Arousal-induced changes in functional brain networks during exploration and exploitation

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BACKGROUND

- What mechanisms allow the brain to rapidly shift between different cognitive processes and maintain a balance between the stability necessary to support ongoing behavior and the flexibility necessary to adapt to new exigencies?
- Cognitive performance appears to be supported by large-scale, dynamic changes in functional brain connectivity [1,2].
- Neural modulation of norepinephrine (NE) may help facilitate these changes [3,4].
- Here we probed the relationship between NE and network dynamics within an exploration/exploitation task, a type of task that is known to induce changes in NE activity as measured by pupil diameter [5].

HYPOTHESES

Both more integrated brain network states and moderate NE activity facilitate focused task performance (exploitation), while less integrated states and high NE activity lead to distraction/error (exploration) [2,6]. Therefore we expect:
- Across blocks, average baseline pupil diameter will be associated with less integration between modules.
- Within blocks, network integration will be correlated with behavior (exploitative vs. exploratory) and pupil diameter.

METHODS

Subjects

N=9 completed 4 fMRI runs (80 trials/run) of an isoluminant version of the Leapfrog bandit task [7] while undergoing continuous pupillometry.

Leapfrog Bandit

A simplified bandit task
- Two armed
- Deterministic reward
- Fixed distance between options
- Options “take turns” being the best, changing based on underlying PNE
- Goal: Always choose the option that is currently the best. This requires balancing exploration and exploitation
- Two Block types: Low volatility (PNE = 0.05), High volatility (PNE = 0.20)
- Volatility level alternates between runs, order counterbalanced across subject

Network Construction

RESULTS

Exploratory choice
- Subjects are sensitive to volatility condition, demonstrating increased exploration in high volatility vs. low volatility blocks (t(8) = 3.11, p = .01)
- However the exploration difference is less than might be expected given the volatility difference (mean f flips: MNE = 0.45 (0.10), MNElst = 0.32 (0.09), t(8) = 8.27, p = .003).

Pupil-linked Arousal

Explore vs. Exploit Trials
- Post-choice pupil dilation (max deviation from pre-trial baseline) is reliably larger on explore trials than exploit trials (Mexploit = 0.59 (0.16), Mexploit = 0.32 (0.09), t(8) = 4.27, p = .003).

Pupil-linked Arousal and Integration

Block level
- Across all data, average baseline pupil diameter is negatively related to block-wise brain network integration (r = -.36).
- This relationship is reliable across subjects (t(8)) = -3.82, p = .005.

Peri-explore (24s sliding window)
- Identifiability of exploration-induced changes: The quadratic trend for peri-explore pupil is reliable at a .05 < p < .10 level (F(1,8) = 3.75, p = .089). The apparent dip in integration around exploration is not significant.

Nonlinear effects?
- Pupil-integration correlations were computed in 20 window sliding windows, demonstrating a large variance across all data [M = .03 (0.48)].
- Block-wise average correlations are related to average baseline pupil diameter (r = -.37).
- This relationship is reliable across subjects (t(8)) = -2.83, p = .02.

SUMMARY & CONCLUSIONS

- We replicate the pupil responses to exploratory choice found in [5].
- We confirm our prediction of decreased integration with increasing baseline pupil diameter at the block level.
- Within block, there is a nonsignificant dip in integration during exploration. This effect may not be robust due to a potential nonlinear relationship between integration and pupil diameter that appears dependent on baseline pupil diameter. Our window size may also be too large.
- Overall, these results support a role for NE in brain network reconfiguration.

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REFERENCES