A spiking neural network model of the N400 congruency effect

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Introduction

The most common underlying cause of the dementia syndrome is Alzheimer's Disease (AD), a progressive neurodegenerative disorder characterized by the presence of neurofibrillary tangles, amyloid beta plaques, and loss of synaptic densities (Burns & Iliffe, 2009). AD diagnosis is difficult and therefore biomarkers are being researched to improve diagnosis (Olichney, Yang, Taylor, & Kutas, 2011). Biomarkers are defined as external reproducible and relevant measures of a patient's medical state (Strimbu & Tavel, 2010). For AD, biomarkers are essentially measures of pathology. While, Amyloid beta presence is the most studied biomarker, synaptic loss correlates best with psychological symptoms in post mortem studies (Terry et al., 1991).

Electroencephalography

- Electroencephalography (EEG) is an inexpensive, non-invasive measure of synaptic (dys)function.
- EEG signals are continuous measures of electrical potential across the scalp relative to a neutral reference.
- Scalp recorded EEG signals are generated by pyramidal neurons perpendicular to the scalp and parallel to each other as indicated in Figure 1 (Mazzoni, Brunel, Cavallari, Logothetis, & Panzeri, 2011).
- Event related potentials (ERPs) are EEG signals time locked to stimulus or response events, averaged across multiple repetitions.
- ERP components are defined by their amplitude, time from the event onset and topography and are considered indicative of cognitive processes.

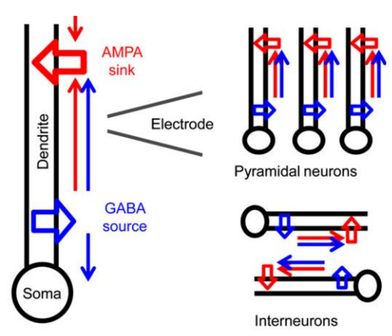

Figure 1: *Neuronal source of EEG signals (adapted from Mazzoni et al., 2011, p. 5).*

The N400 Congruency effect

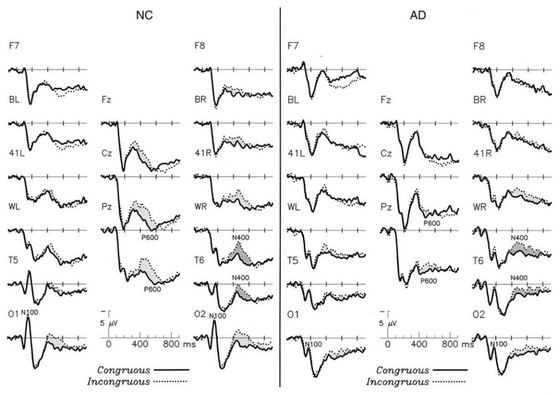

Figure 2: *N400 congruence effect (Olichney et al., 2006, p. 1323).*

- The N400 ERP is a relatively negative peak at 400ms from stimulus onset, consistently present for most meaningful or potentially meaningful stimuli (Kutas & Federmeier, 2011).
- N400 peak amplitude is highly sensitive to context maximal for stimuli incongruent with the established context. The amplitude difference between congruent and incongruent stimuli is defined as the N400 congruity effect.
- Figure 2 shows the N400 congruity effect from healthy individuals (left) and individuals diagnosed with mild AD. As the data suggests, in AD patients, the effect while marginally significant is greatly diminished (Olichney et al., 2006).

Aims of the study

While the N400 ERP and the N400 congruency effect in healthy individuals has been widely simulated, the exact neural mechanisms have not been understood. The aim of the current study is to simulate the N400 congruence effect accounting for neuronal dynamics at the synaptic level to permit further simulations of N400 in AD.

Methods

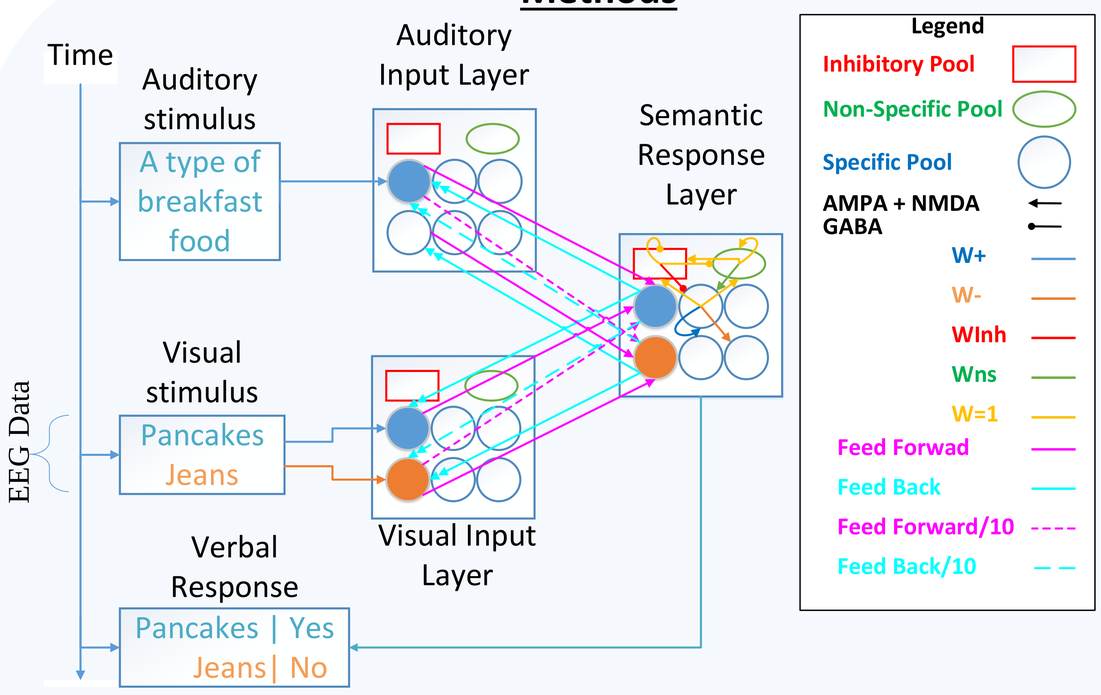

Figure 3: *Model architecture and the implementation of the semantic category judgment task.*

The current study attempts to model the semantic category judgment task used for patients (Olichney et al., 2006).

- **Architecture:**
  - The architecture and its neuronal characteristics are based on the sSoTS model (Mavritsaki, Heinke, Allen, Deco, & Humphreys, 2011).
- **Neuronal Characteristics:**
  - 4000 integrate-and-fire neurons. 80:20 excitatory to inhibitory neurons
  - Figure 4 describes the individual current implemented in the simulations.
  - The model also incorporates Poisson noise at 3Hz through 800 external neurons, modulated to simulate subjects by varying signal to noise ratio.
- **Connectivity:**
  - The general connectivity simulates competitive dynamics through global inhibition.
  - Connection weight parameters are approximated using the **mean field approach**.
  - The **mean field approach** uses transfer functions to calculate average activation of pools of similar neurons simplifying the process and reducing the computational requirements for calculating connectivity weight parameters.

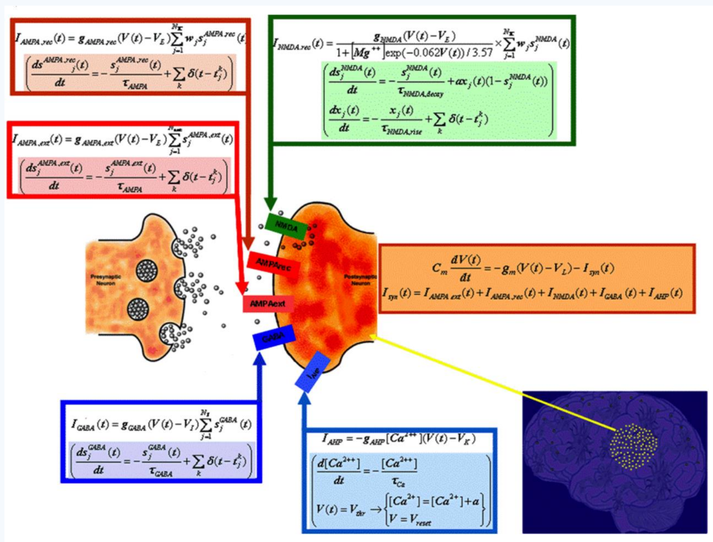

Figure 4: *An integrate-and-fire neuron in the model. (Mavritsaki et al., 2011, p. 7).*

Mean Field Results

- Recurrent (W+) and inhibitory (WInh) weights were modulated at the mean field level to examine a parameter space of 9261 combinations of parameters.
- Overall only a small portion of the parameter space was non-stationary (Blue).

Figure 5: *Mean Field stationary regions classification.*

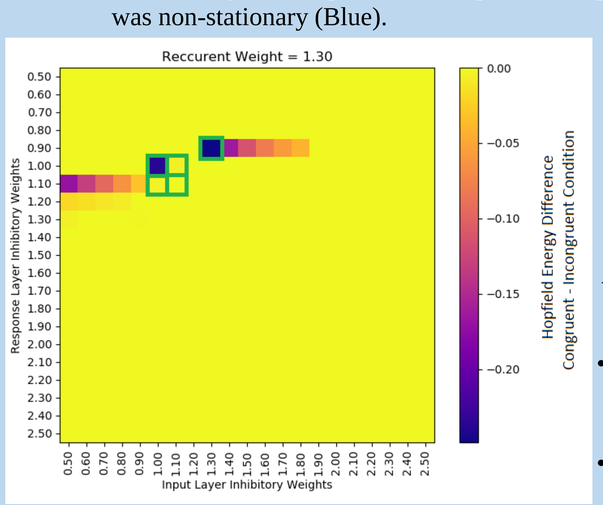

Figure 6: *Mean Field level Hopfield energy difference between congruent and incongruent conditions.*

- Difference between Hopfield energy for congruent and incongruent conditions was used to further filter parameters.
- Five indicative parameter combinations (Green square highlights) were selected for further simulations at the spiking level.

Spiking level Results

- The N400 congruence effect generated as the absolute sum of all the currents simulated for the most indicative of the selected parameter combinations.
- Simulation results from 10 subjects with 20 trials per subject per condition.

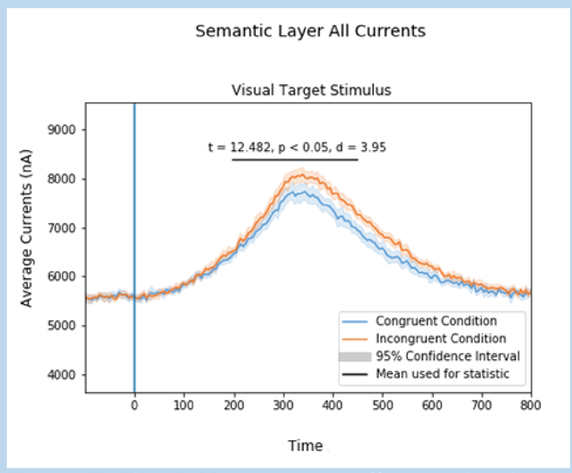

Figure 7: *The N400 congruency effect simulated in the model*

Conclusion

The current model architecture successfully simulates the N400 congruence effect. This is the first step for understanding AD disease through the biomarkers identified in the N400 congruency effect. The presented computational model includes both network properties as well as low level properties of the system through AMPA, GABA, NMDA and I_{AHP} currents. These different properties of the presented model allow us to simulate both synaptic loss as well as changes in neurotransmitters observed in Alzheimer's' disease (i.e. acetylcholine).

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