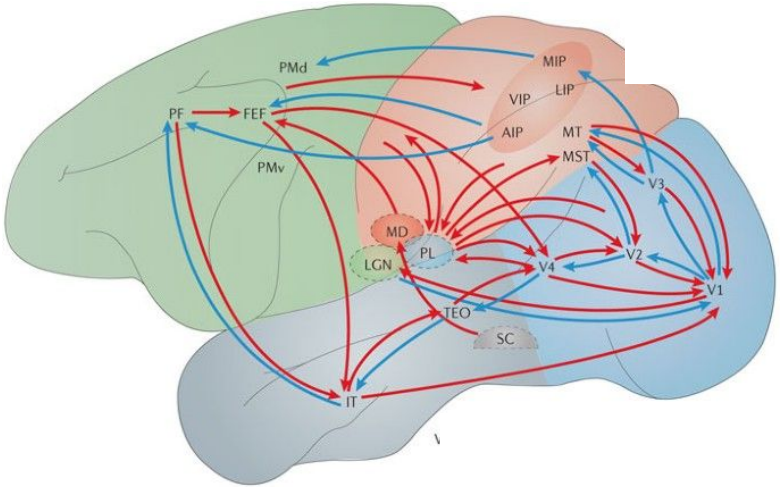
Irreversibility of EEG Data in Perceptual Decision Making

Master's Thesis:

Jake Tear



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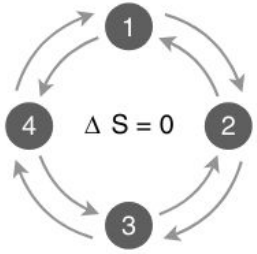
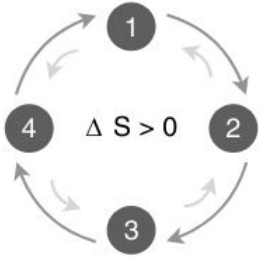
What is Irreversibility?

Systems in equilibrium =
no net probability of a state transition.



(Reversible in Time)

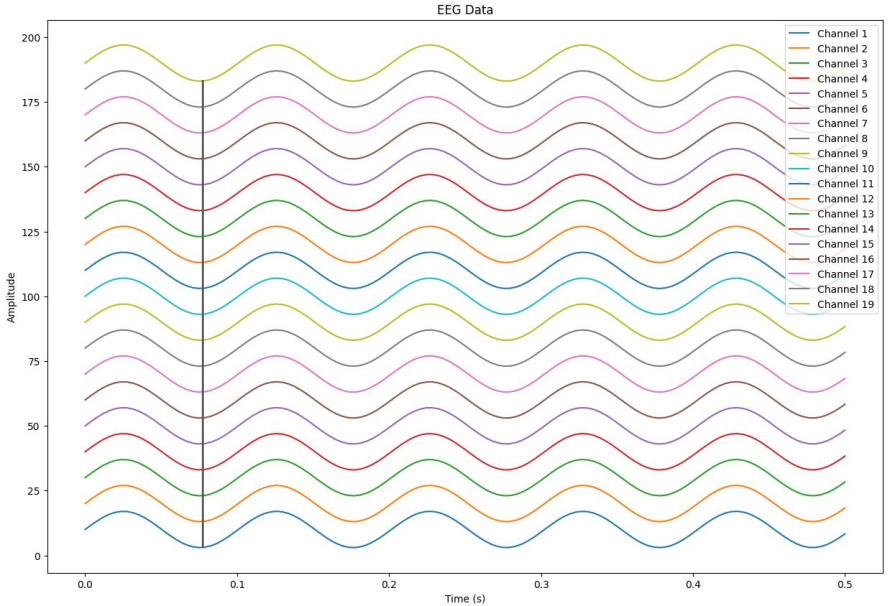
Non-equilibrium =
directionality in state transitions.



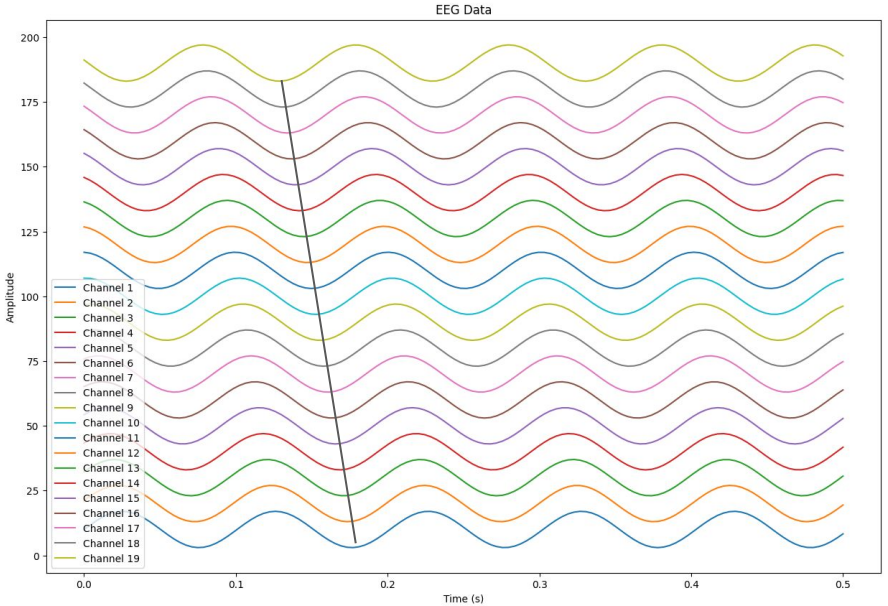
(Irreversible in Time)

Irreversibility simple example:

Reversible



Irreversible



High Irreversibility = hierarchical interactions = more directed information flow

Irreversibility using the INSIDEOUT Framework:

Time-shifted correlations on forward and reversed time-series:

$$FS_{forward,ij}\left(\triangle t\right) = -\frac{1}{2}\log\left(1 - < x_i\left(t\right), x_j\left(t+\triangle t\right) >^2\right)$$

$$FS_{reversal,ij}\left(\triangle t\right) = -\frac{1}{2}\log\left(1 - < x_i^{(r)}\left(t\right), x_j^{(r)}\left(t+\triangle t\right) >^2\right)$$

The squared difference between all the pairwise correlations:

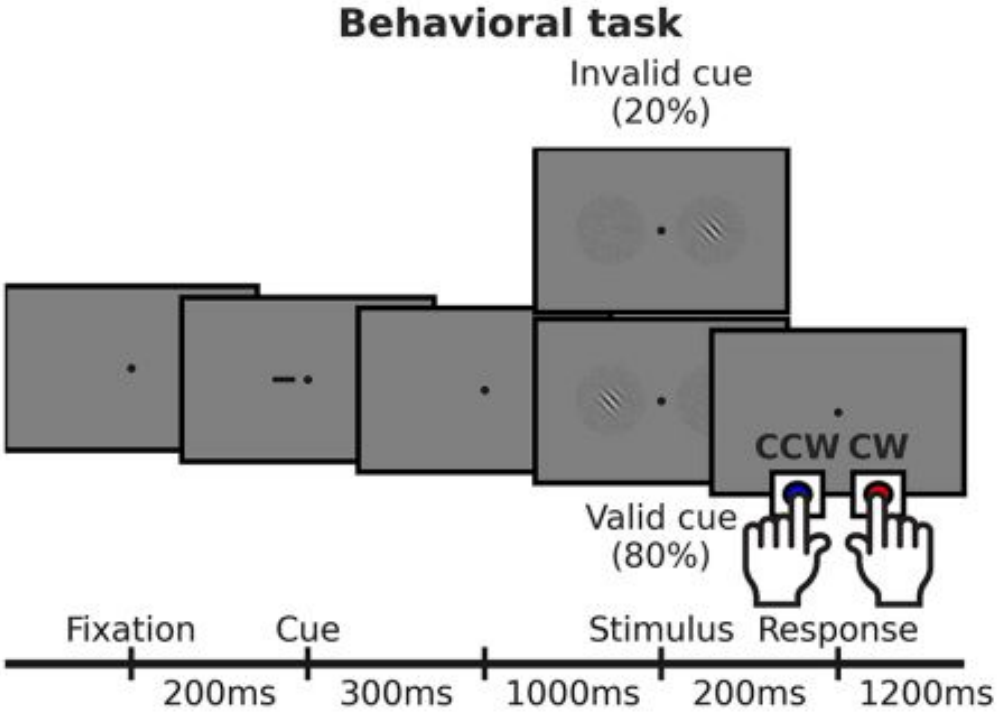
$$FS_{diff},ij = \left(FS_{forward},ij\left(T\right) - FS_{reversal},ij\left(T\right)\right)^2$$

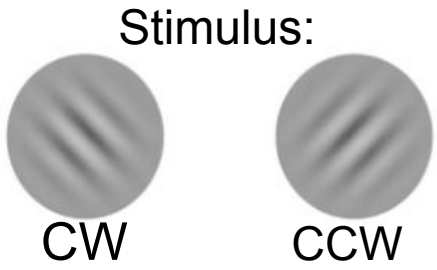
Mean of those pairwise values gives us one global irreversibility value:

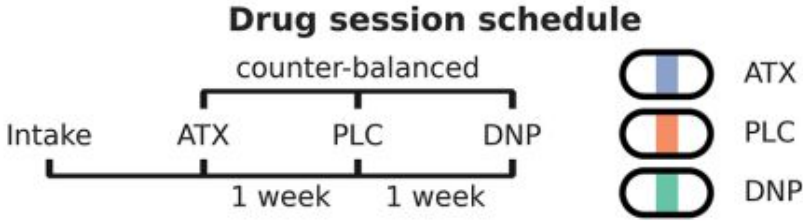
$$I_i = \frac{1}{n}\sum_j \left(FS_{\text{forward}}ij(T) - FS_{\text{reversal}}ij(T)\right)^2.$$

Perceptual Decision Making

Decide whether a stimulus is oriented clockwise or counter-clockwise.







Previous Work on Irreversibility

1) Irreversibility was **higher** in wakefulness than both sleep and anaesthesia.

2) Irreversibility was **higher** in healthy controls compared with Alzheimer's.

3) Irreversibility was **higher** in seven tasks compared to rest.

4) Irreversibility was **higher** in controls vs. minimally conscious vs. unresponsive.

5) Irreversibility was **lower** in movie watching compared to resting state.

Relevant to the effects of Atomoxetine:

6) Irreversibility was **lower** in psychedelics compared to placebo.

Exploratory Results

1) **Irreversibility relationship to task performance**
    a) **Pre-stimulus irreversibility**-- Mid levels of irreversibility are optimal (Yerkes Dodson Law).
    b) **Post-stimulus irreversibility**-- More irreversibility is beneficial during stimulus processing.
    c) **Post-stimulus CPP irreversibility**-- Related to a neural marker for evidence accumulation.

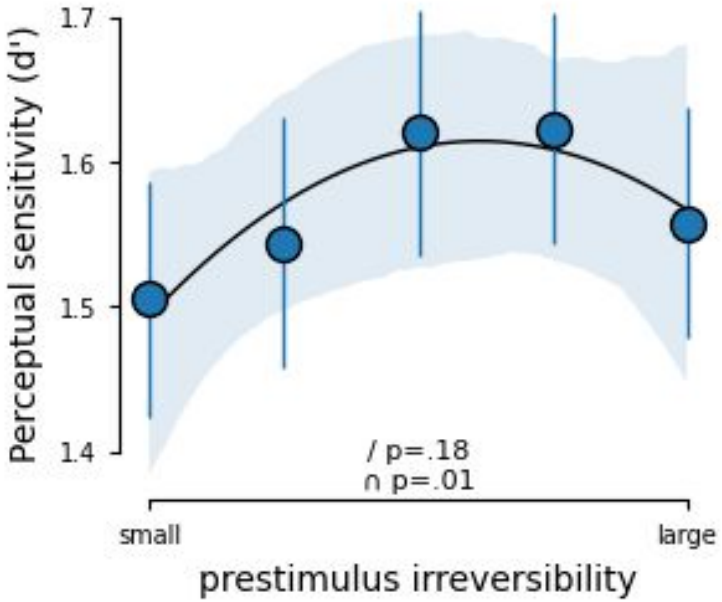
2) **Changing irreversibility to task demands** -- Pre-stimulus is more variable than post-stimulus.

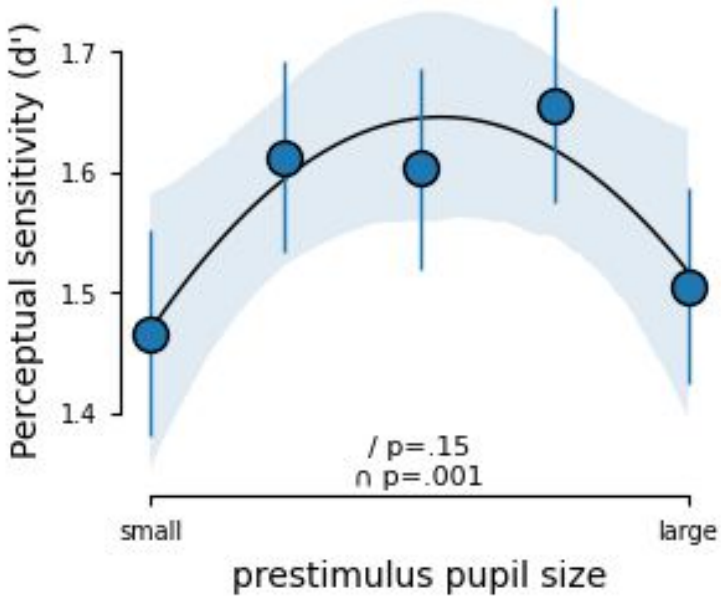
3) **Drug effects on irreversibility** -- Lowest irreversibility in Atomoxetine, then Placebo, then Donepezil.

4) **Irreversibility and other markers of brain state-- Pupil Size and Alpha Power**

1a) Pre-stimulus Irreversibility and Performance (d')

Prestimulus Irreversibility (left) shows an Inverted U relationship to performance, similar to prestimulus pupil size.

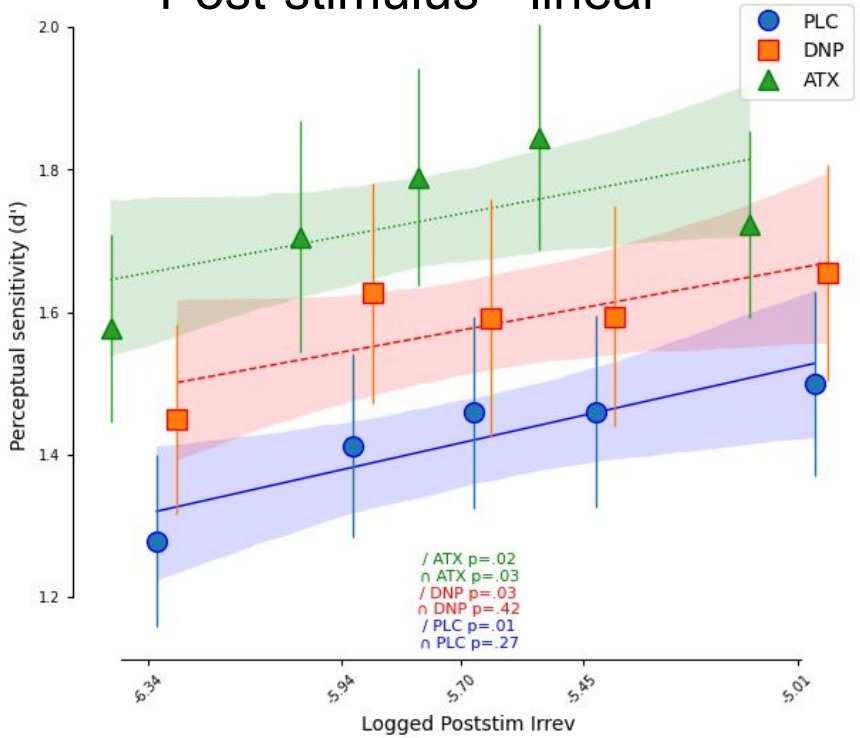




1b) Post-stimulus Irreversibility and Performance (d')

Hypothesis: During stimulus processing we expected higher asymmetric information flow (irreversibility) = better processing. Expected a linear relationship to performance.

Result: Post-stimulus-- linear



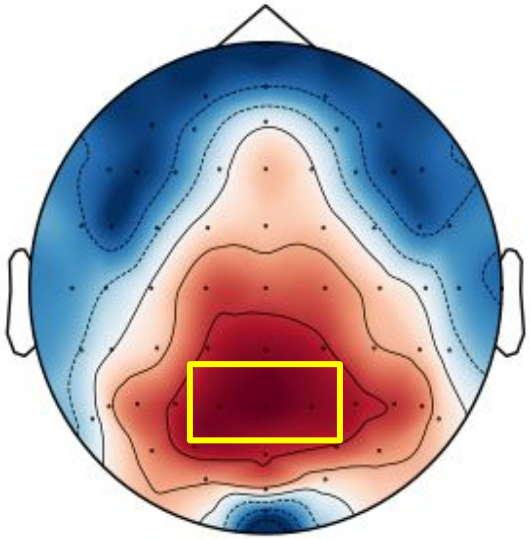
Hypothesis supported

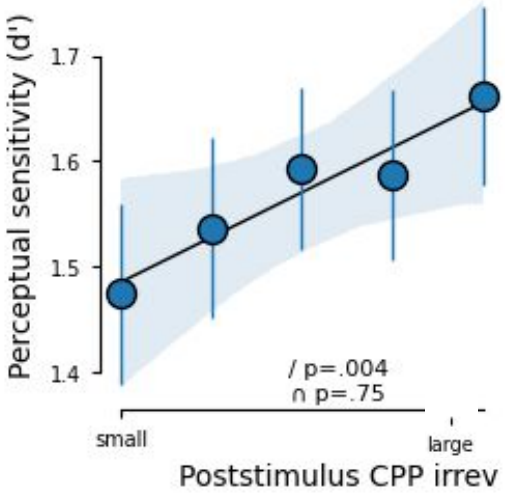
1c) CPP Electrodes in Post-stimulus

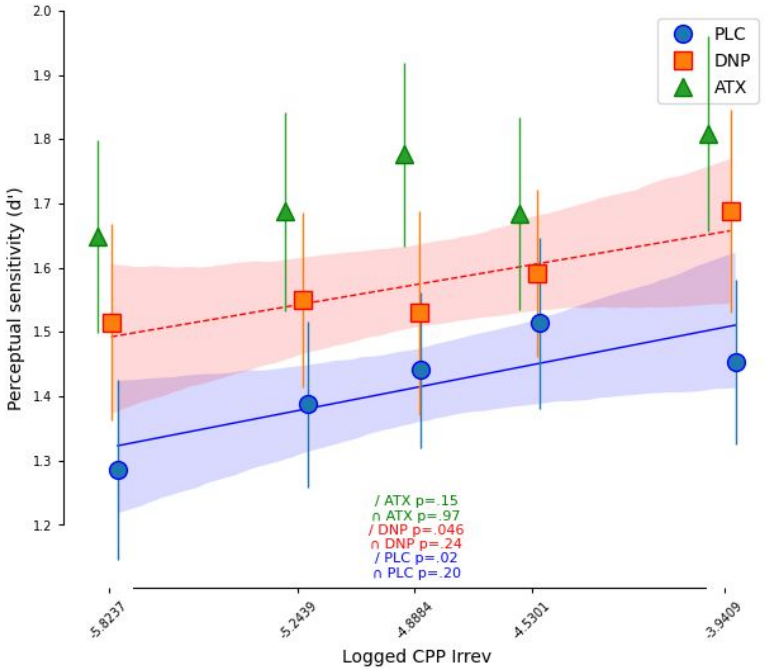
Hypothesis: We expect the previous relationship to hold true for irreversibility in electrodes CPz, Cp1, and Cp2 (CPP).

The CPP has been shown to reflect evidence accumulation in a perceptual decision.

Result:

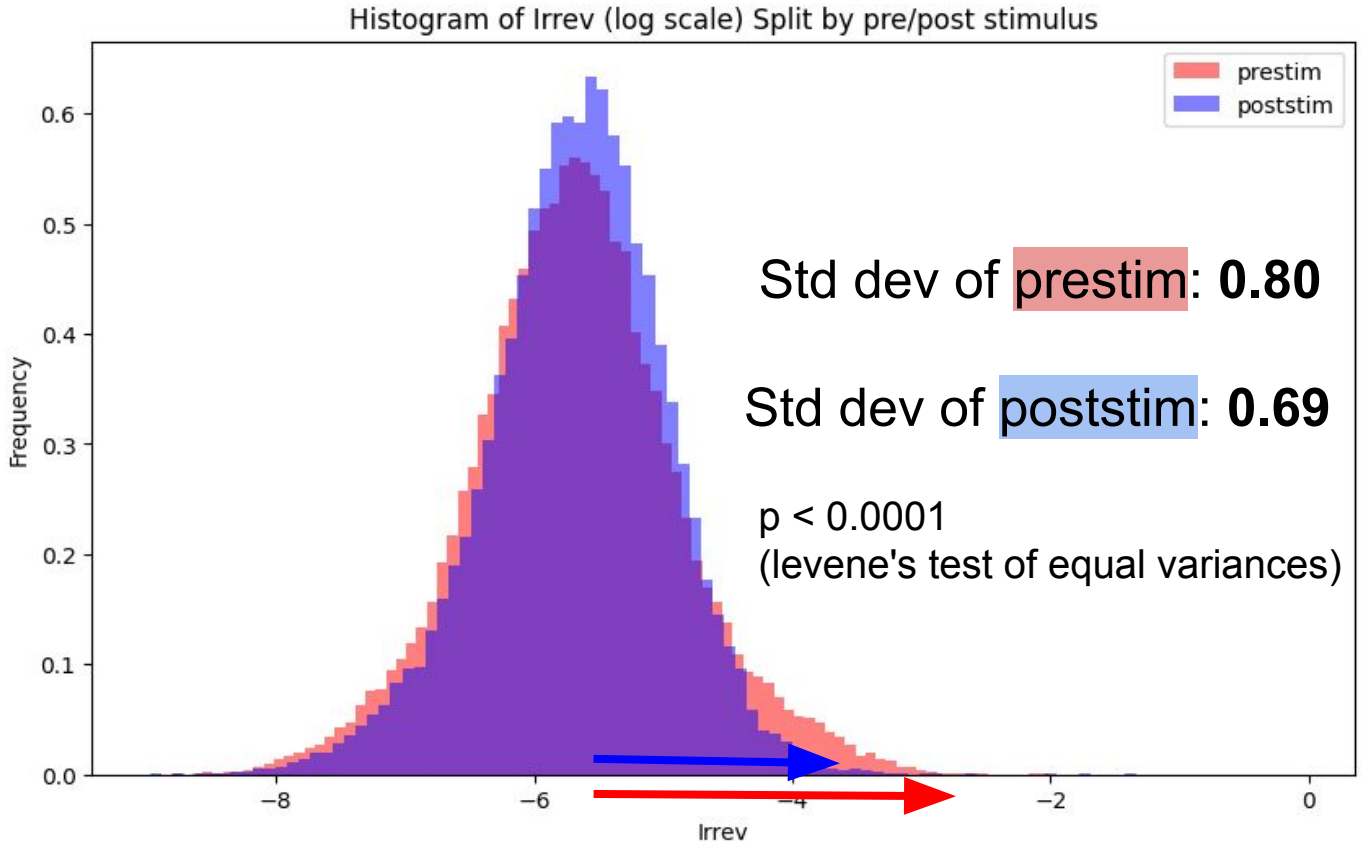




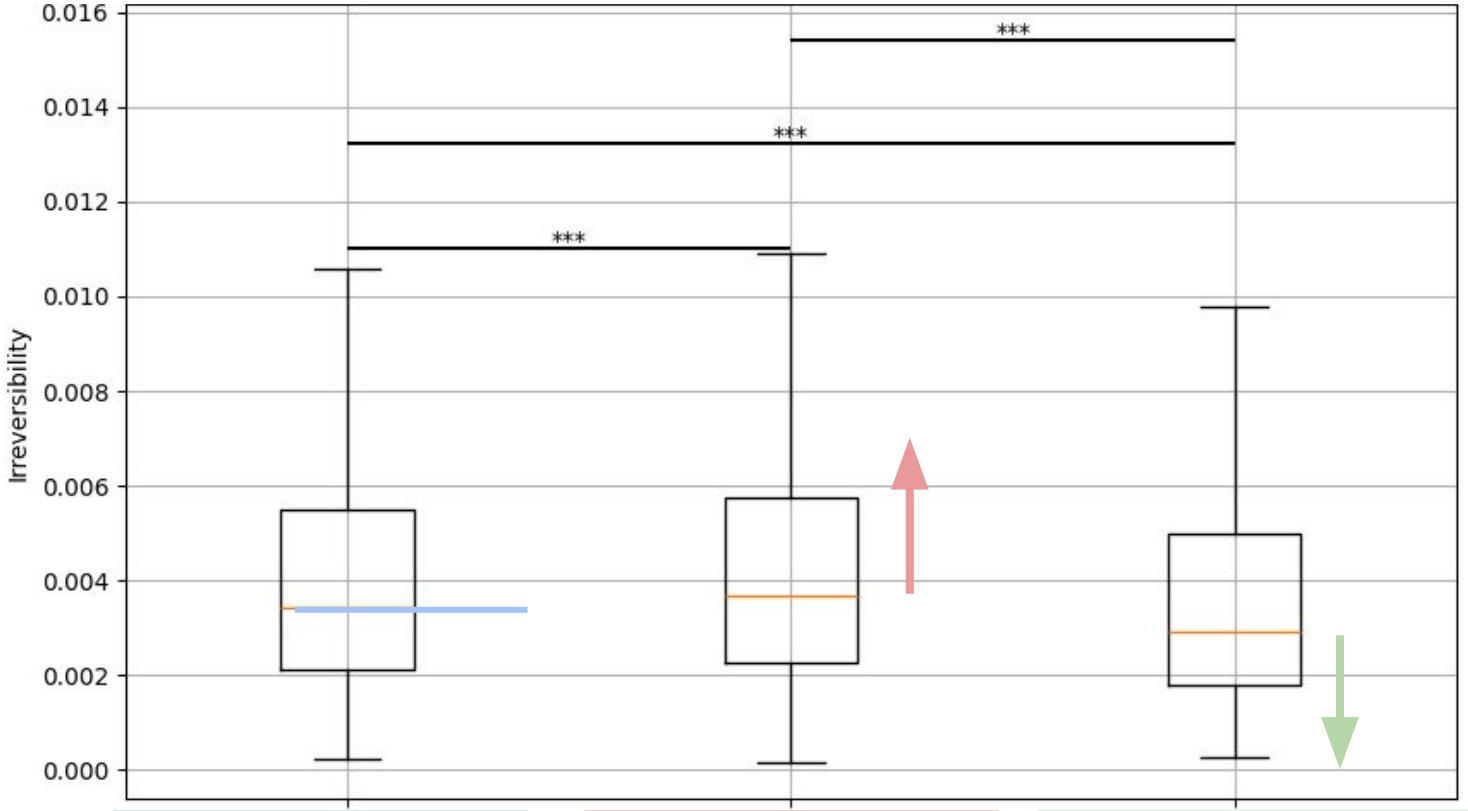


2) The variability of irreversibility changes to task demands

Less variability during post-stimulus processing (all drugs)--



3) Drug Effects on Irreversibility

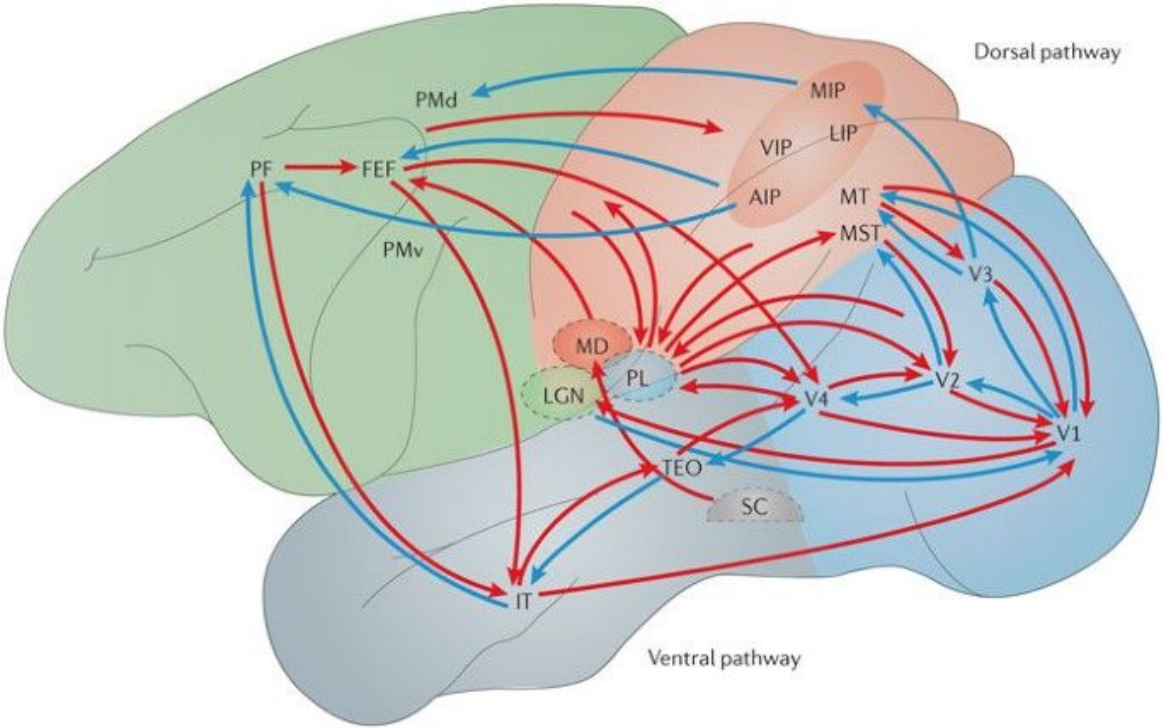


Placebo = middle

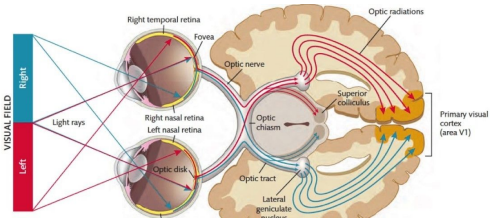
Donepezil = high

Atomoxetine = low

3) Atomoxetine: Balanced information flow = lower irreversibility



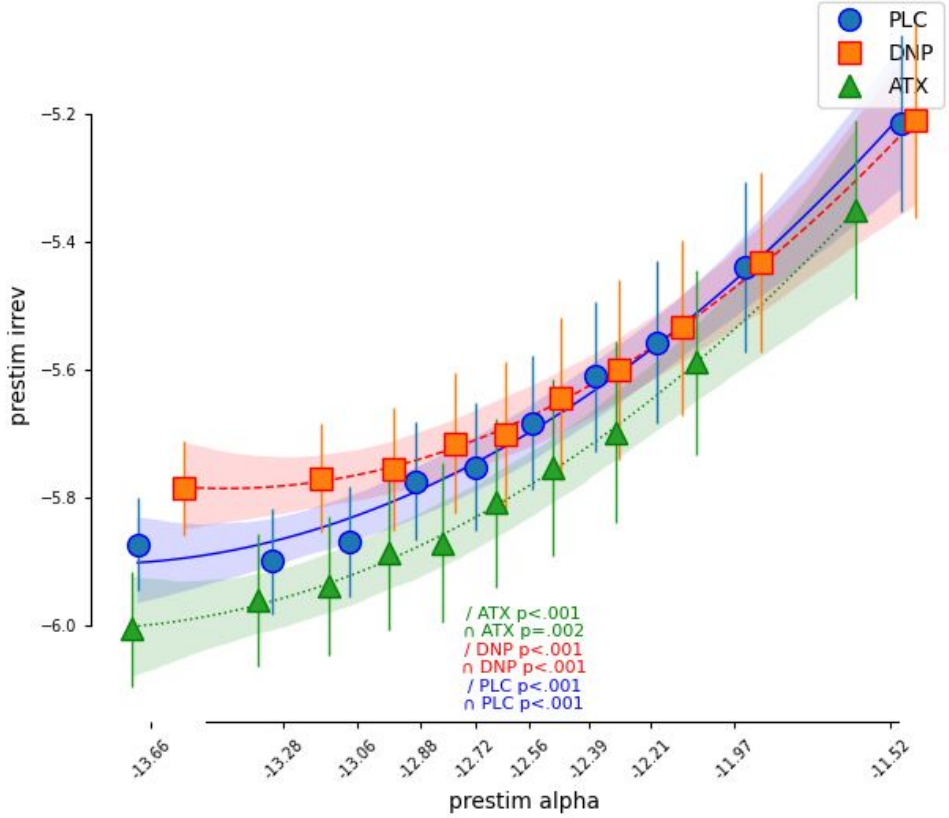
During **task**, asymmetry driven by bottom up flow

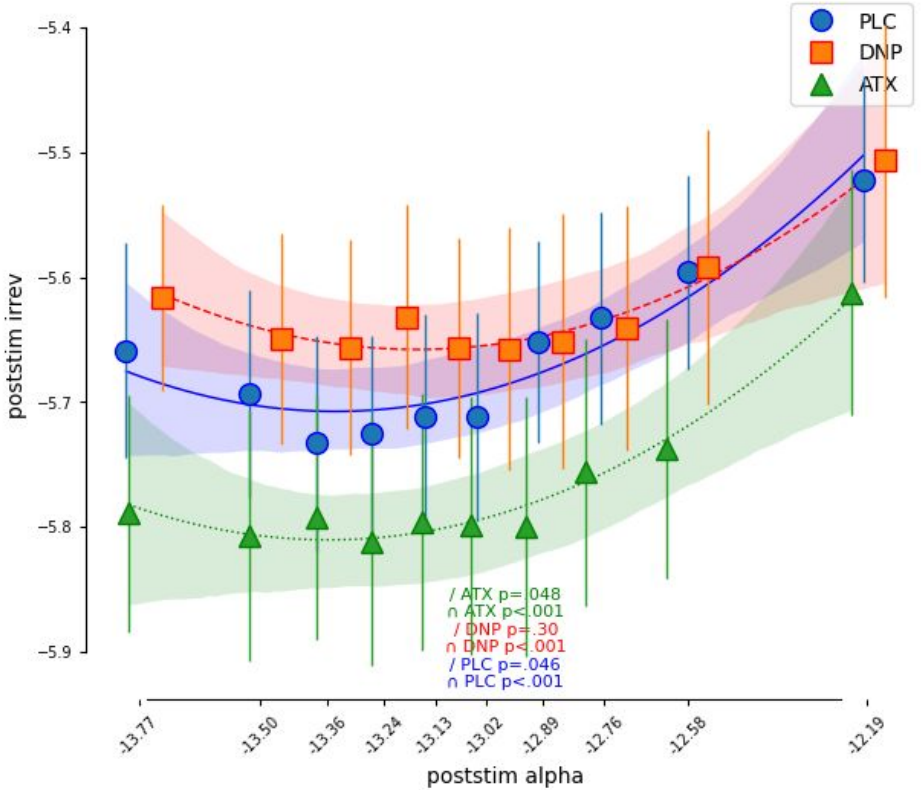


During **rest**, asymmetry driven by top-down flow

It's likely **context dependent**.

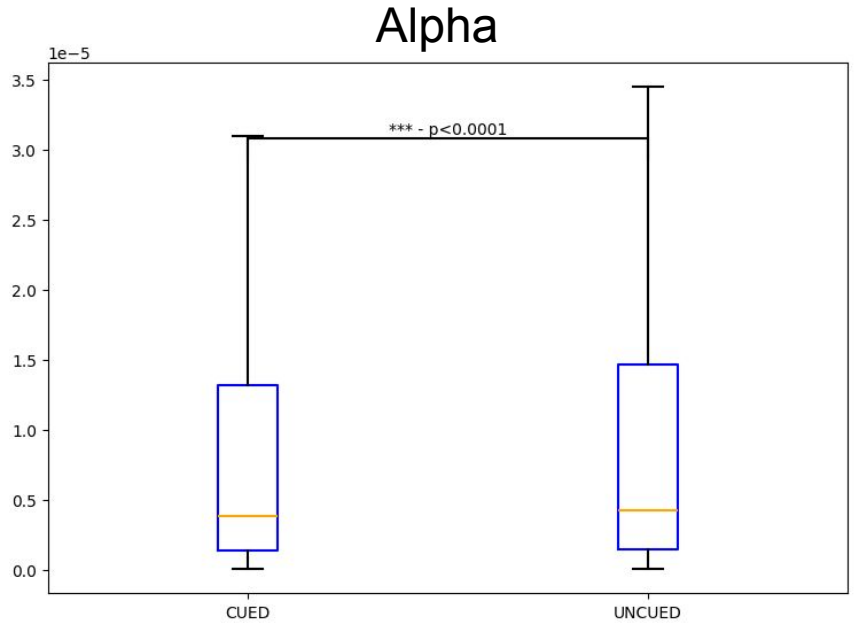
4a) Average Alpha Power X Global Irreversibility (logxlog)

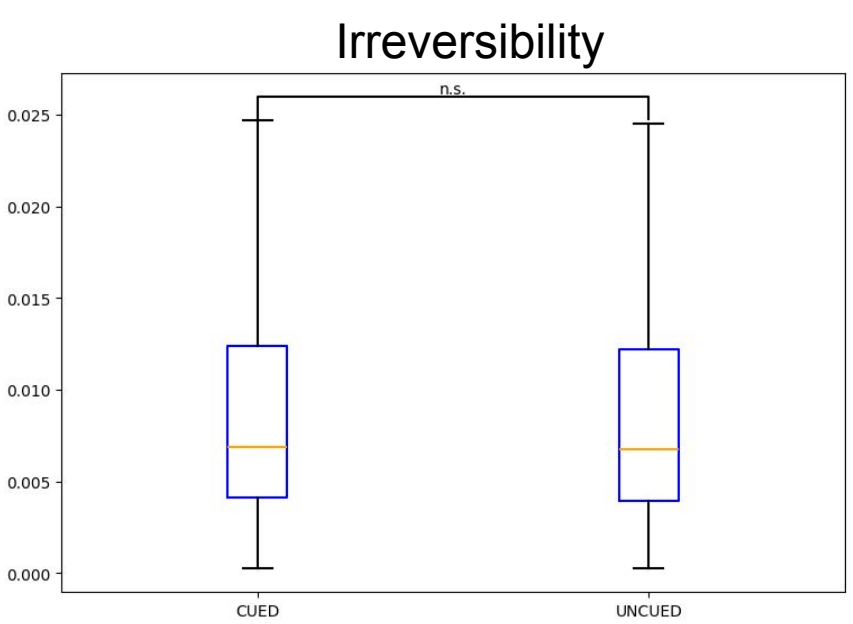


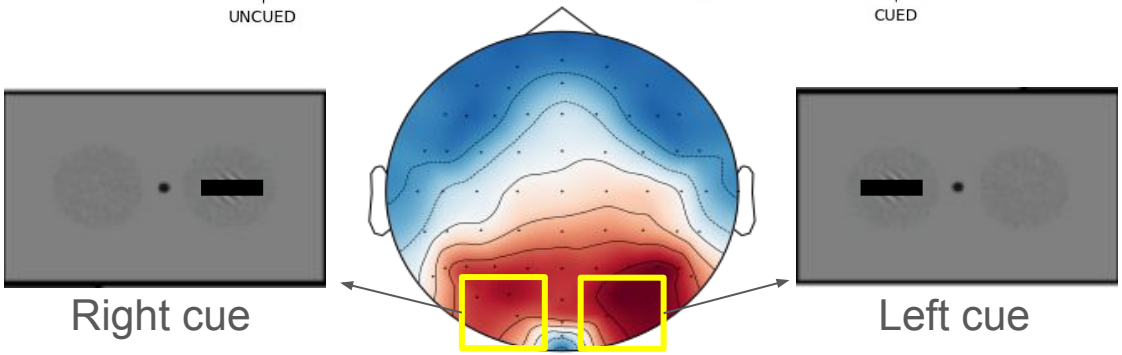


Relationship between alpha power and irreversibility changes pre to post.

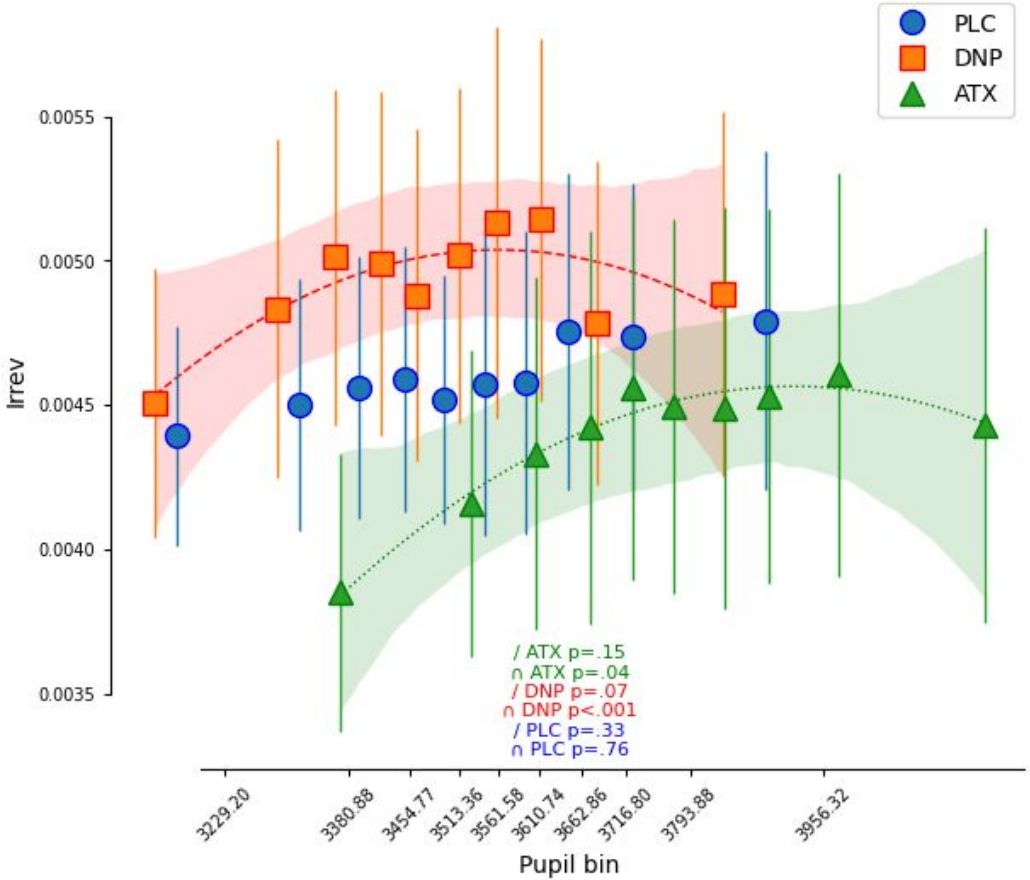
4b) Functional difference between alpha and irreversibility

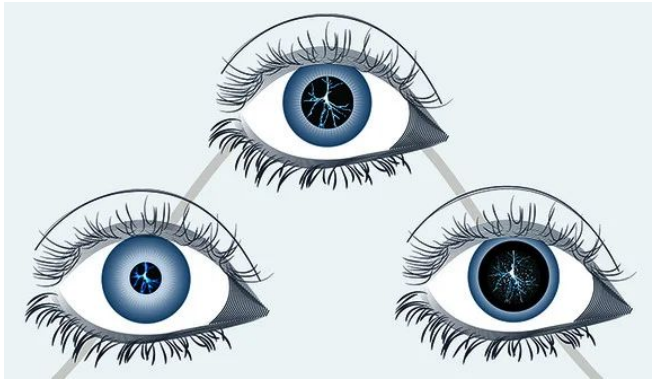






4c) Pre-stimulus Pupil Size X Irreversibility





But, the relationships between pupil size, alpha power, network dynamics and perception are still not so clear.

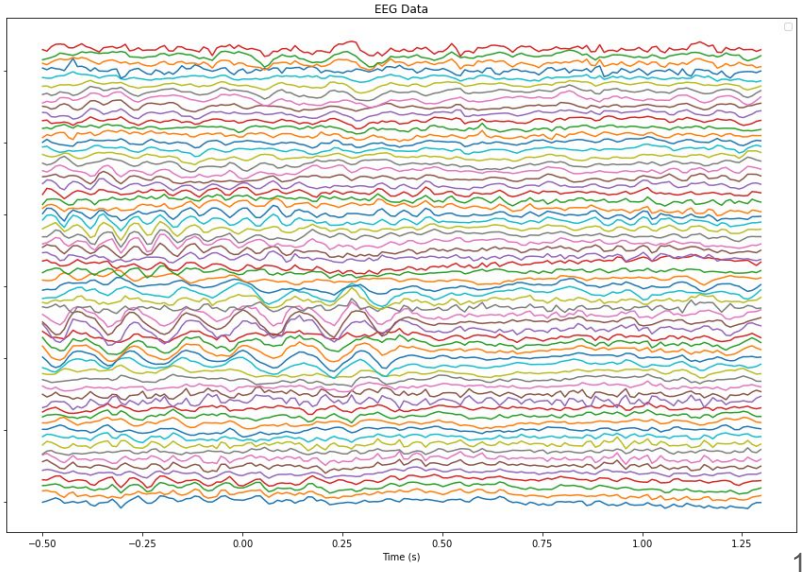
Summary & Limitations

1) Window size -- We used 500 ms epochs. Other studies used much longer windows of continuous data.

2) Incoming vs. Outgoing information flow.

INCOMING

OUTGOING



Thank you all for such an amazing Masters!