Whole-brain Effective Connectivity during Social Reward and Punishment Reinforcement Learning in Healthy Controls

Haimei Yu[1], Poornima Kumar[1,2]

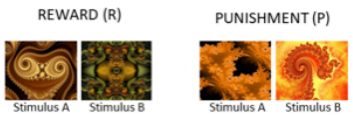
1. Center for Depression, Anxiety, and Stress Research, McLean Hospital, United States of America 2. Department of Psychiatry, Harvard Medical School, United States of America

1. Background

- Reinforcement learning is the ability to learn about rewards and punishments in the environment and modify the behavior to maximize rewards.
- There is mixed evidence to the notion of overlapping neural correlates underlying reward vs punishment learning, and the whole brain connectivity during reward vs punishment has not been systematically compared [1, 2, 3].
- To unfold this critical issue, we conducted a study to compare the effective whole-brain connectivity during reward and punishment reinforcement learning from task-based fMRI.

2. Experimental Design

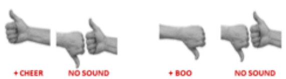
- **Subjects**: 14 healthy subjects
- **2 conditions:** reward vs punishment learning blocks



- **Stimuli**: 2 images in each conditions (stimuli A and B shown above)
- Probability of association between the stimuli and feedback changed throughout the task and shown below
- 80 trials in each blocks, order counterbalanced

Sub-Block	Stimulus A	Stimulus B
1	80	20
2	10	90
3	50	50
4	80	20

- **Feedback**: thumb up & down with cheer and boo sounds



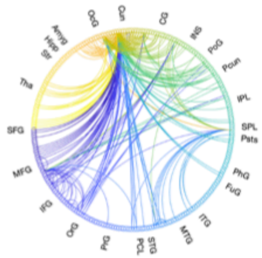
3. Regression Dynamic Causal Model (rDCM)

- rDCM was used to estimate whole-brain connectivity from fMRI [4, 5].
- We parcellated fMRI data with the Brainnetome atlas, which divides human brains into 246 areas, including 210 cortical and 36 sub-cortical regions [6].

4. Result

4.1 Top overlapping connections between Reward (R) and Punishment (P) learning

Figure A



- Figure A shows the top 300 overlapping connections between reward and punishment learning. These top connections involve regions in visual areas, such as Cuneus (Cun) and Occipital Gyrus (OcG), and Cingulate Gyrus(CG).

4.2 Significant distinct connections between Reward and ` Punishment learning

Figure C: R>P

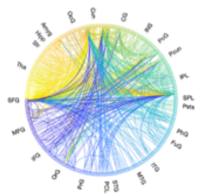
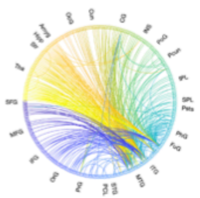
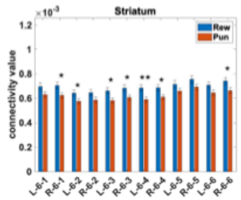


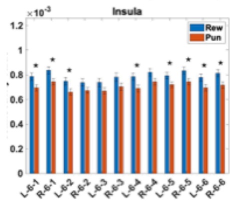
Figure D: P>R

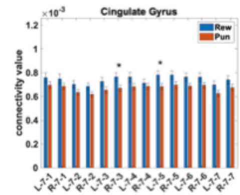


- Among all the positive connections, **figure C** shows 497 significant connections that are strongly connected during reward vs punishment learning (p<.05);
- **Figure D** shows the 356 significant connections that are stronger during punishment than reward learning (p<.05).
- The top 9 connections that are stronger in reward vs punishment learning all involve connections to subregions in cingulate gyrus (dominated by dorsal area 23).
- The top 35 connections that are stronger in punishment learning all involve connections to subregions in Superior Temporal Gyrus (dominated by lateral area 38).

4.3 Connections from Striatum, Insula, and Cingulate Gyrus







- Striatum, insula, and cingulate gyrus were selected *apriori* as these regions are associated to reward, emotion, and reinforcement learning processing [3, 8].

- Regions with significant difference between averaged connections in reward and punishment learning:
  - Insula: L-6-1, R-6-1: left and right hypergranular insula; L-6-2: left ventral agranular insula; L-6-4: left ventral granular insula; L-6-5, R-6-5: left and right dorsal granular insula; L-6-6, R-6-6: left and right dorsal dysgranular Insula;
  - Stratum: R-6-1: right ventral caudate; L-6-2: left globus pallidus; L-6-3, R-6-3: left and right nucleus accumbens; L-6-4, R-6-4: left and right ventromedial putamen; R-6-6: right dorsolateral putamen;
  - Cingulate gyrus: R-7-3: right pregenual area; L-7-5: left caudodorsal area;

5. Conclusion

- The connectivity between striatum, insula, and cingulate gyrus are strongly connected during reward learning;
- There are other regions including the visual and temporal cortices differed between reward and punishment learning;
- Our study reveals the needs to further investigate the effective connectivity in finer ways to unfold the difference and similarity in the underlying brain mechanisms during reward and punishment learning.

6. Future Direction

- Explore finer brain parcellation maps;
- Comparing these results to individuals with major depressive disorder.

7. References

[1] Klöbl, Manfred, et al. Frontiers in human neuroscience 14 (2020): 304.
[2] Kohls, Gregor, et al. Neuropsychologia 51.11 (2013): 2062-20
[3] Niv, Yael. Journal of Mathematical Psychology 53.3 (2009): 139-154.
[4] Frässle, Stefan, et al. Neuroimage 155 (2017): 406-421.
[5] Frässle, Stefan, and Klaas E. Stephan. Network Neuroscience 6.1 (2022): 135-160.
[6] Fan, Lingzhong, et al. Cerebral cortex 26.8 (2016): 3508-3526.
[7] Davey, Christopher G., et al. Human brain mapping 31.4 (2010): 660-668.
[8] Uddin, Lucina Q., et al. Journal of clinical neurophysiology: official publication of the American Electroencephalographic Society 34.4 (2017): 300.

8. Acknowledgments

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