Modelling tempo representation in the basal ganglia during sensorimotor synchronization

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Background

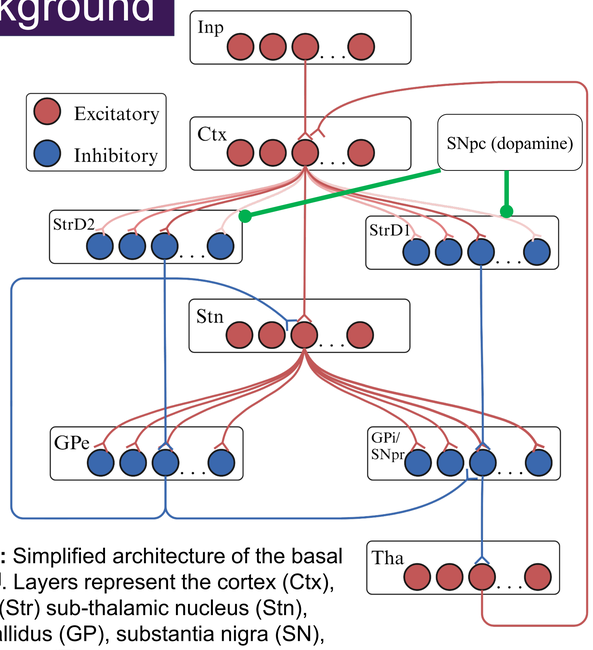


Figure 1: Simplified architecture of the basal ganglia[6]. Layers represent the cortex (Ctx), striatum (Str) sub-thalamic nucleus (Stn), global pallidus (GP), substantia nigra (SN), and thalamus (Tha).

- Evidence from fMRI[1], PET scan[2], and Parkinson's[3,4] indicate that **basal ganglia (BG) and its dopamine are important to maintaining a steady finger-tapping tempo.**
- The BG are composed of segregated, parallel, and recurrent cortico-striatal loops[5,6], with striatal neurons prominently modulated by dopamine (Fig 1).
- According to the classic model, exciting a striatal population disinhibits a corresponding action-related cortical population, activating that action.[5]
- A loop may encode an entire action sequence and its continuous movement parameters (e.g., speed).[7,8,9]
- Dopaminergic modulation of striatum is thought to respond to reward prediction errors and possibly sensory prediction errors.[10]

Model

In our model of metronome-synchronized finger tapping…

- **A continuum of overlapping cortico-striatal loops produce tapping at a continuum of possible tempi.**
- **Tapping tempo is adjusted when inter-click interval measurements provide input to a new set of loops.**
- **Dopamine strengthens a positive feedback loop that "locks in" a tempo, making it resist change and drift.**
- **Greater tap/click asynchronies reduce dopamine.**

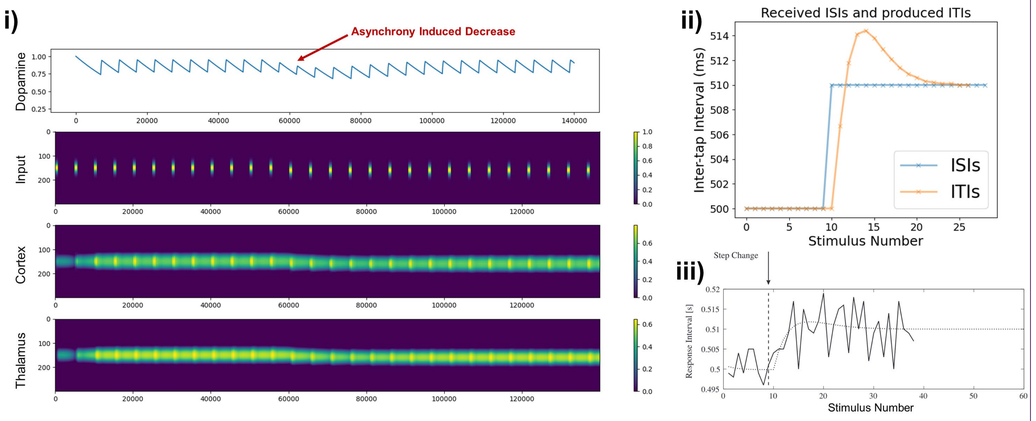
- We model each basal ganglia subregion as a collection of 300 firing-rate units (adapted from [6]).
- Measurements of durations between metronome clicks provide cortical input to a subset of these loops.
- Loops overlap due to spreading cortico-striatal connections.
- Taps are executed at intervals determined by thalamic activation, with (unmodeled) phase correction of asynchrony.
- Dopamine positively and negatively modulates striatal D1 and D2 layers, respectively.

This model reproduces two key results:

1. **We adapt to large metronome tempo changes more immediately than smaller ones.[11]**
2. **Parkinsonian patients tap with greater variability during synchronization and continuation.[3,4]**

Results

Small tempo adjustments (500 ms to 510 ms) occur gradually.



Large tempo adjustments (500 ms to 550 ms) occur instantaneously.

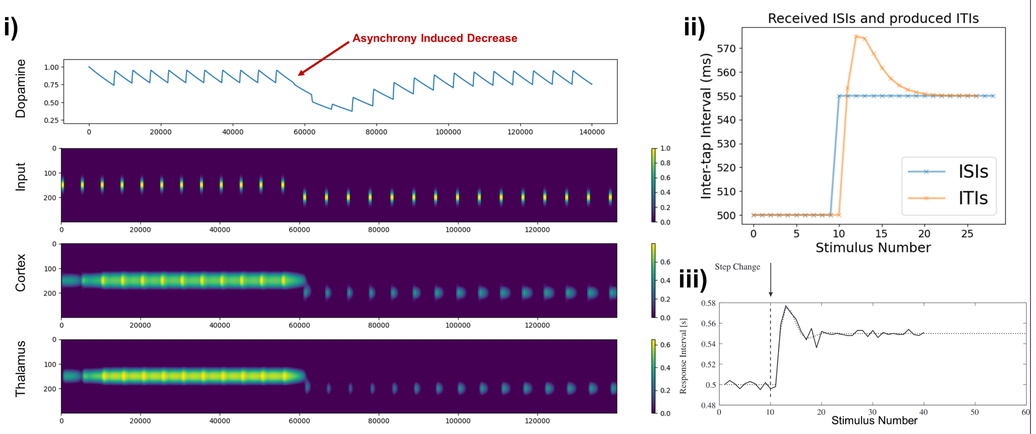


Figure 2: Network behaviour in response to tempo changes. Note that adaptation to small changes is gradual, while adaptation to large changes is sudden. i) Activations of all units in specific layers across simulation. ii) Inter-tap intervals produced across the simulations. iii) Mean inter-tap intervals of human subjects adapting to tempo changes in a sensorimotor synchronization task (reproduced from [11]).

Reduced dopamine increases tapping variability.

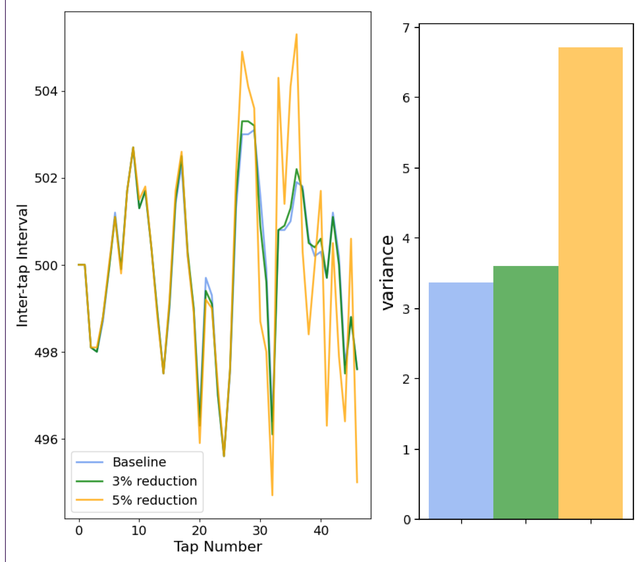


Figure 3: Inter-tap intervals become more variable as dopamine levels drop, as observed in Parkinson's.[3,4]

Conclusion

- We have designed an model of the cortico-basal-ganglia circuit's maintenance of tempo during sensorimotor synchronization, including a dopaminergic link between reward prediction error and action switching.
- Our model replicates gradual changes to small tempo shifts, and instantaneous changes to large shifts.[11]
- Also demonstrated is increased tap interval variability with decreased dopamine, as seen in PD patients.[3,4]
- **Model could be generalized to describe interaction of sensorimotor error and other continuously encoded movement parameters.**

References

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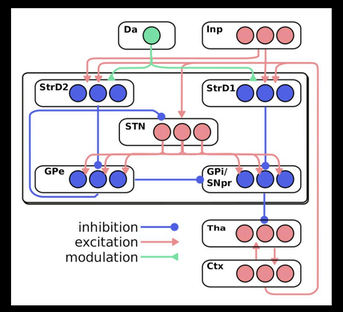
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StrD2
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inhibition
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modulation
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