Effects of Neuromodulation and Adaptive Behavior on Reciprocity During Human-Robot Interactions

Derrik E. Asher[1], Andrew Zaldivar[1], Brian Barton[1], Alyssa A. Brewer[1], & Jeffrey L. Krichmar[1,2]

1 Department of Cognitive Sciences, University of California, Irvine
2 Department of Computer Science, University of California, Irvine

INTRODUCTION

•Elucidating the neurobiological basis for decision-making under competitive and conflicting situations is an important step towards understanding reciprocity, social cognition, cooperation, and competition [1,2].

•Game theory has been successful in describing such social behaviors [3,4,5] and has been applied to the investigation of their neural bases [1,6,7,8].

•The raphe nucleus, which is the source of serotonin in the central nervous system (CNS), may underlie cognitive control of stress, social interactions, and risk-taking behavior [9].

•In studies of the neural basis of decision-making during games of conflict, subjects typically play against opponents with predetermined strategies.

•The present study introduces a neurobiologically plausible model of action selection and neuromodulation, which adapts to its opponent's strategy and environmental conditions [10,11]. The model is based on the assumption that dopaminergic and serotonergic systems track expected rewards and costs, respectively.

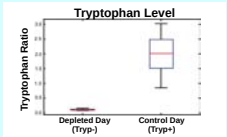
•The model controlled both simulated and robotic agents playing Hawk-Dove and Chicken games against subjects.

METHODS

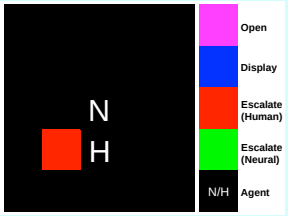
Acute Tryptophan Depletion

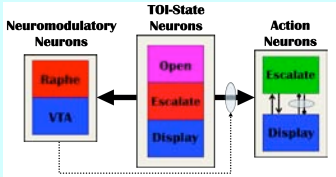
PROCEDURE

- 8 participants
- Double blind study
- 24 hour dietary modification pre-experimental day
- Drink amino acid shake w/ and w/o tryptophan
- 2 experimental days separated by 1 week (7 days)
- Blood draw pre-consumption
- Blood draw 5.5 hours post-consumption
- Game playing

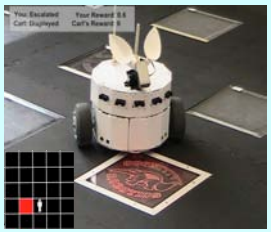


Hawk-Dove Game





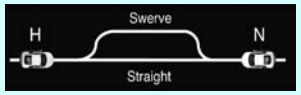
From	To	Initial Weight	Plastic	Phasic Neuromodulation
TOI-State	Action	0.1	Y	Y
TOI-State	Neuromodulatory	0.1	Y	N
Action-Escalate	Action-Display	0.1	N	N
Action-Escalate	Action-Display	-0.1	N	Y
Action-Display	Action-Escalate	0.1	N	N
Action-Display	Action-Escalate	-0.1	N	Y

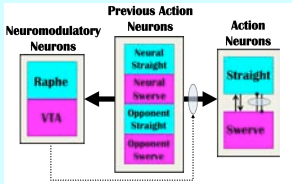


Hawk-Dove Experimental Conditions

Conditions	Control	Raphe	$P_{SI} = 0.25$	$P_{SI} = 0.75$	Robot	Sim
A	x		x		x	
B		x	x		x	
C	x			x	x	
D		x		x	x	
E	x		x			x
F		x	x			x
G	x			x		x
H		x		x		x

Chicken Game





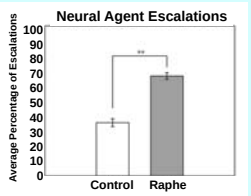
From	To	Initial	Plastic	Phasic
Previous Action	Action	0.1	Y	Y
Previous Action	Neuromodulatory	0.1	Y	N
Action-Straight	Action-Swerve	0.1	N	N
Action-Straight	Action-Swerve	-0.1	N	Y
Action-Swerve	Action-Straight	0.1	N	N
Action-Swerve	Action-Straight	-0.1	N	Y

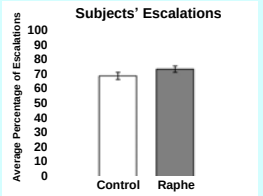
Chicken Experimental Conditions

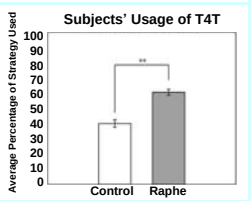
Conditions	Control	Raphe	Robot	Sim
A	x		x	
B		x	x	
C	x			x
D		x		x

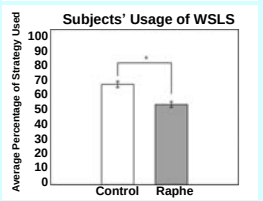
RESULTS

Hawk-Dove Game

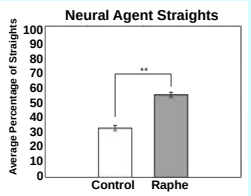


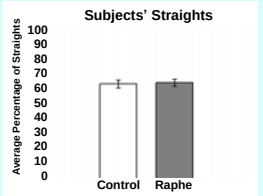


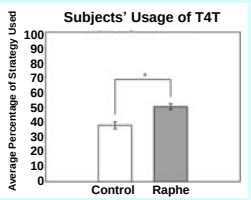


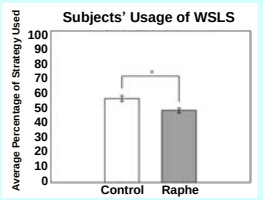


Chicken Game



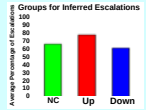




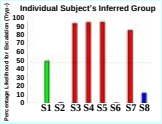


Bayesian Analysis of Hawk-Dove

- A hierarchical Bayesian Cognitive Model was utilized to explore the possibility of sub-groups within the subject pool.
- The model makes a general prediction about a subject's base-rate amount of Escalations independent of tryptophan depletion by assuming the prior to be a flat Gaussian distribution.
- The model utilizes a Markov chain Monte Carlo (MCMC) approach to approximate the target distributions for the potentially different groups that result from changes in percentage of Escalations when tryptophan depleted.



- Three groups emerge for percentage of Escalations when tryptophan depleted (Tryp-)
- NC Group (Green) => no change in Escalation percentage
- Up Group (Red) => inferred increase in Escalation percentage
- Down Group (Blue) => inferred decrease in Escalation percentage



- Green => tryptophan depletion does not alter percentage of Escalations
- Red => tryptophan depletion results in greater percentage of Escalations
- Blue => tryptophan depletion results in decreased percentage of Escalations

CONCLUSIONS

•When playing against an aggressive version of the model, there was a significant shift in the subjects' strategy from Win-Stay-Lose-Shift to Tit-For-Tat.

•Subjects became retaliatory when confronted with agents that tended towards risky behavior.

•These results highlight the important interactions between subjects and agents utilizing adaptive behavior. Moreover, they reveal neuromodulatory mechanisms that give rise to cooperative and competitive behaviors.

•In previous studies, treatment with ATD has led to an increased number of defections in the Prisoner's Dilemma [12] and more rejections of offers in the Ultimatum Game [13]. In contrast, we did not observe a decrease of cooperativeness in our subjects due to ATD, but rather the emergence of a significant shift in strategies based on opponent type.

•It may be that iterative interactions with a responsive, adaptive agent outweighed the effects of ATD in our human subjects.

•Our study sheds light on how humans interact with others in conflicting situations and assists in the development of neural agents that can respond more naturally in human-robot interactions.

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CONTACT INFORMATION

For additional information or questions please contact:
Derrik E. Asher at dasher@uci.edu
Andrew Zaldivar at azaldiva@uci.edu
Brian Barton at bbarton@uci.edu
Alyssa A. Brewer at aabrewer@uci.edu
Jeffrey L. Krichmar at jkrichma@uci.edu

Hierarchical Bayesian Cognitive Model

$\mu_\phi \sim \text{Gaussian}(0, 1)$
$\sigma_\phi \sim \text{Unif}(0, 1)$
$\phi_i \sim \text{Gaussian}(\mu_\phi, \sigma_\phi)$
$z_i \sim \text{Bern}(0.5)$
$\sigma^c \sim \text{Unif}(0, 1)$
$\mu^u \sim \text{Gaussian}(0, 1)\ \mathrm{I}(0, \infty)$
$\mu^d \sim \text{Gaussian}(0, 1)\ \mathrm{I}(0, \infty)$
$\Psi^u_{ij} \sim \text{Gaussian}(\mu^u, \sigma^c)$
$\Psi^s_{ij} \sim \text{Gaussian}(0, \sigma^c)$
$\Psi^d_{ij} \sim \text{Gaussian}(\mu^d, \sigma^c)$
$d_{ijk} \sim \text{Bern}(\theta_{ijk})$

$$\theta_{ijk} \leftarrow \begin{cases} \frac{\exp(\phi_i + \Psi^s_{ij})}{1+\exp(\phi_i + \Psi^s_{ij})} & \text{if } t_j = 1 \\ \frac{\exp(\phi_i + \Psi^u_{ij})}{1+\exp(\phi_i + \Psi^u_{ij})} & \text{if } t_j = 2 \text{ and } z_i = 1 \\ \frac{\exp(\phi_i - \Psi^d_{ij})}{1+\exp(\phi_i - \Psi^d_{ij})} & \text{if } t_j = 2 \text{ and } z_i = 2 \end{cases}$$