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Modeling the exploratory dynamics of the Indirect Pathway in the Basal Ganglia using a network ofChaotic Attractors

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Abstract:
Parkinson's Disease (PD) is a neurodegenerative disorder, caused by the loss of dopaminergic neurons in the Substantia Nigra pars compacta (SNc). We had earlier proposed that when the BG is described using Reinforcement Learning (RL), the Direct Pathway subserves exploitation, while the Indirect Pathway subserves exploration. The putative role of the Subthalamic Nucleus (STN) in exploration, is supported by the loss of complex dynamics in STN under PD conditions. We describe a model of the Basal Ganglia (BG) in which loss of complex dynamics in STN, which is modeled by a network of chaotic Rossler systems, is manifested as impaired performance in Iowa Gambling Task (IGT). The dynamics of the Rossler network are characterised by the parameter 'a', which allows the network to move from a periodic to a chaotic regime, characterised by uncorrelated desynchronised oscillations. The network is tuned to exhibit chaotic behaviour in normal conditions and synchronised periodic oscillations in PD conditions. The network receives feedback via mean-field diffusion from SNc, which controls the collective behaviour of the network. This network also receives inputs (Iext) from the striatum (D2R neurons), which can induce STN transition into a periodic regime. The BG circuitry is trained for IGT using RL. Temporal difference error (δ) is analogous to dopamine in SNc. We define epsilon (ε) as the exploratory parameter, which is a function of δ and linearly controls 'a' in STN. The initial stages of training demand a greater exploration (high ε), which necessitates the network to operate in a chaotic regime. To simulate the dopamine loss in PD condition, the δ value is delimited which in turn constrains ε, restricting STN to a periodic regime. This limits the BG circuit's ability to learn the IGT task. IGT is evaluated by a score computed as the difference between advantageous deck choices and disadvantageous deck choices. The entire task is split into 5 bins, each of 20 picks. Fig. 1 (d) shows that the proposed BG circuit is able to improve the IGT score in normal condition as opposed to in PD condition.

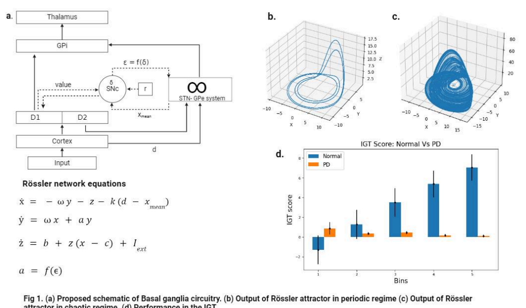

Fig 1. (a) Proposed schematic of Basal ganglia circuitry. (b) Output of Rössler attractor in periodic regime (c) Output of Rössler attractor in chaotic regime. (d) Performance in the IGT

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