The amygdala becomes reward-sensitive when an outcome cannot be assigned to the correct decision

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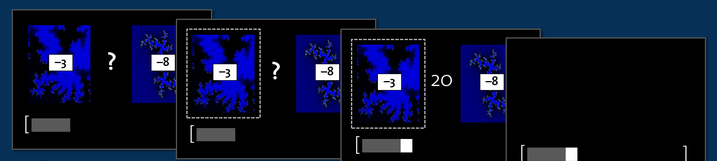
1 Summary

- Optimal decision making requires us to be able to detect changes in the environment and update learned contingencies accordingly. A cardinal test of this ability has been reversal learning.
- In a recent experiment, we showed in monkeys that a lesion to the orbitofrontal cortex (OFC) keeps reward processing intact but is fatal to the ability to associate rewards with their correct contingent choices [1].
- Investigations in rats revealed a similar reversal deficit, but also led to the surprising finding that an additional lesion to the amygdala *restored* the ability for reversal learning [2,3].
- We found a potential explanation for this phenomenon: the amygdala becomes reward-sensitive when contingencies are ambiguous.

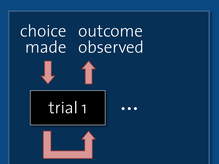
2 Experimental design

In a novel probabilistic decision-making paradigm, 24 healthy participants had to learn the reward probabilities of two options while undergoing 3T fMRI.

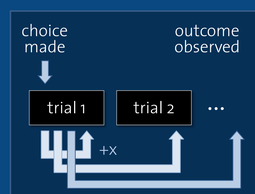


On each trial, participants had to choose between two alternative cards with varying costs. The cards had different probabilities of leading to a reward.

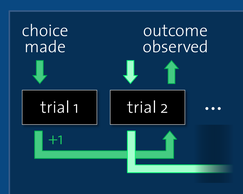
The experiment comprised 180 trials, split up into 12 blocks. At the beginning of each block, subjects were given one of the following three types of instruction:



In the **contingent** condition, when a rewarded option was chosen, its reward was presented on the *same* trial.



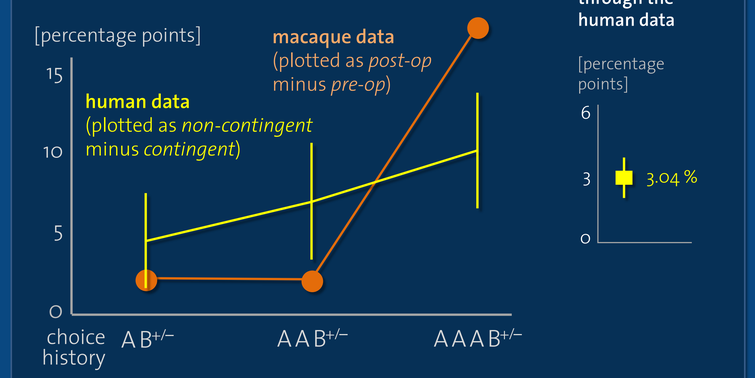
In the **non-contingent** condition, rewards were delayed by a random number of trials such that outcomes could no longer be linked to their causative decisions.



In the **control** condition, rewards were delayed by exactly one trial such that a reward had to be linked to the choice made on the *previous* trial.

3 Behavioural validation of the design

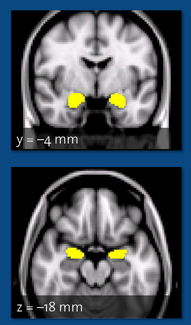
- Our experimental manipulation in humans induced the same behaviour that was observed in OFC-lesioned macaques.



- Referring to the two available options as A and B, after a rewarded B choice compared to an unrewarded B choice, **macaques** were more likely to choose A post-operatively than pre-operatively. This effect increased with the number of recent A choices.
- This is the exact opposite of what would be expected from normal reversal learning, which would have led to negative values on the y-axis throughout.
- In the present study, we replicated this failure to forge correct associations in **humans**. As intended, after a rewarded B choice, subjects were more likely to choose option A in the **non-contingent** condition than in the **contingent** condition.

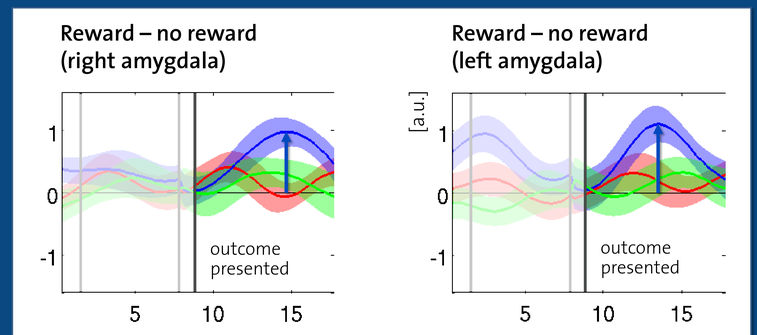
4 Imaging analysis

- OFC activity was examined in a companion abstract (see oral presentation #366 WTh).
- Here, we focussed on the amygdala, where lesions had restored the ability for contingent learning in already OFC-lesioned rats.
- The amygdala was defined as an anatomical mask (yellow), based on the Harvard/Oxford sub-cortical atlas (p > 50%).



5 Imaging results

- When, as in previous fMRI experiments, direct contingencies could be made between choice and outcome (**contingent** and **control** condition), amygdala BOLD activity at the time of processing the outcome of a decision did not distinguish rewarded from unrewarded trials.
- By contrast, when exact contingencies could *not* be established, and hence competing OFC mechanisms could *not* operate (**non-contingent** condition), reward sensitivity emerged in the amygdala bilaterally.



Temporal evolution of a simple 'reward – no reward' contrast in the right and left amygdala (contrast parameter estimates +/– contrast variance). Vertical bars separate trial phases (decide, wait, outcome, inter-trial interval).

6 Conclusions

- Contingent and non-contingent reversal learning can be robustly induced in subjects purely on the basis of different experimental instructions.
- While activity in the left OFC indicates whether the correct contingency is being applied, the amygdala becomes reward-sensitive when contingencies are ambiguous.
- The simpler reward-processing system of the amygdala, which emerges in the absence of contingent choice, might account for the reversal deficit witnessed when a lesion is made to the OFC. We will test this hypothesis in a future study by examining interactions between OFC and amygdala.

References

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