Modelling cortico basal-ganglionic loops and the development of sequential information encoding

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Abstract

A connectionist model consisting of thirty cortico-basal ganglionic loops was implemented. This model encodes temporal information into a spatial pattern of neuronal activations in the prefrontal cortex using neurophysiologically plausible activation functions and circuitry without learning. This neural architecture was used to model experiments with infants. Initial results suggest that the cortical basal ganglionic circuitry has an inherent ability to differentiate sequential information.

1. The model

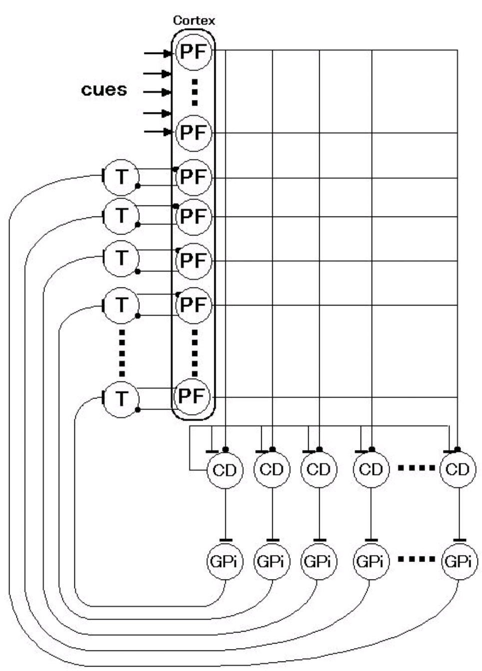

Figure 1: The network architecture of the model

The model (Beiser and Houk, 1998) was implemented in order to explore its ability to model infants' memory for patterns of sequential information. This model consists of a number of prefrontal cortico-basal ganglionic loops, as shown in figure 1. The model uses neurophysiologically plausible activation functions and connectivity, in order to transform sequentially presented sensory cues into spatial patterns of sustained activity in the prefrontal (PF) cortex units. The key features of this model in generating sustained activity are, 1) a random matrix of synaptic weight connecting prefrontal units to caudate nucleus (CD) units, 2) competition between caudate nucleus units, 3) low threshold calcium channels and post-inhibitory rebound at the thalamus (T) triggered by disactivation of tonically activating globus pallidus interna (GPi), and 4) excitatory reciprocal connections between the thalamus and prefrontal cortex.

In later sections, result from experiments with infants are simulated by this model.

2. Application to experimental data

2.1 Visual expectation in the first year of age

Reznick (Reznick et al., 2000) investigated infants' visual expectations. 128 infants saw two 40-trial sequences of a videotaped toy appearing in various locations. The sequence of toy locations had either an alternating pattern (eg. ABABAB) or a pivot pattern (eg. ABCBA). Infants showed better anticipation in response to the alternating pattern.

We presented equivalent sequences of sensory cues to the neural network. Our input data replicated the timings and durations used in the original experiment: each cue was presented for 1 second and was followed by a 1 second inter-stimulus interval (ISI).

2.2 *Discrimination of sound sequences by newborn infants*

In two experiments on auditory sequence discrimination (McAdams and Bertoncini, 1997), repeated rising and falling four-tone sequences were presented to newborn infants in two configurations of timbre and spatial positions. In both experiments, three cycles of four rising continuous tones were presented and followed by three cycles of its retrograde. The only difference was the length of tones and ISIs (15ms tones + 85ms ISIs for Experiment 1 and 200ms tones + 250ms ISIs for Experiment 2). Newborn infants could differentiate rising and falling tones only at Experiment 2. As in the previous simulation, the experimental procedure was closely followed in the simulation.

3. Analyses and discussion

In both sets of simulations, ten neural networks with different random PF-to-CD weights, but otherwise identical parameter values, were used. Figure 2 illustrates a typical example of the activity generated in the prefrontal cortex units in response to a pivot pattern from 'application 1', which is the final output of the network.

Results were evaluated by determining the extent to which each neural network could differentiate different sequences of sensory cues. Hence, the following analyses were conducted to evaluate the differences in the spatial patterns of sustained activity generated in the prefrontal cortex units.

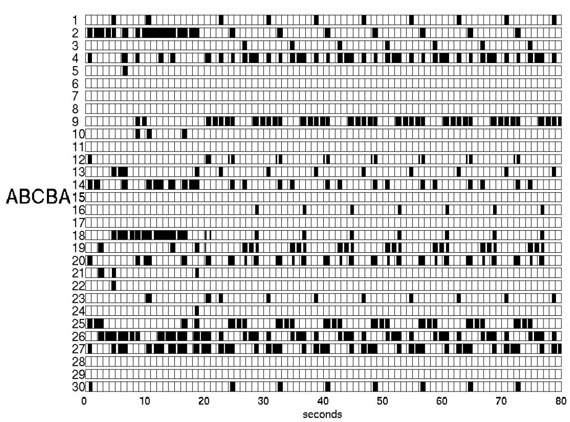

Figure 2: The activation of all units in the prefrontal cortex units in response to the pivot pattern (ABCBA)

3.1 *Analyses for application 1*

Analysis 1-1 Spatial patterns of sustained activity in response to the presentation of alternation and pivot patterns were compared during selected ISIs just after the presentation of cues. There are six possible patterns of the expectation (i.e. $A \Rightarrow B$, $A \Rightarrow c$, $B \Rightarrow A$, $B \Rightarrow C$, $C \Rightarrow A$, and $C \Rightarrow B$). In this analyses, variance of the spatial patterns of sustained activity during a certain pattern of the expectation in response to alternation and pivot pattern was calculated and compared. The variance was smaller at alternation patterns, meaning that the network performed better anticipation at alternation patterns, which followed results of the original experiment.

3.2 *Analyses for application 2*

Analysis 2-1 As in analysis 1-1, spatial patterns of sustained activity during selected ISIs were compared. In this case, the model was checked to see what extent it differentiates rising four tones from falling four tones, by comparing the spatial patterns of sustained activity during ISIs just after rising and falling four tones. The model showed better differentiation at the experiment in the lower time resolution (200ms tones + 250ms ISIs), simulating the findings from the infant data.

Analysis 2-2 From the onset to the end of cue presentation, all units' activation in response to rising tones were subtracted and normalised from that of falling tones. This derives a whole difference of model's all PF units response to rising tones from falling tones across one experiment. The difference was greater in the experiment in the lower time resolution, following the original work as well.

3.3 *Concluding remarks*

Since the model could successfully differentiate patterns without employing any learning mechanism, we can suggest that the prefrontal cortico-basal ganglionic circuitry embodies an inherent mechanism capable of discriminating sensory sequences. This could be fundamental mechanism for memory of any sequential information including auditory, vision, and motor.

References

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