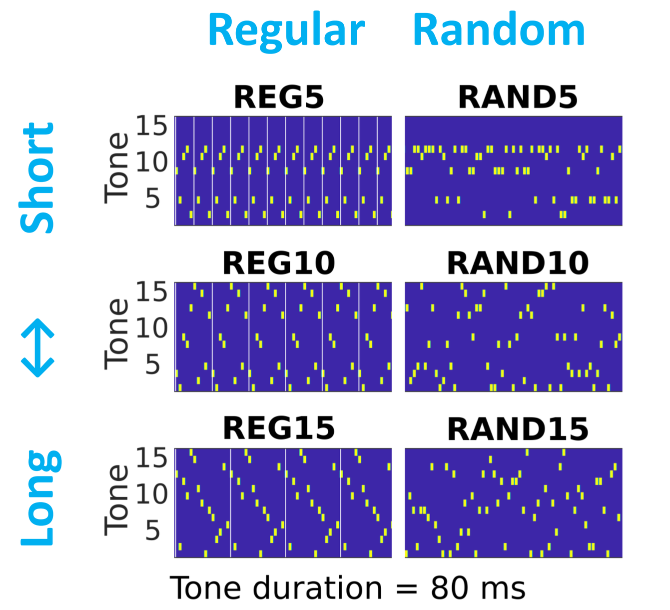
Introduction

- In the previous study, we proposed the *generic deviance detection principle* [1], where deviance dection can be divided into two stages: ***regularity formation*** and ***change detection***.
- In this study, we focused on the ***regularity formation*** in sound sequences.

How is the **predictability** of sound sequence represented in the auditory cortex?

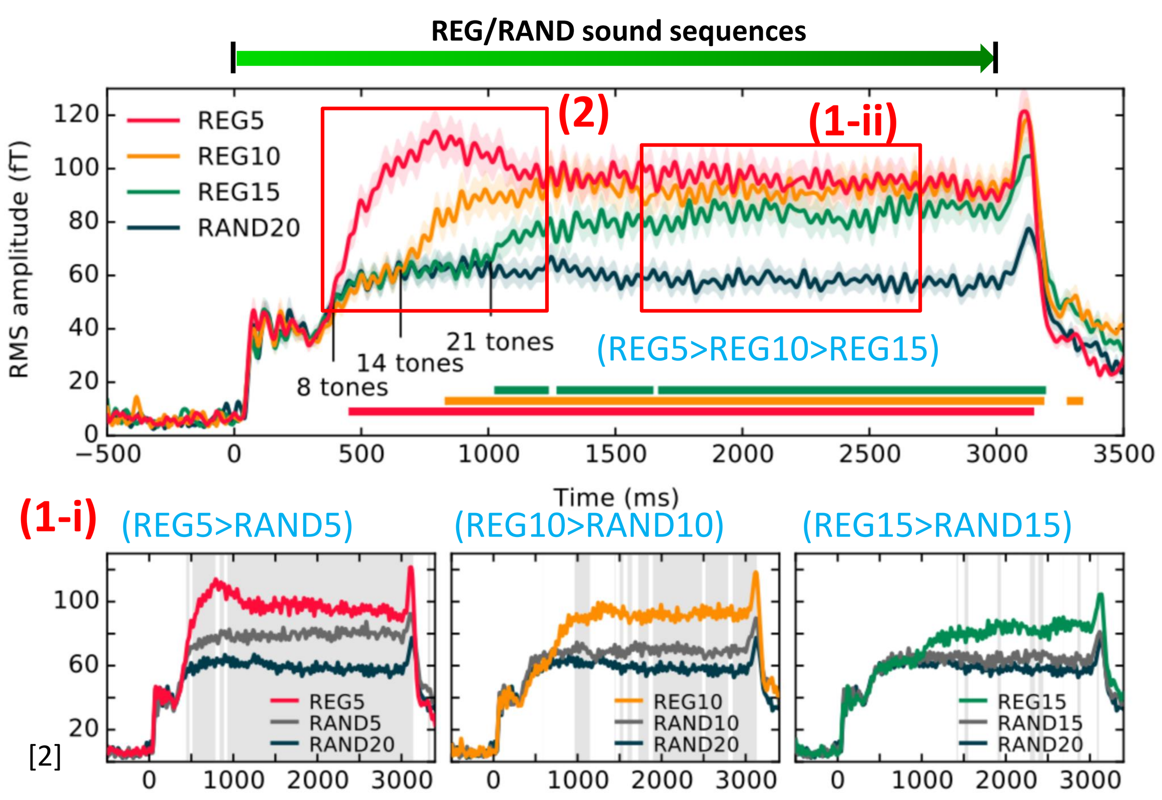


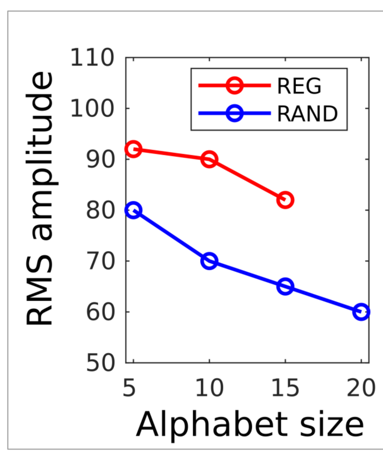
Sound sequences

- Regular(REG) vs. Random(RAND)
- Alphabet size: 2, 3, ..., 15 (tones)

- **MEG observations [2]**

(1) RMS amplitude correlates with predictability.





RMS amplitude as a function of

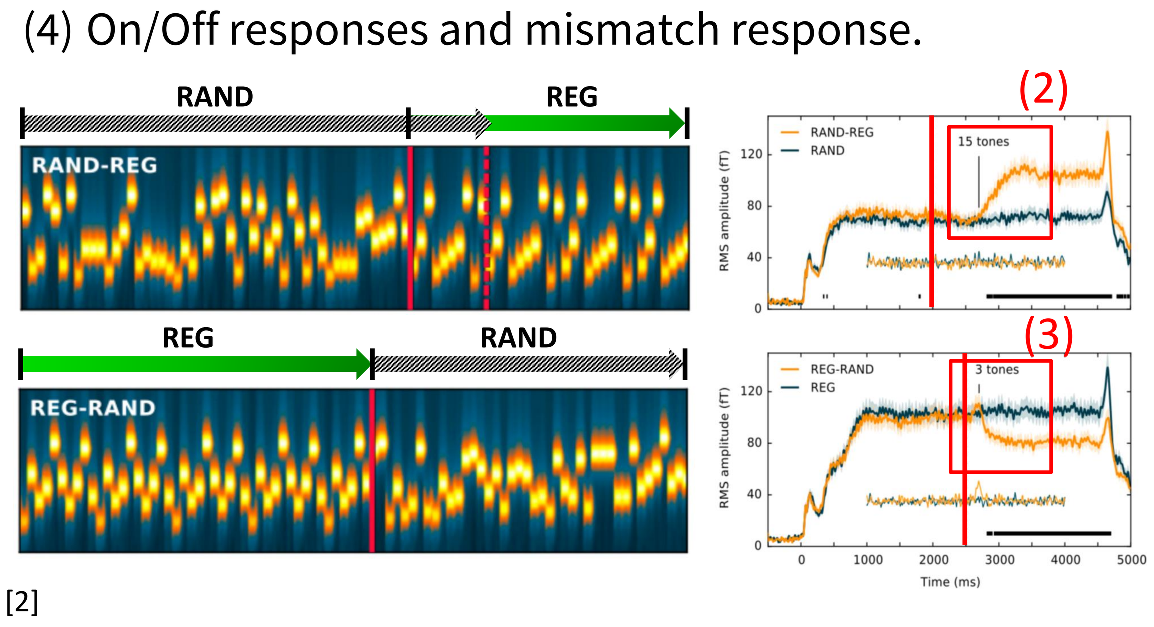
(1-i) regularity

REG5 > RAND5
REG10 > RAND10
REG15 > RAND15

(1-ii) alphabet size

REG5 > REG10 > REG15
RAND5 > RAND10 > RAND15

(2) Gradual increase in RMS amplitude (RAND → REG).
(3) Quick decrease in RMS amplitude (REG→RAND).
(4) On/Off responses and mismatch response.



- **Goal**
- To explain the MEG observations (1, 2, 3) in [2].
- To find the important ingredients that facilitate the **regularity formation** in local neural circuits.

Methods

- Network structure

$$\tau_e \dot{v}_j^E(t) = -v_j^E(t) + \sum_{k=1}^{N} a_{jk} b_{jk} w_{jk}^{EE} m_k^E(t) - \sum_{k=1}^{N} w_{jk}^{EI} m_k^I(t) + \sum_{q=1}^{M} w_{jq}^{EX} x_q(t)$$

$$\tau_i \dot{v}_j^I(t) = -v_j^I(t) + \sum_{k=1}^{N} c_{jk} w_{jk}^{IE} m_k^E(t) - \sum_{k=1}^{N} w_{jk}^{II} m_k^I(t)$$

v(t): postsynaptic potential
m(t): firing rate
x(t): external input
w: connection strength
τ: time constant

- Short-term plasticity (STP)

$$\dot{a}_{jk} = \frac{1 - a_{jk}}{\tau_a} - \gamma_a a_{jk} m_k^E(t)$$ (w^{EE} depression)

$$\dot{b}_{jk} = \frac{1 - b_{jk}}{\tau_b} + \gamma_b b_{jk} [x_j(t) x_k(t - \Delta t)]$$ (w^{EE} facilitation)

$$\dot{c}_{jk} = \frac{1 - c_{jk}}{\tau_c} + \gamma_c (1 + |1 - c_{jk}|) [x_k(t) x_j(t - \Delta t) - x_j(t) x_k(t - \Delta t)]$$ (w^{IE} facilitation&depression)

- Assymetry Index (AI) of *W*

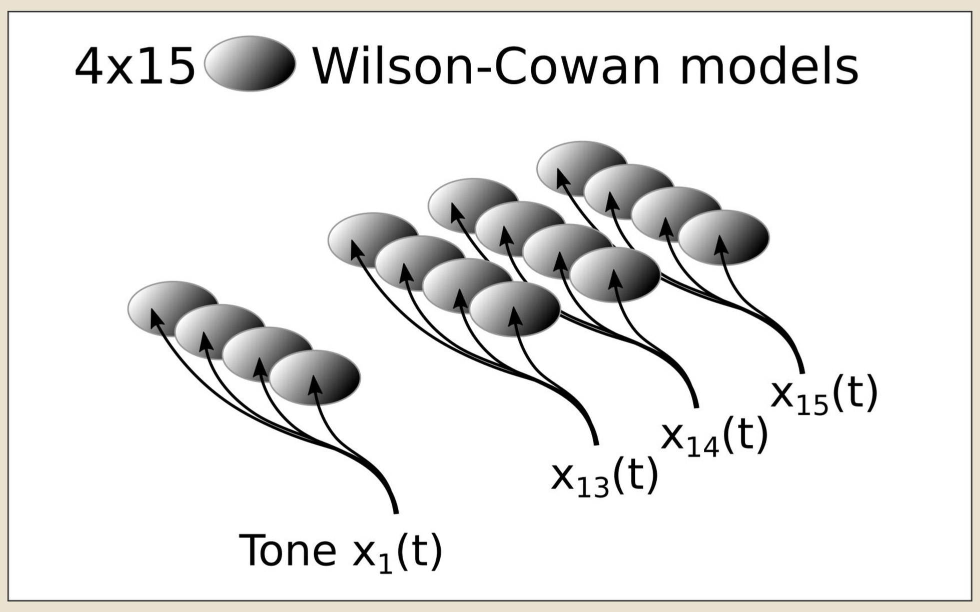
$$AI = \frac{\|W - W^T\|}{\|W + W^T\|}$$

- Simulated MEG signal

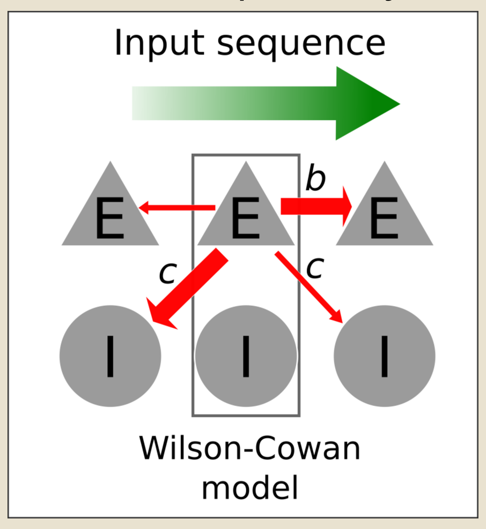
(Ca^{2+}, Na^+ current) (Cl^- current)

$$R(t) = \sum_{j=1}^{N} \sum_{k=1}^{N} [ratio1 \cdot a_{jk} b_{jk} w_{jk}^{EE} m_k^E(t) + ratio2 \cdot w_{jk}^{EI} m_k^I(t)]$$

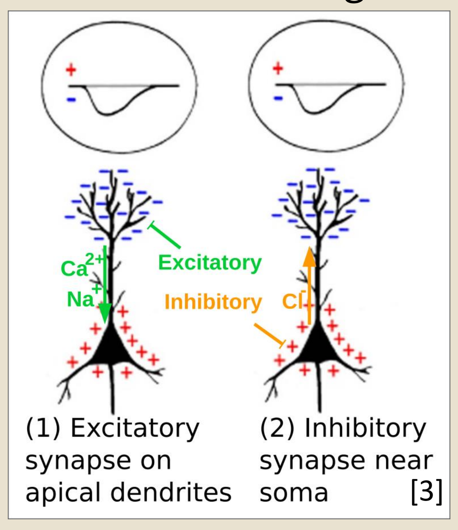
Network structure



Short-term plasticity



Simulated MEG signal



Results

1 Neural activity & connection pattern

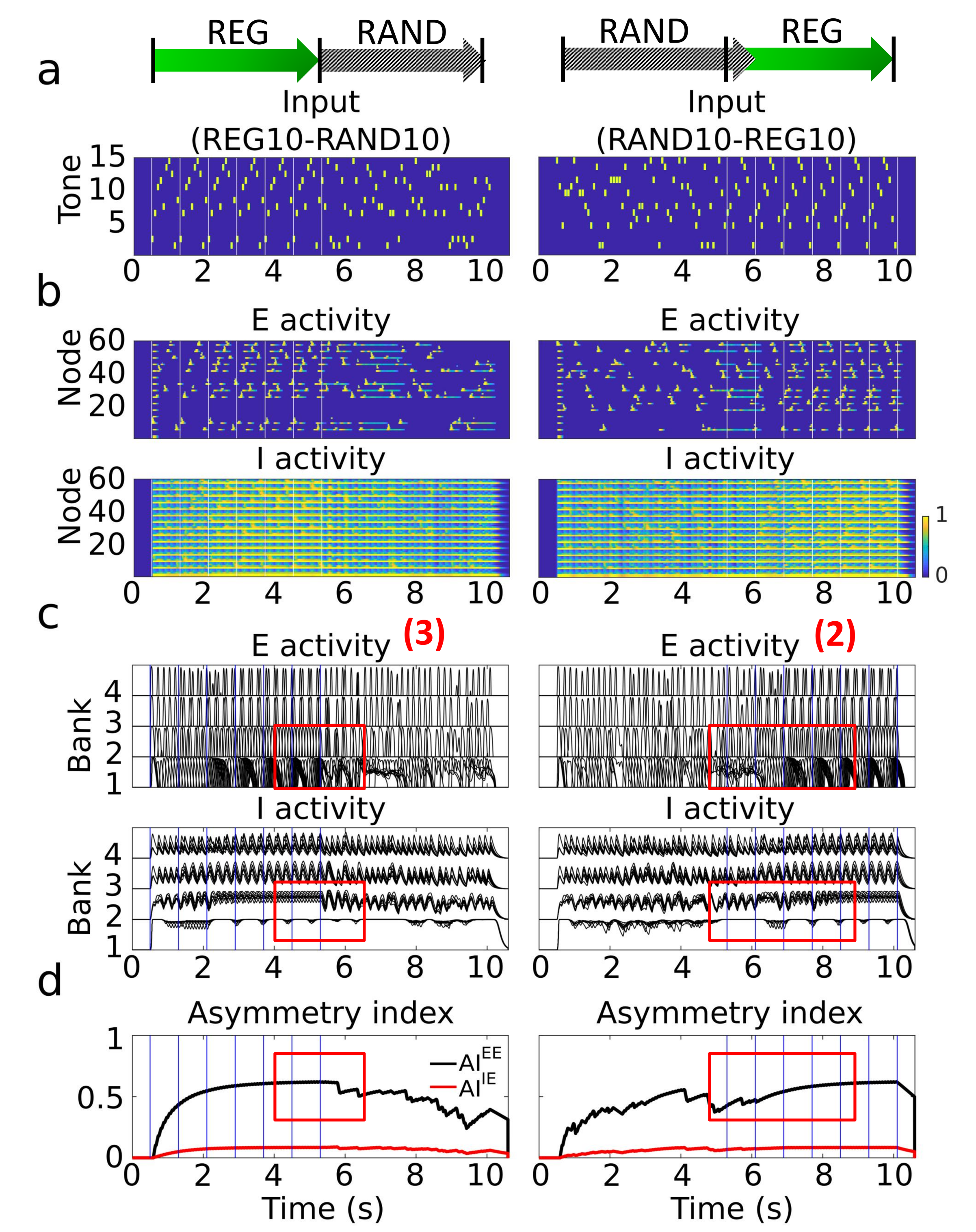


Fig. 1. Simulation examples of REG10-RAND10 and RAND10-REG10. **(a)** The inputs. **(b)** The E/I activity. **(c)** The E/I activity shown seperately in four resonance frequencies. Here we can see that the E/I activity (regularity representation) decreases quickly at the transition from REG to RAND **(3)**, and increase gradually at the transition from RAND to REG **(2)**. **(d)** The asymmetry index (AI) of W^{EE} and W^{IE} takes a few repetitions to reach its plateau.

Fig. 3. The contribution of STP. The left column shows the MEG signals. The middle column shows the mean and std of the MEG amplitude. The right column shows the w_{jk}^{EE}, w_{jk}^{IE}, and w_{kj}^{IE} at the last repetition of REG sequence order k→j. **(a-c)** Only the plasticity term a (on W^{EE}) is considered. **(d-f)** The plasticity terms a (on W^{EE}) and c (on W^{IE}) are condidered. **(g-i)** The plasticity terms a (on W^{EE}), b (on W^{EE}), and c (on W^{IE}) are condidered.

2 Simulated MEG signals

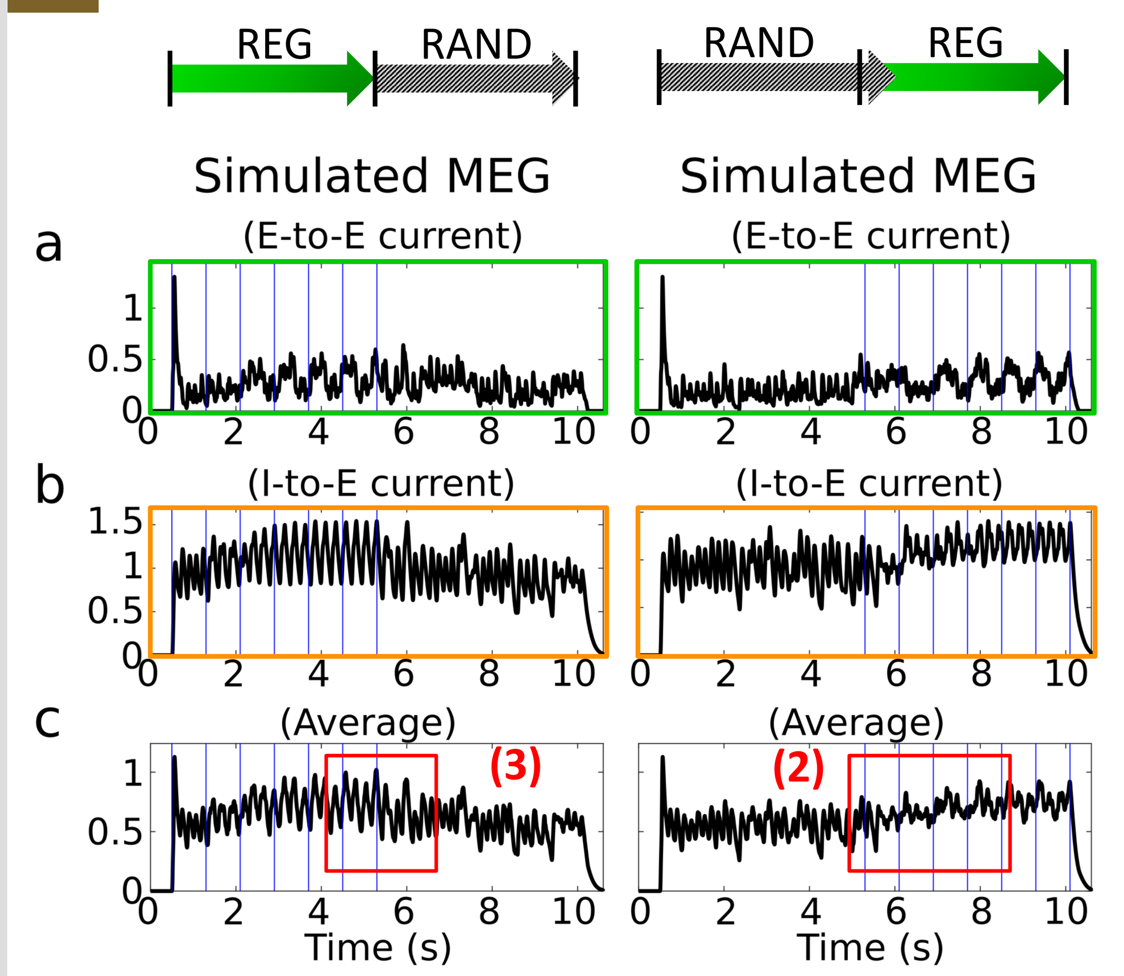
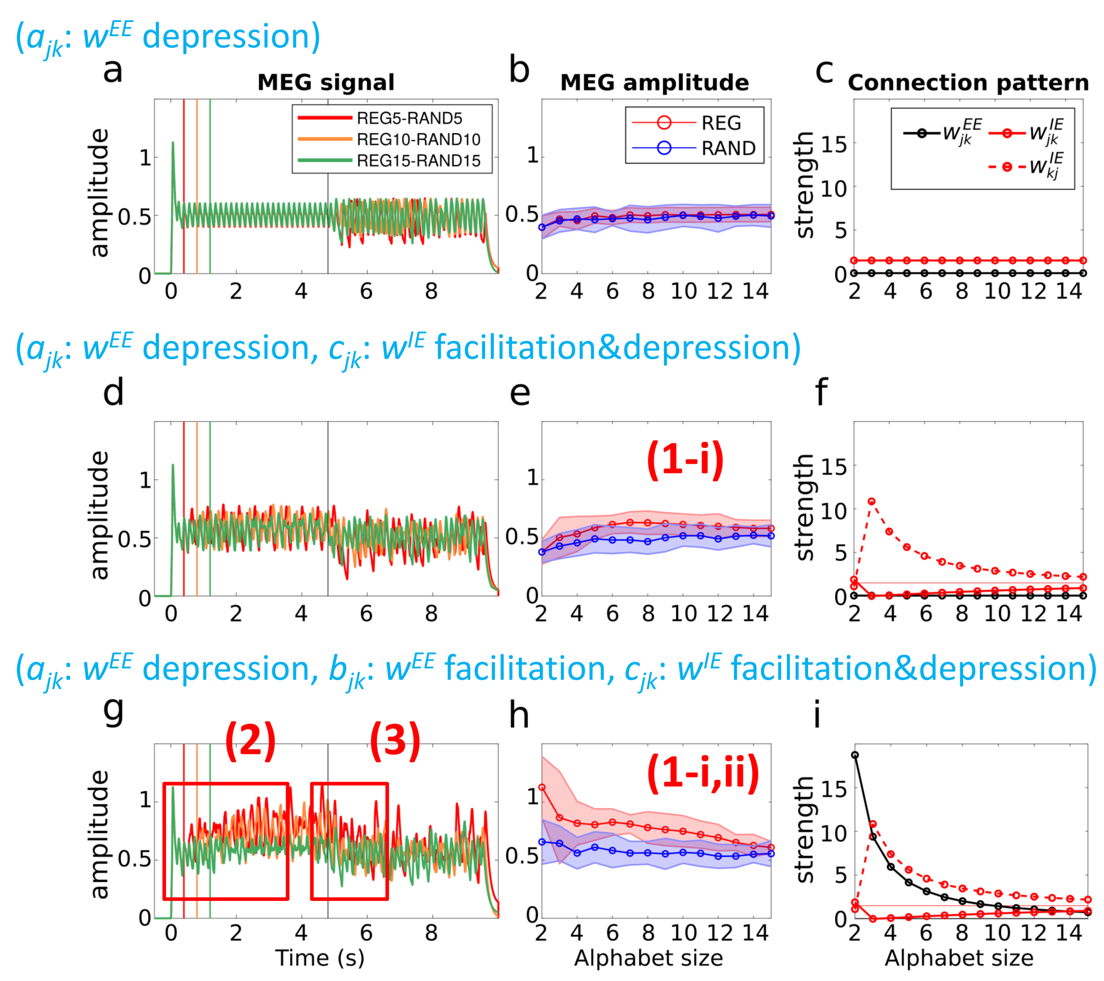


Fig. 2. The simulated MEG signals contributed by **(a)** E-to-E current, **(b)** I-to-E current, and **(c)** the average.

3 Contribution of short-term plasticity



Discussion

- We explain the MEG observations (1, 2, 3) in [2] as below:
- Regularity is <u>encoded in the connection pattern via STP</u>. Therefore, the RMS amplitude (RAND → REG) increases gradually **(2)**, as the AI of W^{EE} and W^{IE} takes a few repetitions to reach its plateau. (Fig. 1d)
- Regularity is <u>represented by the neural activity</u>. Therefore, the RMS amplitude (REG→RAND) decreases quickly **(3)**, because the sound sequence does not fit the connection pattern. (Fig.1c)
- The inhibitory activities contribute to the level shift in MEG amplitude. (Fig. 2)

- Important ingredients for regularity formation:
- The STP term a (on W^{EE}) contributes to the On responses. (Fig. 3a-c)
- The STP term c (on W^{IE}) accounts for the RMS amplitude as a function of regularity **(1-i)**. (Fig. 3d-f)
- The STP term b (on W^{EE}) additionally accounts for the RMS amplitude as a function of alphabet sizes **(1-ii)**. (Fig. 3g-i)

References

[1] S.C. Chien, B. Maess, and T.R. Knösche. "A generic deviance detection principle for cortical On/Off responses, omission response, and mismatch negativity." *BioRxiv* (2019): 582437.

[2] N. Barascud, et al. "Brain responses in humans reveal ideal observer-like sensitivity to complex acoustic patterns." *Proceedings of the National Academy of Sciences* 113.5 (2016): E616-E625.

[3] AF. Jackson, and D.J. Bolger. "The neurophysiological bases of EEG and EEG measurement: A review for the rest of us." *Psychophysiology* 51.11 (2014): 1061-1071.