A spatio-temporal analysis on neural correlates of intertemporal choice

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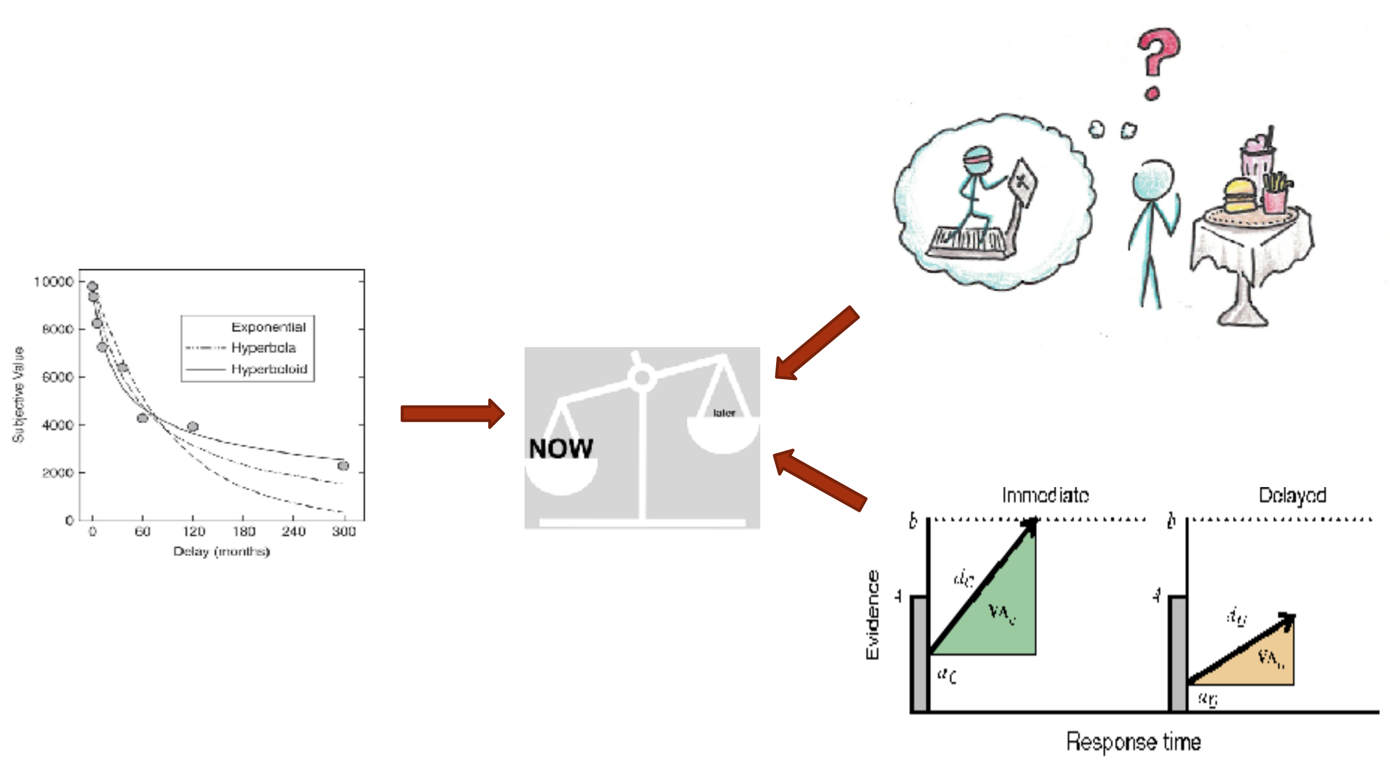
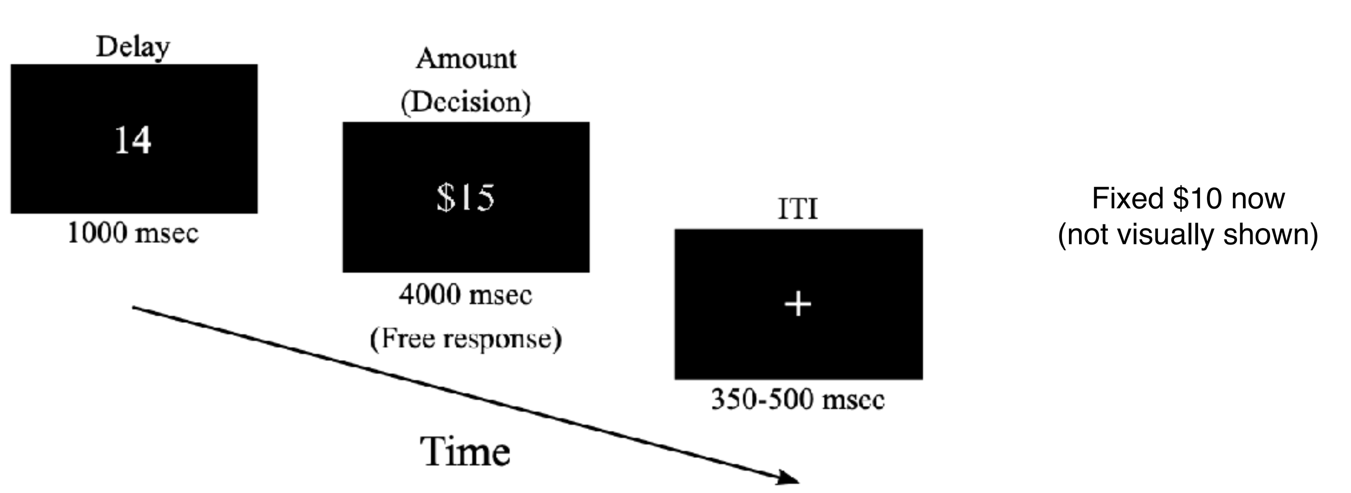
Background

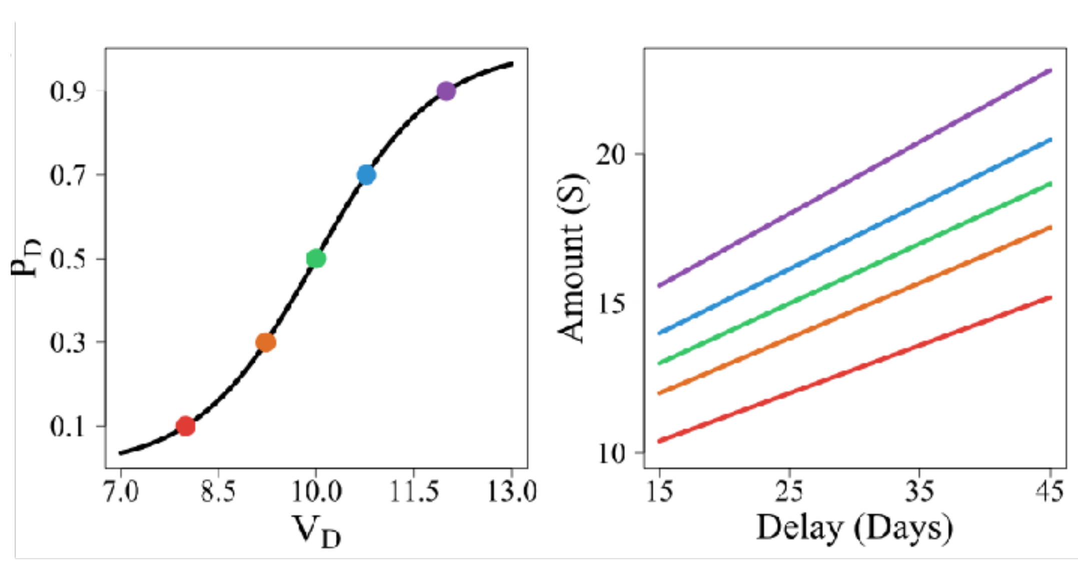
- Intertemporal choice requires a tradeoff between time delay and the amount of the reward.
- Three cognitive processes assumed to subserve intertemporal choice decision making: subjective valuation, self-control, and value accumulation.
- This study was focused on the underlying neural mechanism of value accumulation, and how it interacts with subjective valuation and self control.



EEG Experiment



- Participants chose between a fixed immediate option $10 now and a delayed option.
- The delayed time and dollar amount were presented sequentially to reduce eye movements.



- We manipulated five different probabilities of choosing delayed options for each subject via a hyperbolic discounting function

$$V_D = \frac{r}{1+kt}$$

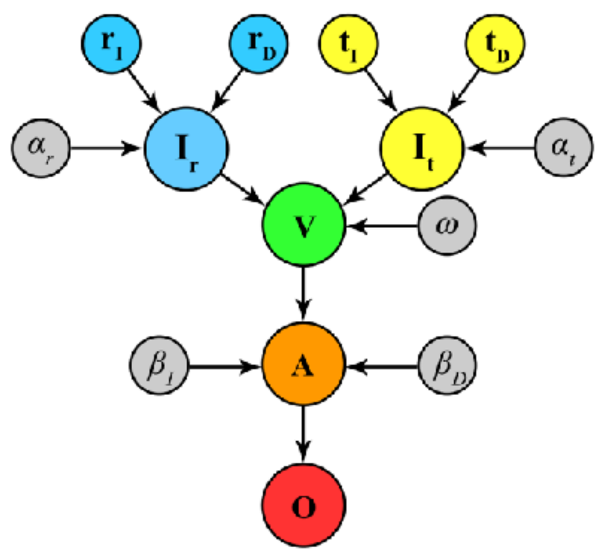
and a softmax function

k: discounting parameter
m: sensitivity parameter

$$P_D = \frac{1}{1+e^{-m(V_D - V_I)}}$$

Computational Model

- We fit a computational model to the choice and response time data (Turner et al., 2019)



- **Subjective Value Transformation**

$$r_I^* = r_I^{\alpha_r};\ r_D^* = r_D^{\alpha_r}$$
$$t_I^* = t_I^{\alpha_t};\ t_D^* = t_D^{\alpha_t}$$

- **Selective Attention** $w(t) \sim \text{Bernoulli}(\omega)$

$$V_I(t) = w(t) r_I^{\alpha_r} + [1-w(t)] t_D^{\alpha_t}$$
$$V_D(t) = w(t) r_D^{\alpha_r} + [1-w(t)] t_I^{\alpha_t}$$

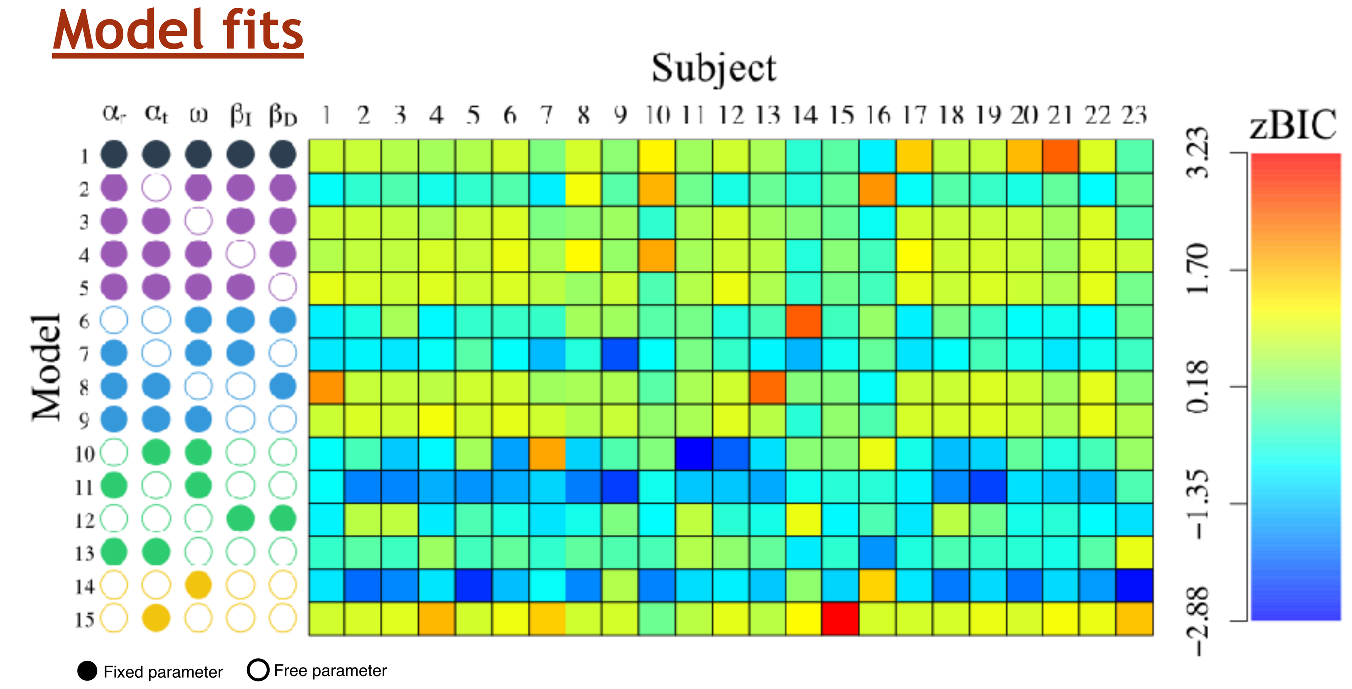
Within the first 1000ms, $V_I(t) = t_D^{\alpha_t}$, $V_D(t) = t_I^{\alpha_t}$

- **Stochastic Evidence Accumulation** $\delta(t) \sim N(0,\sigma)$

$$A_I(t) = A_I(t-1) + [V_I(t) - \lambda_I A_I(t-1) - \beta_I A_D(t-1)]\epsilon + \delta(t)\sqrt{\epsilon}$$
$$A_D(t) = A_D(t-1) + [V_D(t) - \lambda_D A_D(t-1) - \beta_D A_I(t-1)]\epsilon + \delta(t)\sqrt{\epsilon}$$

- Monetary reward and time delay are subjectively transformed into a subjective value through a power function.
- Time delay and the amount of reward are considered as two feature dimensions. A selective attention mechanism decides which feature dimension is sampled at each time moment. As time delay information is presented in the first 1000ms, there is no selective attention within the first 1000ms.
- Evidence at each time point is accumulated by a stochastic evidence accumulation process, including nonlinear processes such as information decay and lateral inhibition.

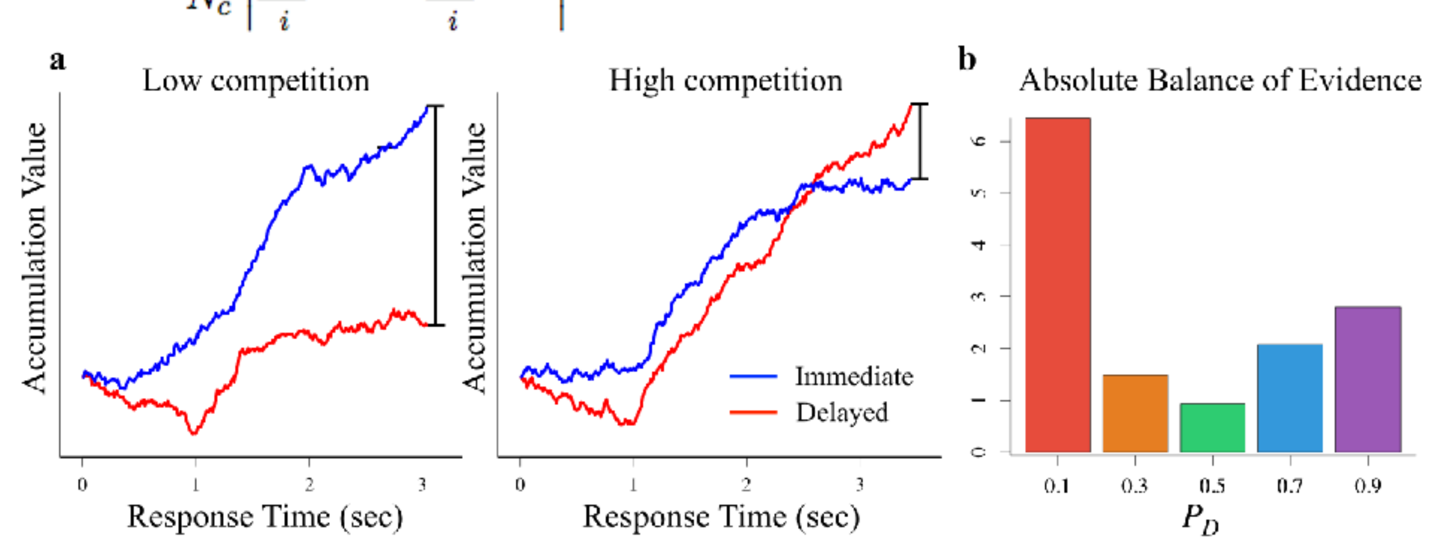
Model fits



- Each model configuration was fit to each subject with hierarchical Bayesian modeling.
- The zBIC measures how each model performs: lower value indicates better model fits.
- The model 11 has the best-fit with 3 free parameters: power transformation of time delay, and two lateral inhibition parameters.

Absolute balance of evidence

$$\text{ABOE}_c = \frac{1}{N_c}\left|\sum_i^{N_c} A_{Ii} - \sum_i^{N_c} A_{Di}\right|$$



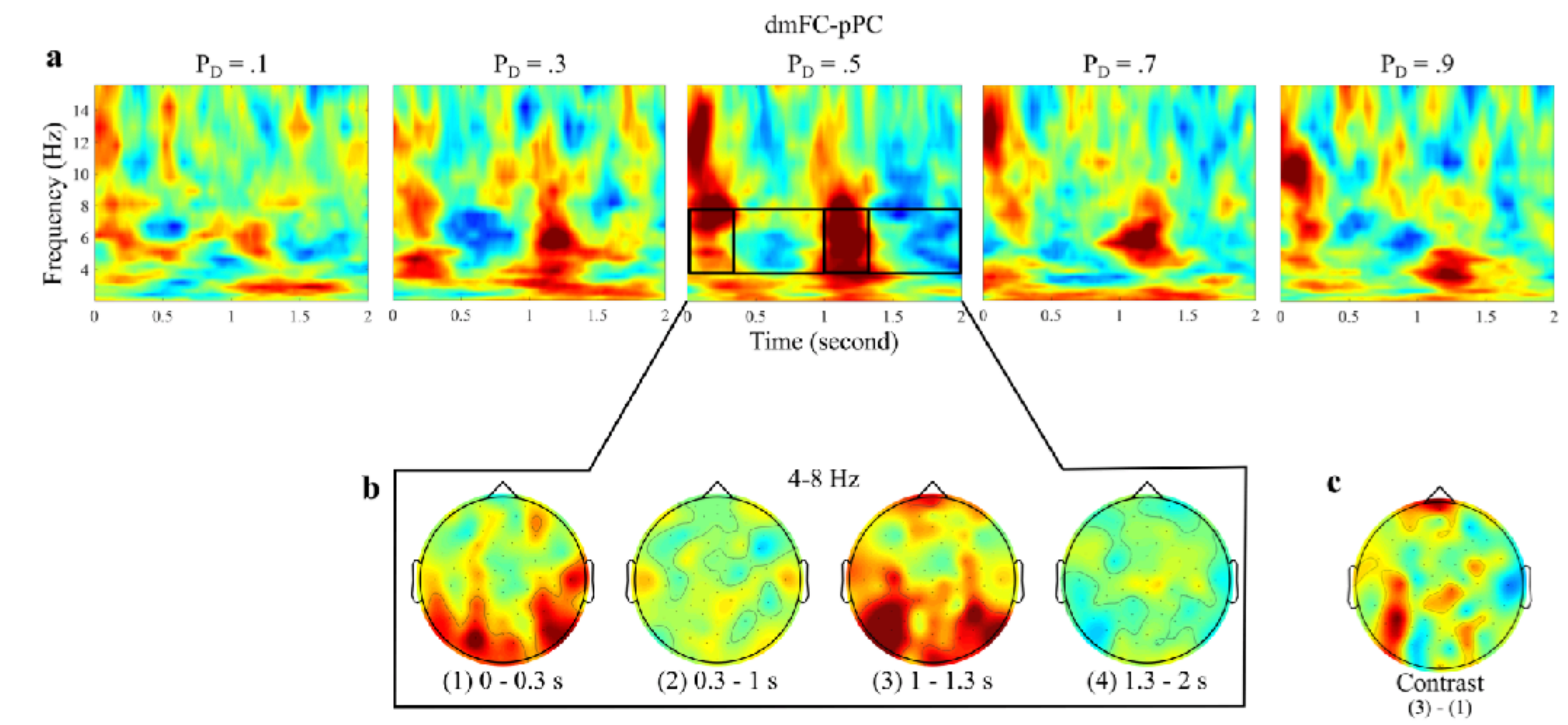
- We simulated the best model using the estimated parameters.
- The measure of absolute balance of evidence measures the distance between the two accumulators at the choice time: higher competition is associated with smaller value of absolute balance of evidence.

EEG - phase-based functional connectivity

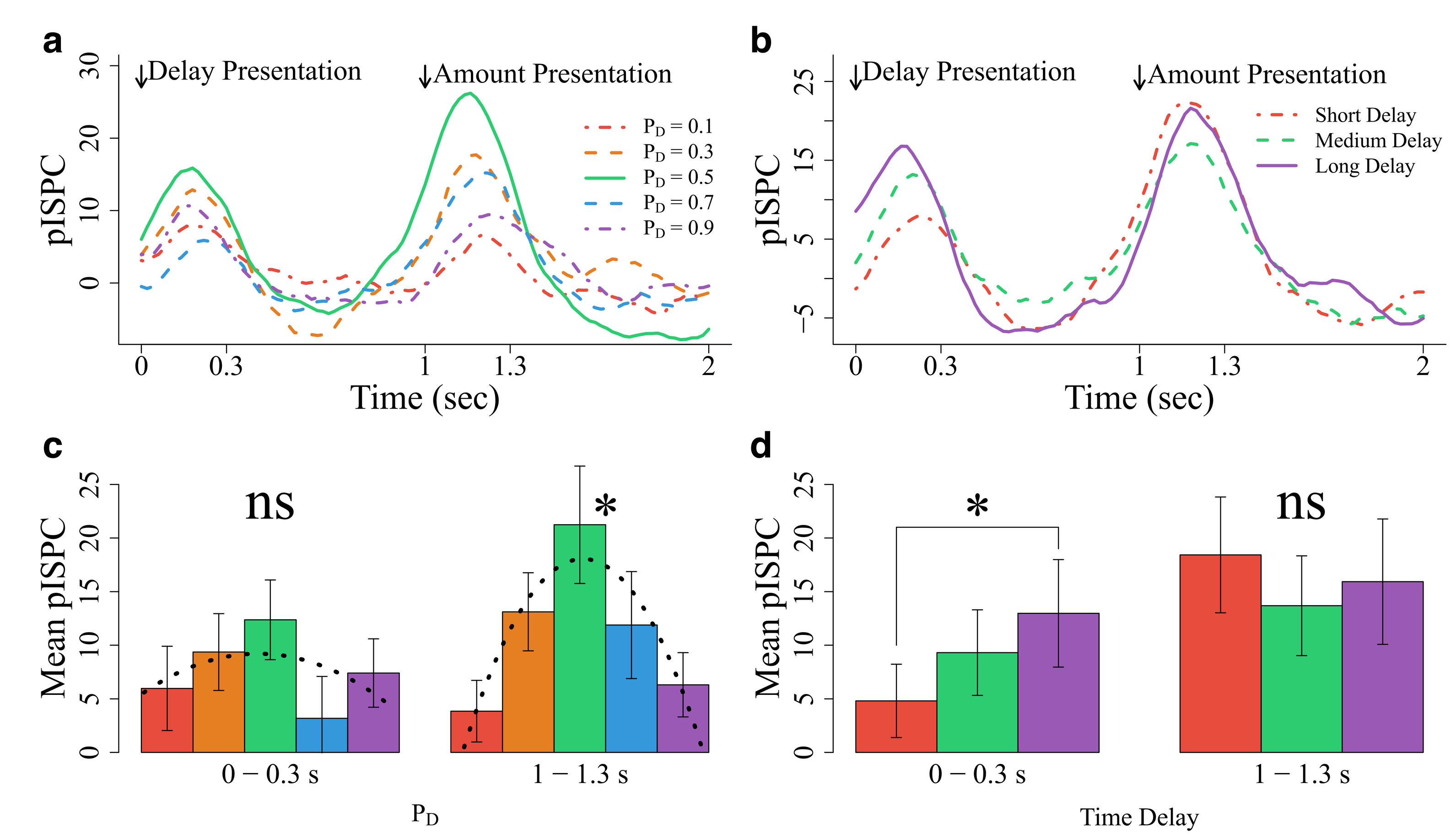
- We measured functional connectivity from EEG by computing inter-site phase clustering (ISPC)

$$\text{ISPC}_{k,j}(t) = \frac{1}{N}\left|\sum_{n=1}^{N} e^{-i(\phi_k(t,n) - \phi_j(t,n))}\right|$$

- ISPC measures the consistency of the difference of phase angles between a pair of electrodes k and j
- N: number of trials
- $\phi_k(t,n)$: instantaneous phase angle of electrode k in trial n at time t



- ISPC increases from PD condition 0.1 to 0.5, and decreases from 0.5 to 0.9.



- Given that only time delay was presented in the first 1s, we conducted another analysis to investigate the effect of time delay on the ISPC values.
- We found higher values of ISPC with increasing time delay within the time window of 0-.3s, but no significant result in the 1-1.3s time window.
- Altogether, we concluded that the ISPC is associated with value accumulation process.

Summary:

- We constructed a computational model to describe the time-course of information processing during intertemporal choice.
- We found that the phase-based functional connectivity between putative dmFC and pPC regions reflects value accumulation in intertemporal choice.

References:

- Rodriguez, C. A., Turner, B. M., Van Zandt, T., & McClure, S. M. (2015). The neural basis of value accumulation in intertemporal choice. *European Journal of Neuroscience*, *42*(5), 2179-2189.
- Turner, B. M., Rodriguez, C. A., Liu, Q., Molloy, M. F., Hoogendijk, M., & McClure, S. M. (2019). On the neural and mechanistic bases of self-control. Cerebral cortex, 29(2), 732-750.

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