Simulation of How Neuromodulation Influences Cooperative Behavior

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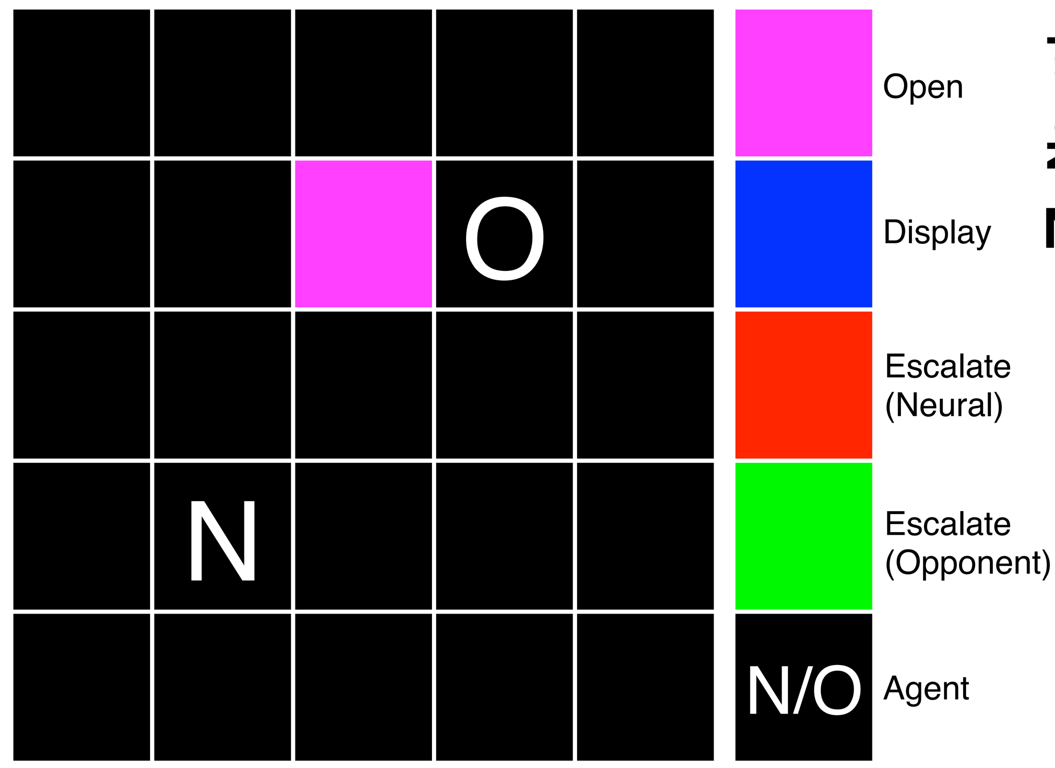
INTRODUCTION

- **Neuromodulators, such as dopamine (DA) and serotonin (5-HT), are known to be important in predicting rewards, costs, and punishments.**
- **Dopamine, which originates in the ventral tegmental area (VTA) and the substantia nigra (SN), appears to be linked to expected reward [1], and incentive salience or “wanting” [2].**
- **Serotonin, which originates in the Raphe nucleus, appears to be related to cognitive control of stress, social interactions, and risk taking behavior [3], [4].**
- **Game theory has been useful for understanding risk-taking and cooperation [5].**
- **To better understand the roles of dopamine and serotonin during decision-making in games of conflict, we developed a computational model of neuromodulation and action-selection.**
- **An agent, whose behavior was guided by the neural model, played the Hawk-Dove game, where players must choose between confrontational and cooperative tactics [5], [6].**

METHODS

Game Playing



Payoff Matrix

Neural \ Opponent	Hawk	Dove
Hawk	(V-D)/2, (V-D)/2	V,0
Dove	0,V	V/2, V/2

Neural Agent

TOI State

$$n_i = \begin{cases} 0.75 + rnd(0.0,0.25); & i = TOIState \\ rnd(0.0,0.25); & Otherwise \end{cases}$$

Neural Activity

$$s_i(t) = \rho_i s_i(t-1) + (1-\rho_i)\left(\frac{1}{1+\exp(-5I_i(t))}\right)$$

Synaptic Input

$$I_i(t) = rnd(-0.5,0.0) + \sum_j nm(t-1) w_{ij}(t-1) s_i(t-1)$$

Learning Rule

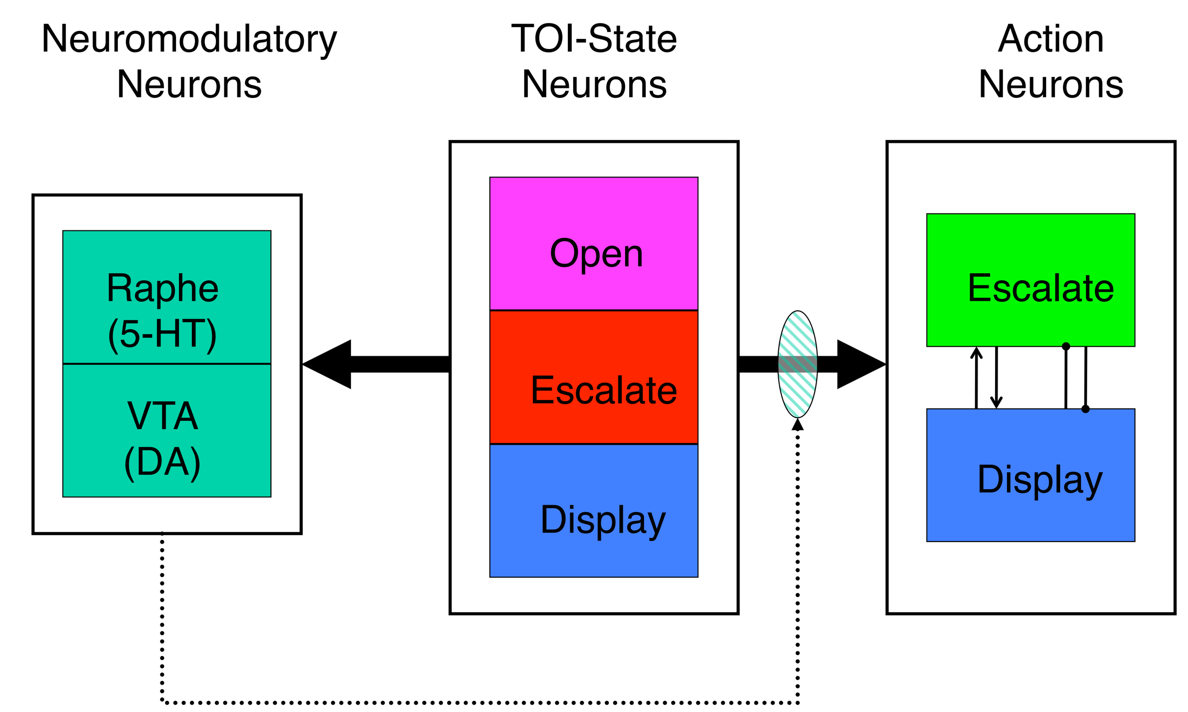
$$\Delta w_{ij} = \alpha * nm(t-1) s_j(t-1)\left(s_i(t-1)\right) * R$$

$$R = \begin{cases} (\text{Reward} - VTA) - (\text{Cost} - Raphe) \\ \text{Reward} - VTA \\ \text{Cost} - Raphe \end{cases}$$

Opponent Agent

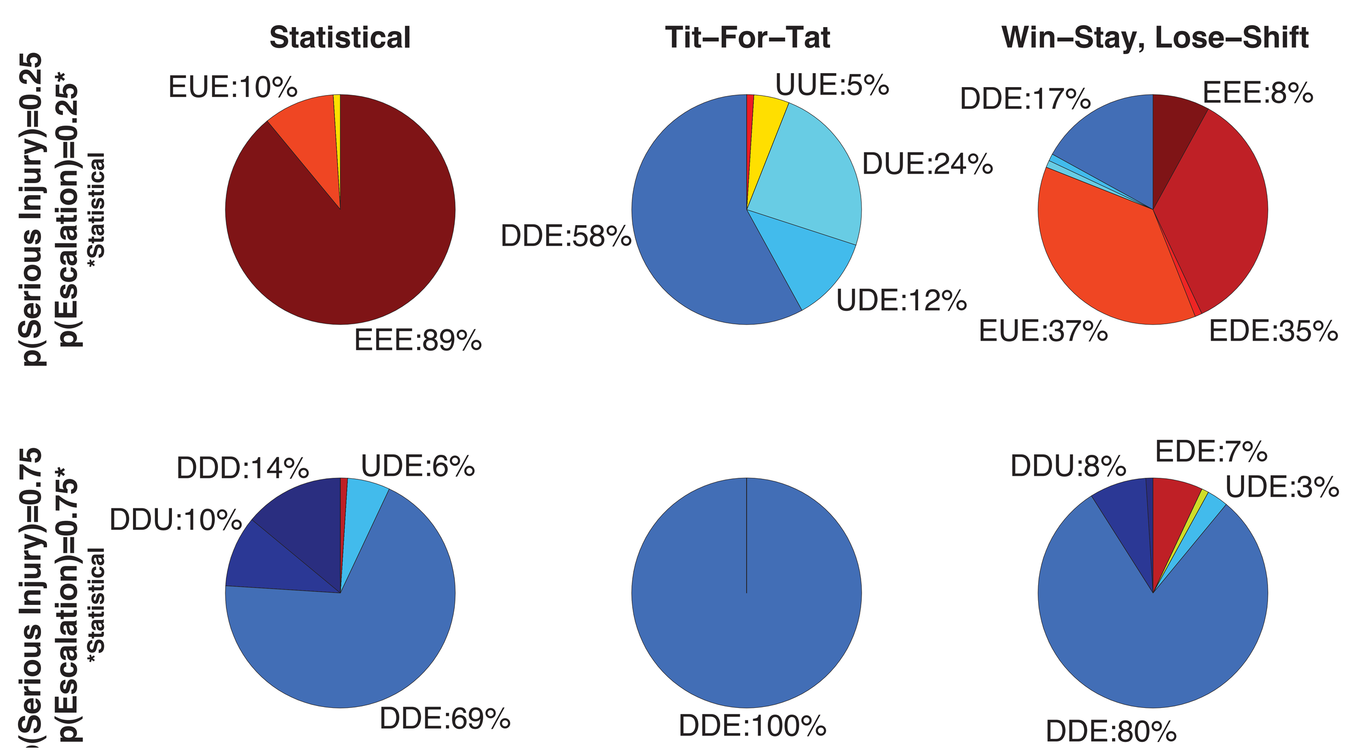
Statistical, Tit-for-Tat, or Win-Stay, Lose-Shift

Network Model



RESULTS

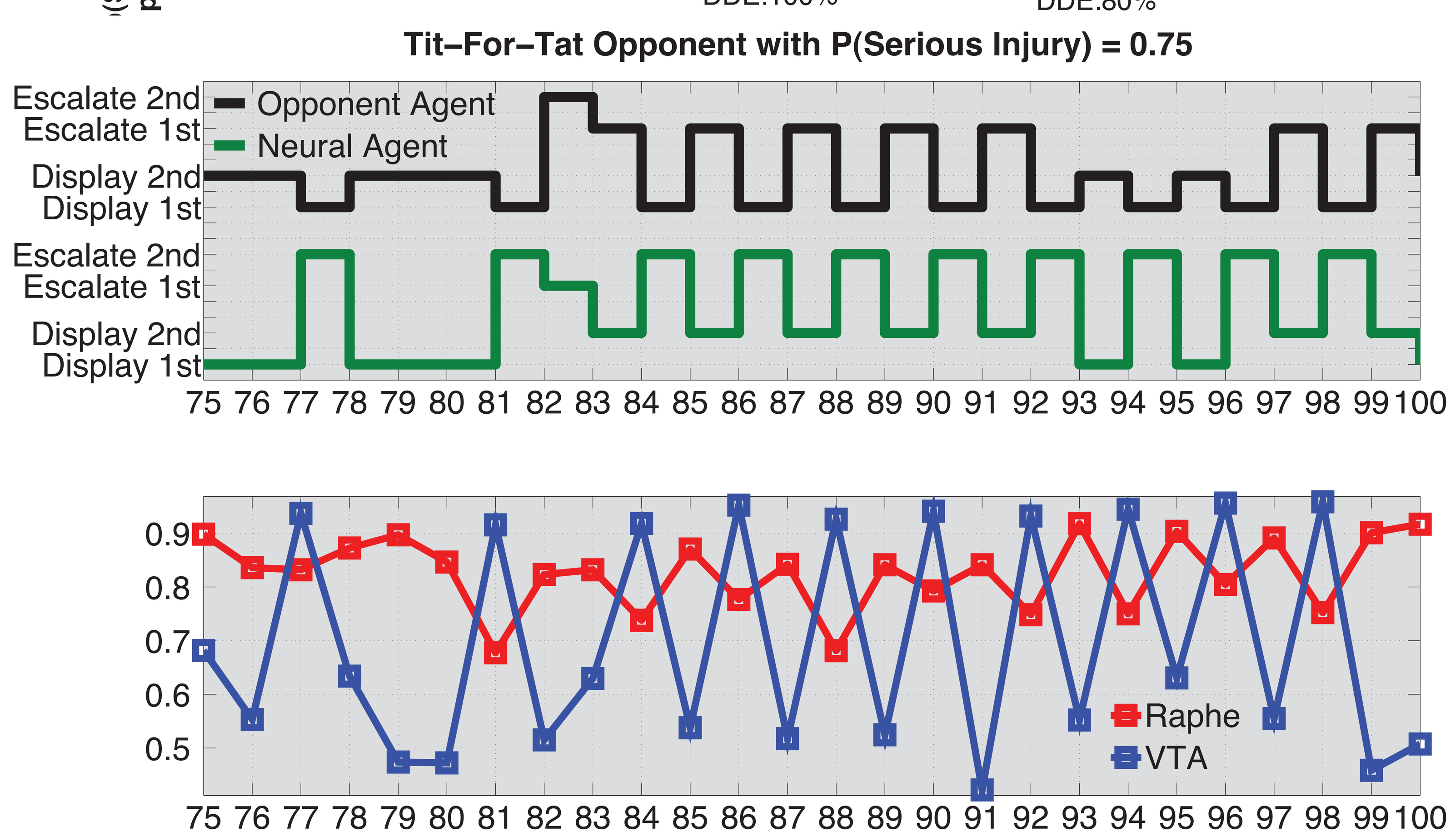
Adopted Strategies

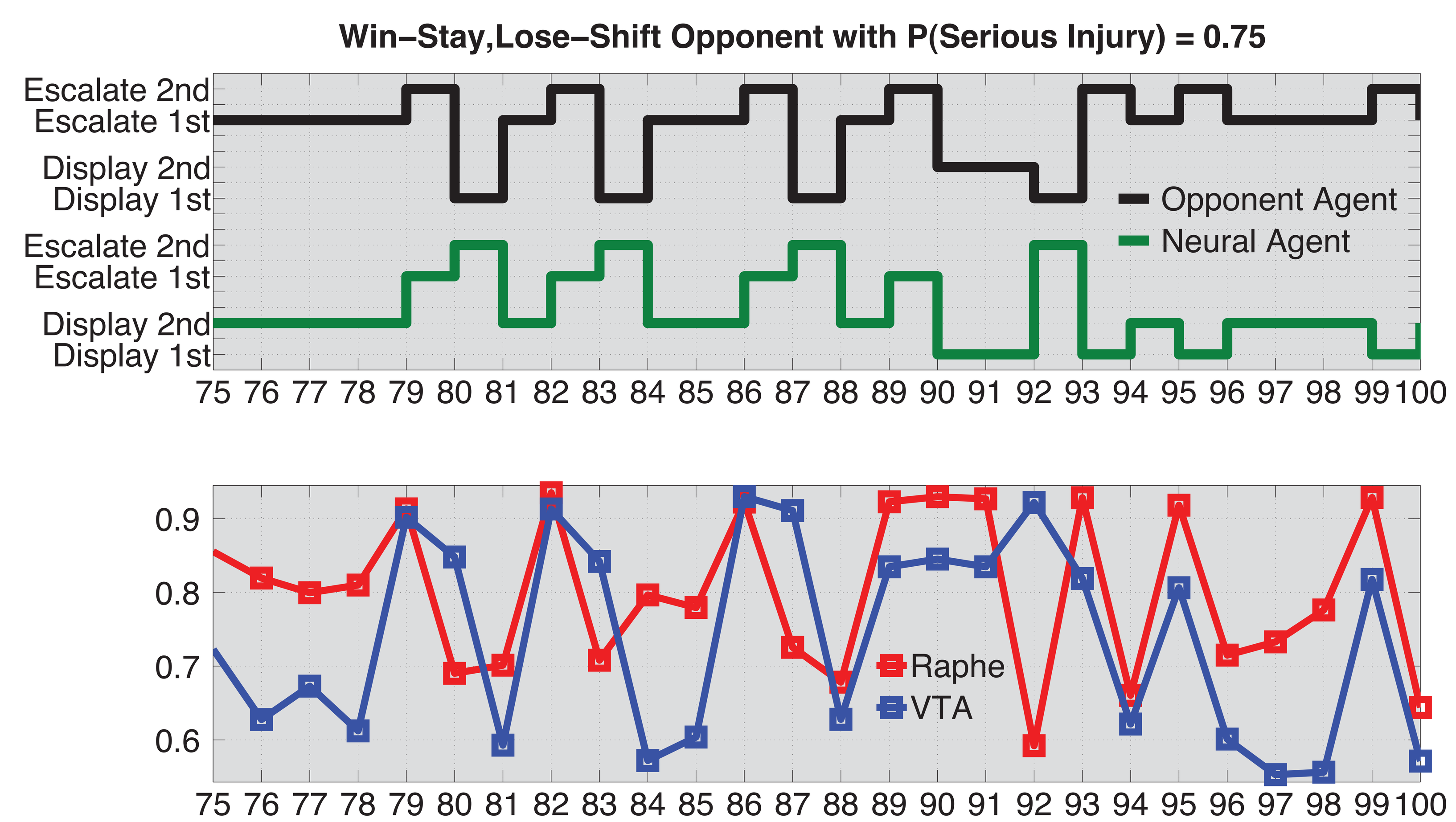


Percentage of Escalation for the Neural Agent

	CTL		Raphe		VTA	
	p(0.25)	p(0.75)	p(0.25)	p(0.75)	p(0.25)	p(0.75)
Statistical	97.65%	10.00%	99.06%	92.86%	34.79%	7.14%
TT	34.15%	13.64%	81.82%	81.82%	24.74%	12.50%
WSLS	93.22%	9.09%	96.88%	96.88%	20.93%	8.22%

Neural Activity





CONCLUSIONS

- **We showed that an agent, whose behavior was guided by a computational model of the neuromodulatory system, learned to adjust its strategy appropriately depending on environmental conditions and its opponent’s strategy in the Hawk-Dove game.**
- **The model makes the following predictions:**
  1. **The interaction between the DA and 5-HT neuromodulatory systems allows for appropriate decision making in games of conflict.**
  2. **Impairment to either the dopaminergic or serotonergic system will lead to perseverant, uncooperative behavior.**
  3. **Although DA and 5-HT activity appears to be related to different expectations (e.g., predictive reward, anticipated cost), the action of these neuromodulators on downstream targets is similar in that it governs decision-making.**

REFERENCES

1. Schultz, W., et. al., Science 275 (1997)
2. Berridge, K.C., Physiol Behav 81 (2004)
3. Millan, M.J., Prog Neurobiol 70 (2003)
4. Crockett, M.J., et. al., Science 320 (2008)
5. Maynard Smith, J., Cambridge University Press (1982)
6. Axelrod, R., et. al., Science 211 (1981)

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