

Midfrontal theta and pupil dilation track subjective conflict in value-based decisions

Modeling decision conflict during intertemporal choice

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INTRODUCTION

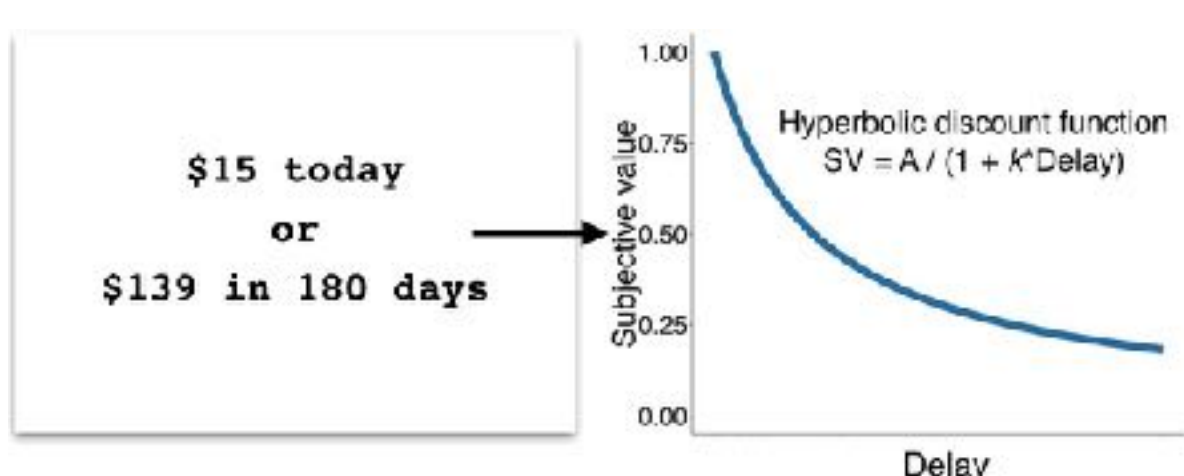
When choosing between equally attractive options, how is decision conflict represented neurophysiologically?

- Medial prefrontal regions, especially anterior cingulate:
- Represent and evaluate value of choices or courses of action¹.
 - Detect response conflict and uncertainty, which are reflected in EEG **frontal theta oscillations**^{2,3}.
 - Connect reciprocally with locus coeruleus/norepinephrine system that drives **pupillary responses**^{4,5}.

1. Do midfrontal theta power and pupil dilation track subjective conflict during economic choice?
2. Do they track conflict in a graded or all-or-none fashion?
3. What neural systems and processes are involved?

METHOD

Part 1: Initial online behavioral session. Fitted hyperbolic discount model of discounting separately to each participant's 144 intertemporal decisions.



Part 2: Laboratory EEG and eye tracking session. Generated a set of idiosyncratic delayed rewards separately for each participant based on their hyperbolic function (k parameter reflects impulsivity: larger k , more impulsive).

Example: $SV = A / (1 + 0.02 \cdot \text{Delay})$

Delayed rewards were presented at 10, 30, and 60 days. These delayed rewards had *subjective values* of 4, 7, 10, 12, 14, 15, 16, 18, 20, 23, and 26. Example delayed rewards ($k = 0.02$):

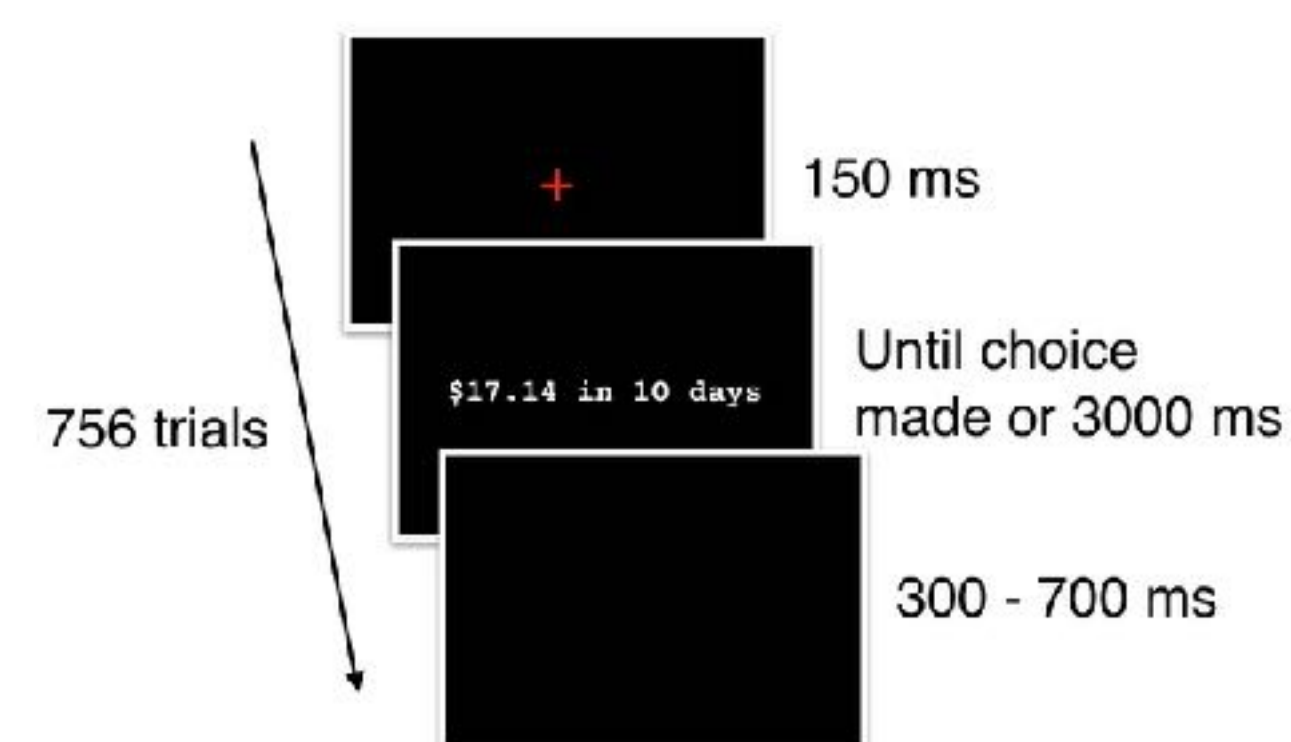
\$22.20 in 60 days (SV: 10)

Difference values (delayed reward SV minus 15) were -11, -8, -5, -3, -1, 0, 1, 3, 5, 8, and 11.

- 0: immediate reward = delayed reward (most conflicting decision)
- + values: immediate reward > delayed reward
- - values: delayed reward > immediate reward

Value difference was used to predict theta power and pupil dilation.

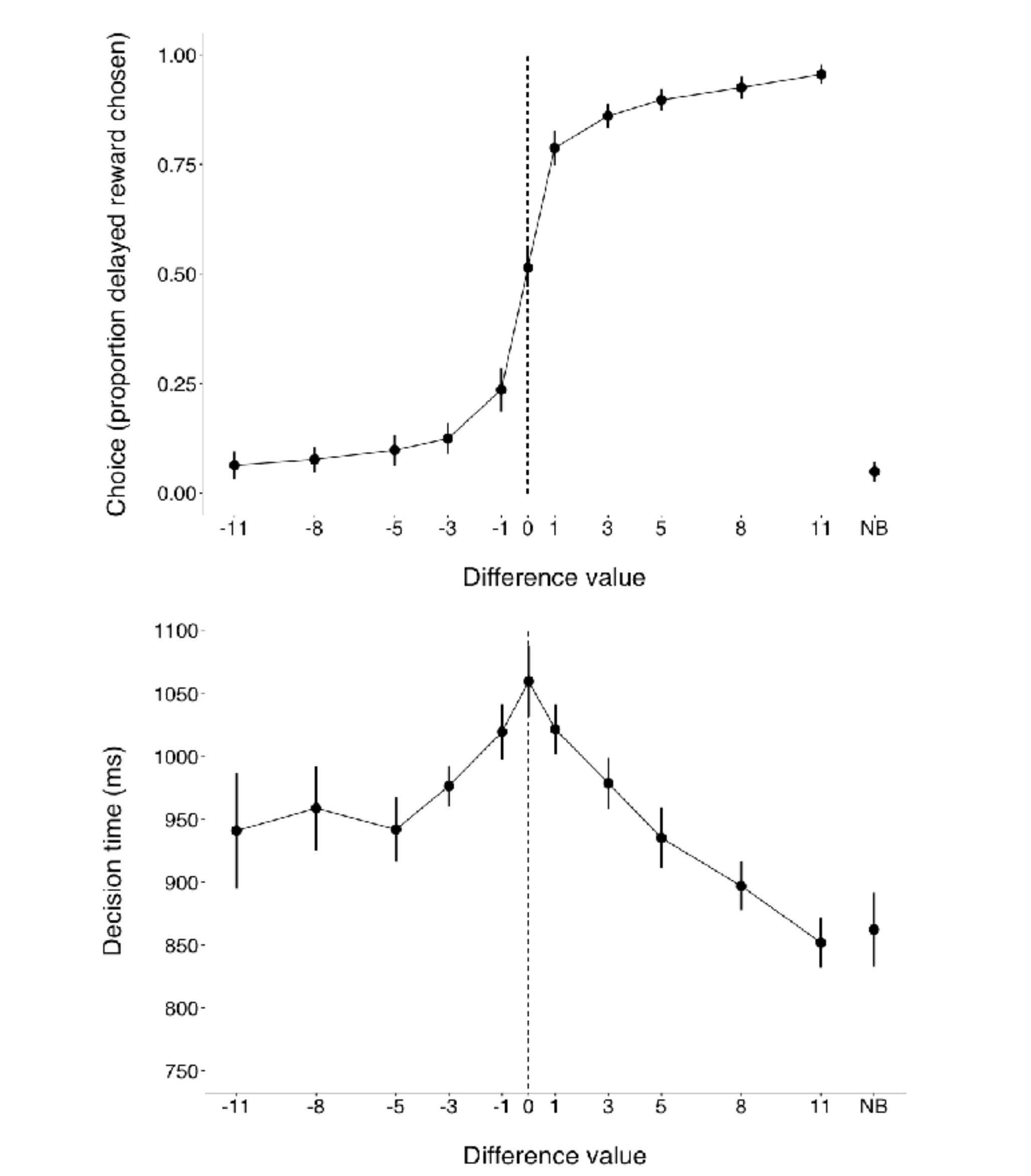
On each trial, participants chose between an immediate (always \$15 today—hence never shown visually) and a *participant-specific* delayed reward (e.g., \$17.14 in 10 days).



RESULTS

When participants ($n = 53$) chose the delayed reward 50% of the time (difference value = 0), decision time was slowest (high conflict). When they clearly preferred one reward over the other (e.g., difference value = 11, proportion delayed reward chosen = 89%), decision time was faster (low conflict).

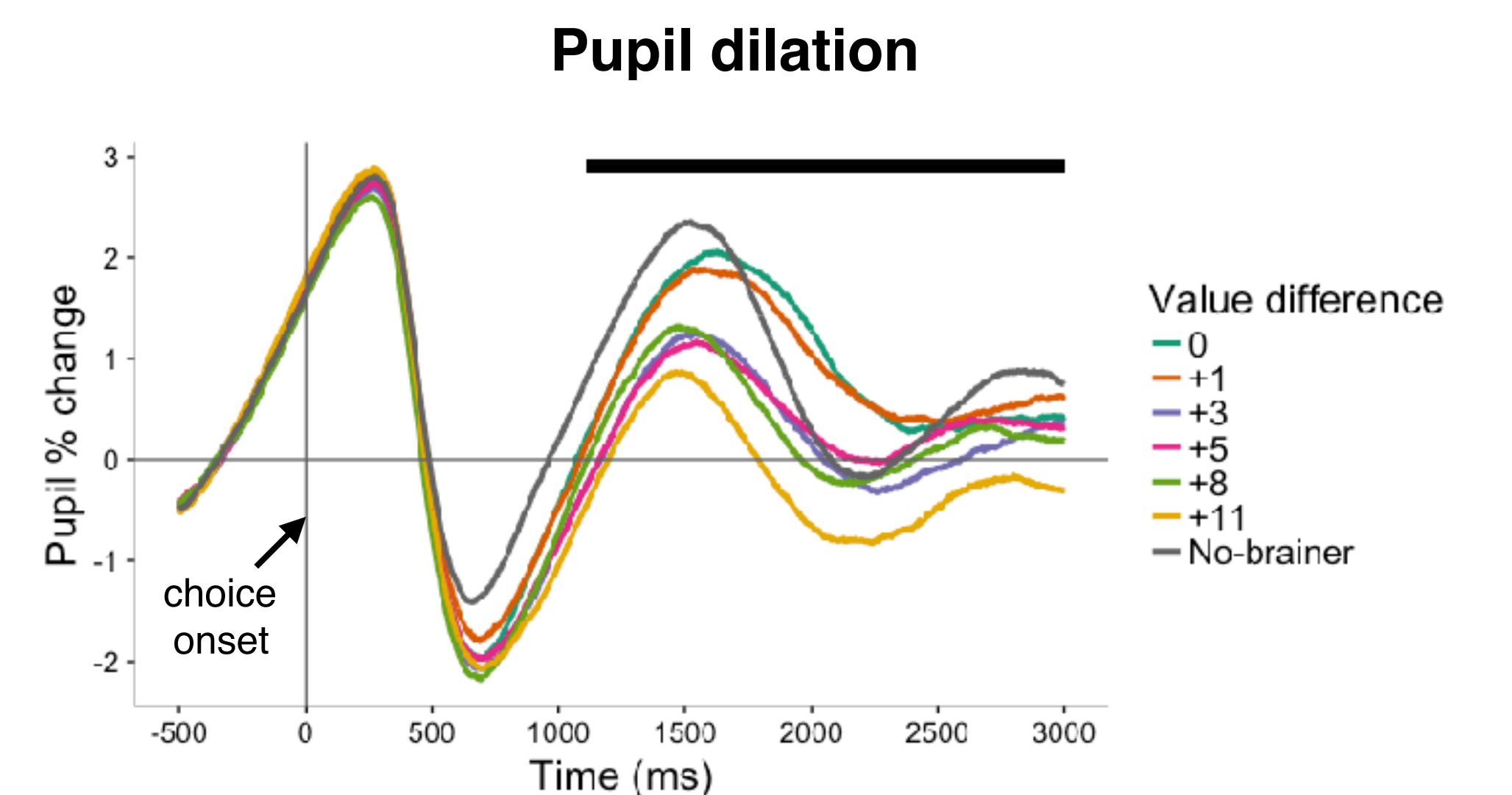
*NB refers to no-brainer catch choices. Participants had to choose between \$15 today or \$15 presented at either 10, 30, or 60 days.



Difference Value (subjective value of delayed reward minus immediate reward)

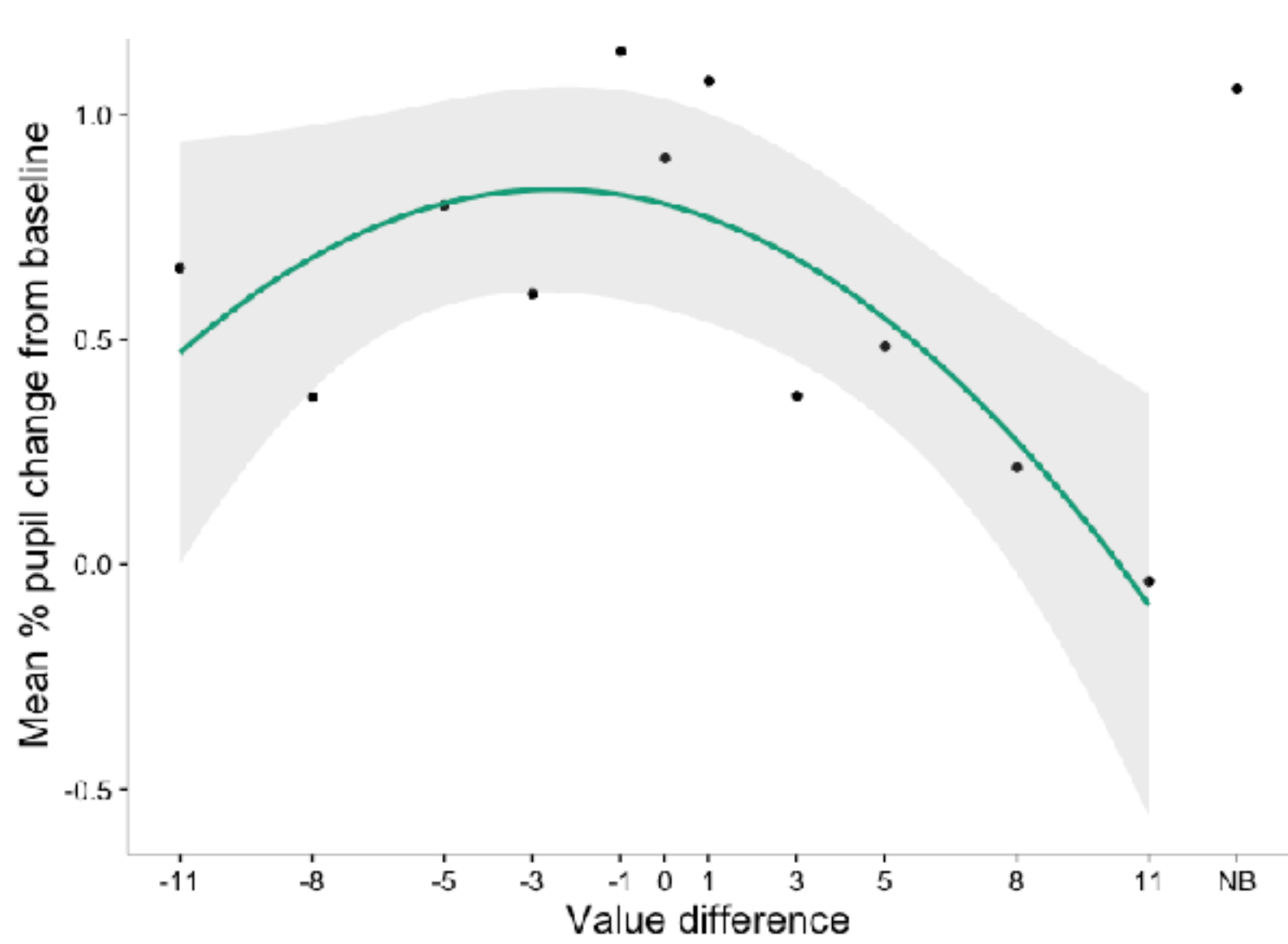
immediate reward better ← indifference point → delayed reward better

less conflicting ← most conflicting → less conflicting

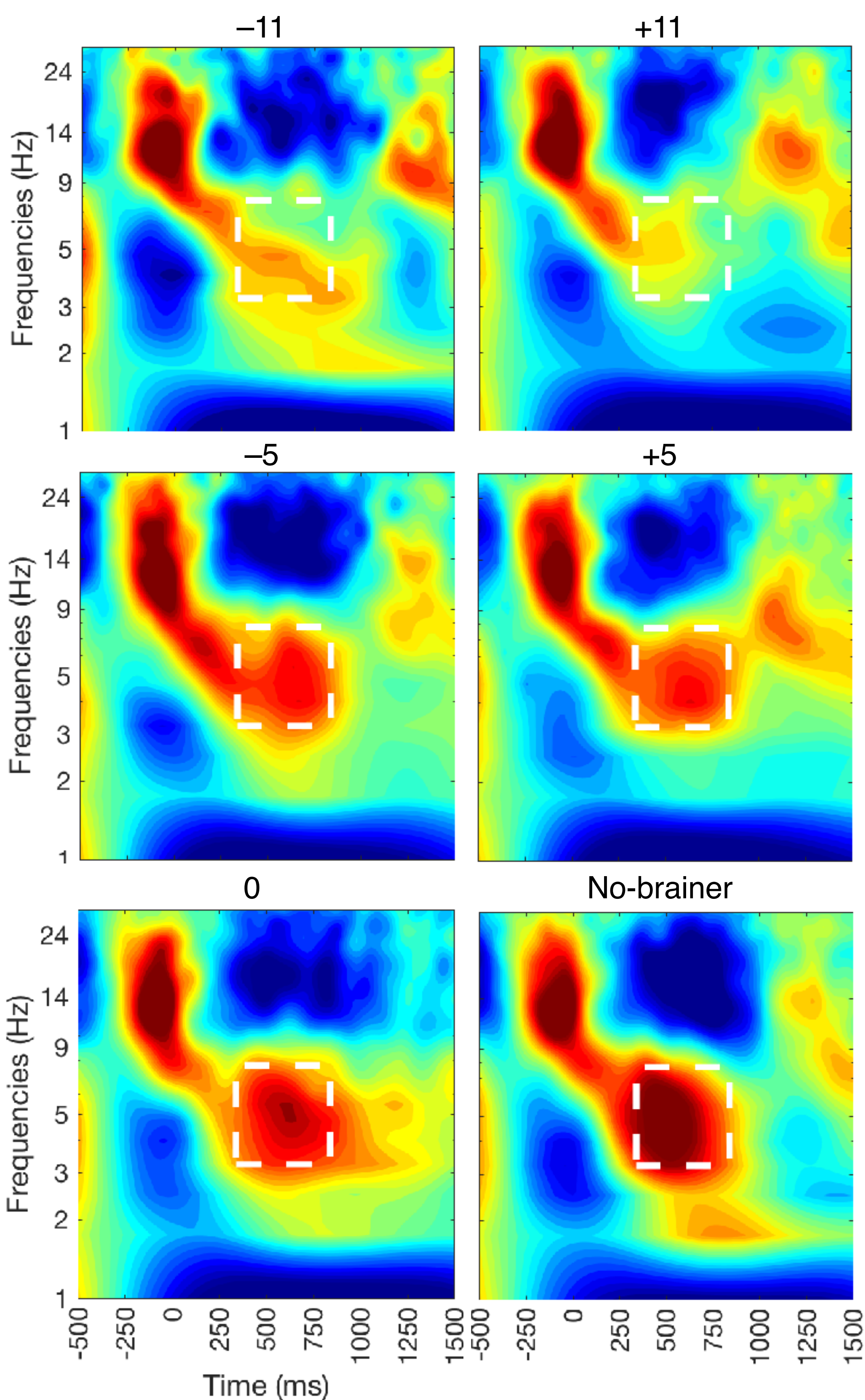


Pupil dilation responses (1110 to 3000 ms post choice presentation) track decision conflict in a graded manner. Black horizontal line: time points where quadratic relationship is significant after false-discovery rate correction ($p < .05$).

Pupil dilation tracks subjective conflict

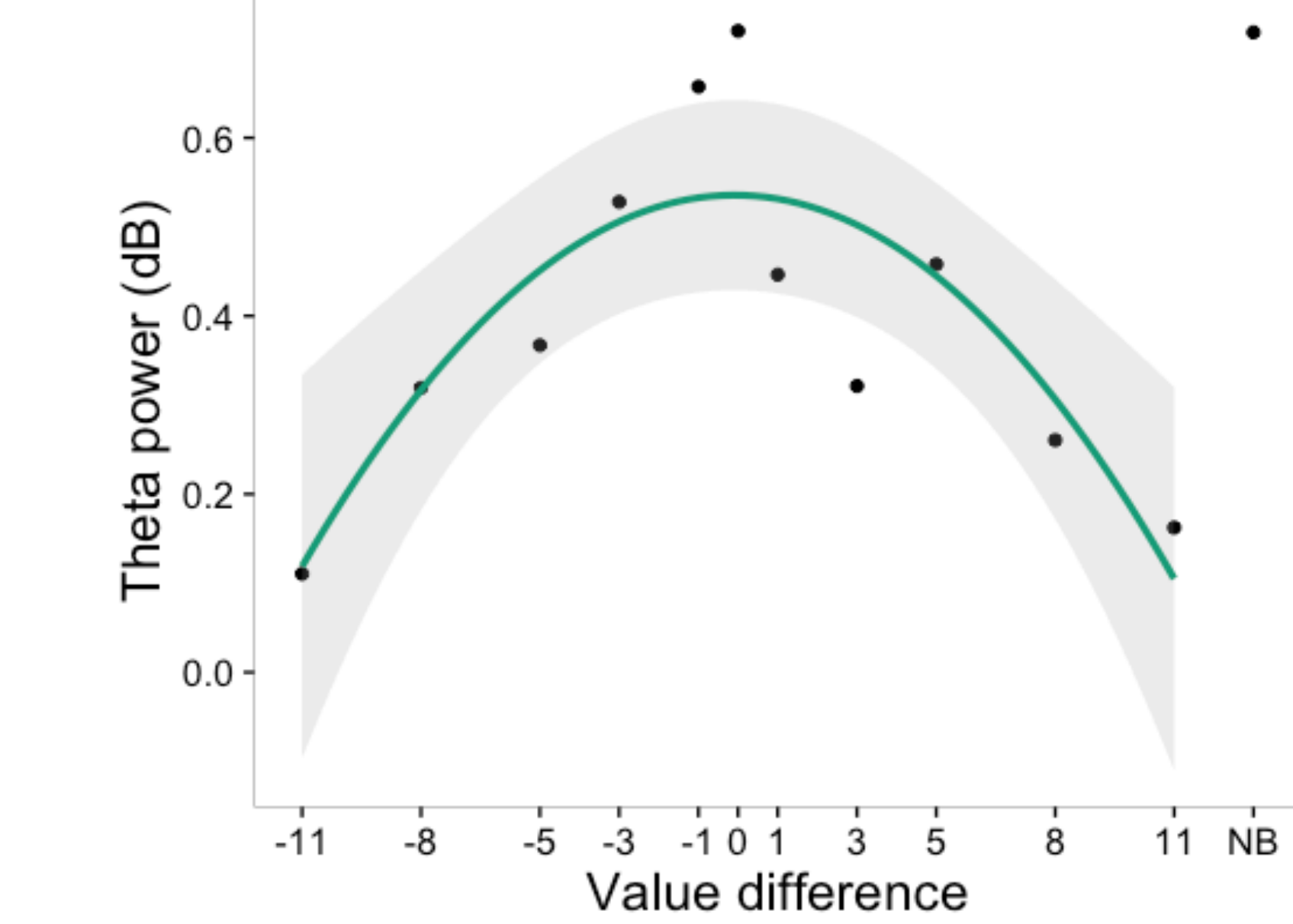


Midfrontal theta (~4–8 Hz) power

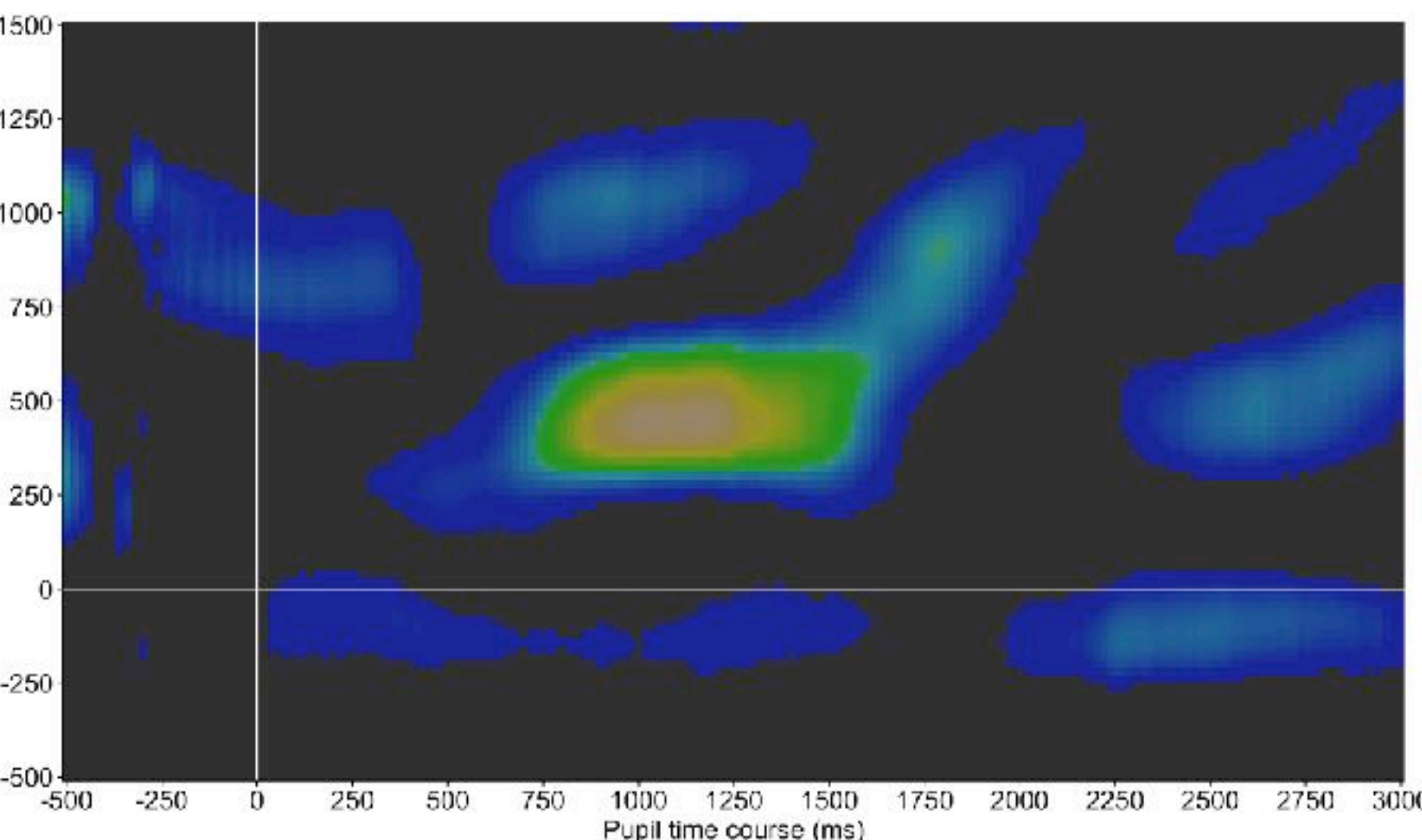


Midfrontal theta power (340 to 840 ms) tracked subjective conflict in a graded manner.

Midfrontal theta power tracks subjective conflict



Theta-pupil correlations over time



DISCUSSION

Midfrontal theta power and pupil dilation track **different degrees of subjective conflict**.

Do midfrontal theta and pupil dilation track **events requiring increased attention**, of which subjective conflict is a special case?

Midfrontal theta power reflects anterior cingulate conflict-monitoring processes² and pupil dilation reflects locus coeruleus/norepinephrine system activity⁴—they form part of a network that mediates value representation, conflict, arousal, and neural gain^{4,5}, as well as coordinates downstream brain structures to facilitate decision making⁶.

Neuroeconomic and psychophysiological approaches can be integrated to study decision processes.

REFERENCES

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