A Dual Integrator Model determines the When and What in perceptual decisions

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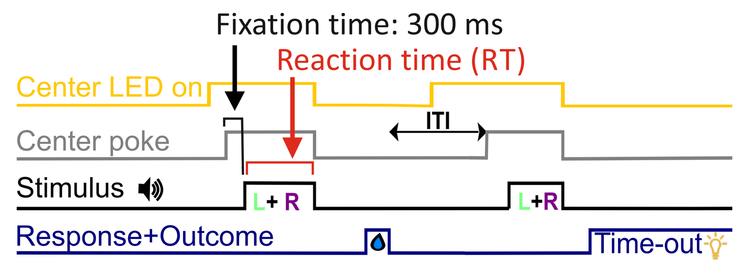
Introduction

Decisions in animals are not only grounded on current stimulus information, but **urgency** and **previous experiences** do also play an essential role in **choices** and **reaction times** (RTs) [Hermoso-Mendizábal et al., 2018]. However, the mechanisms that govern the decision process and shape the distribution of RTs are still unclear.

- Does the standard **Drift-Diffusion Model capture rats' RTs?**
- Are there **other mechanisms** besides stimulus integration (e.g. anticipation, urgency) **shaping RTs?**
- Does the **post-error slowing** arise from stimulus integration alone?
- How does trial index (i.e. **tiredness and satiety**) modulate RTs?

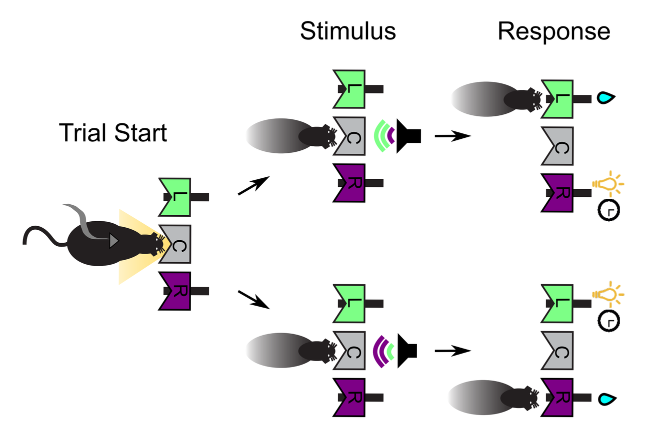
Methods

Task

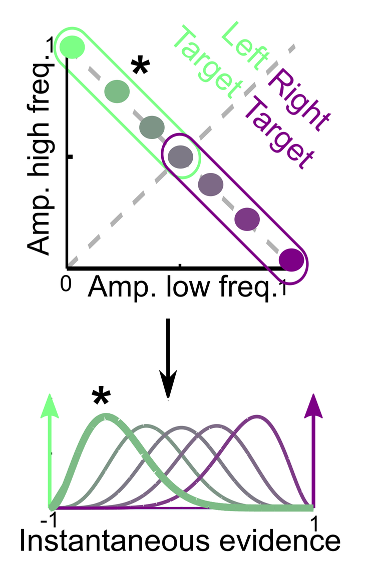


Fixation time of 300 ms to initiate stimulus. Mean reaction time RT ≈ 150 ms. One session per day, around 500 trials each (≈73 sessions and ≈56,384 trials per animal).

Rats (N=10) performed a **reaction time two alternative forced-choice (2AFC) acoustic discrimination task.**



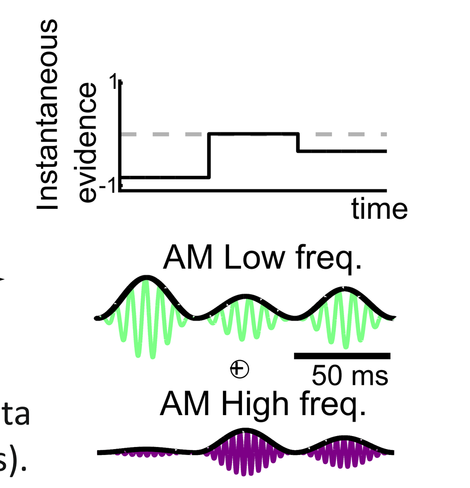
Stimulus evidence



Amplitude is drawn from a Beta distribution on every frame (50 ms).

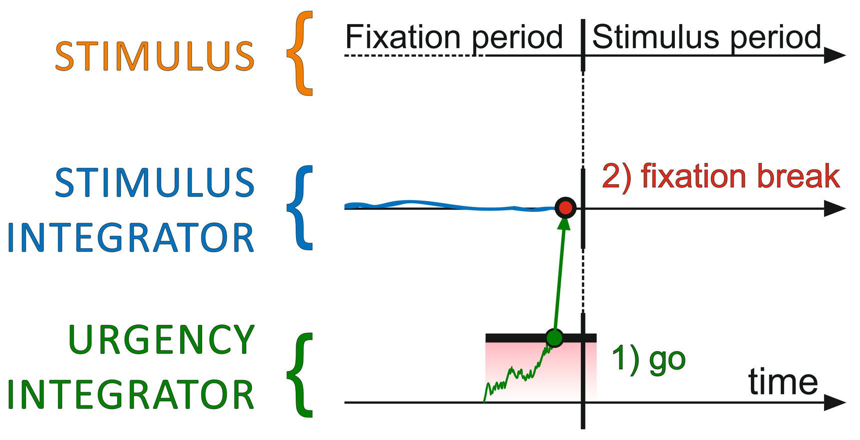
Acoustic stimulus

Sum of two amplitude-modulated tones of high and low frequency (31 kHz and 6.5 kHz).



The Dual Integrator Model

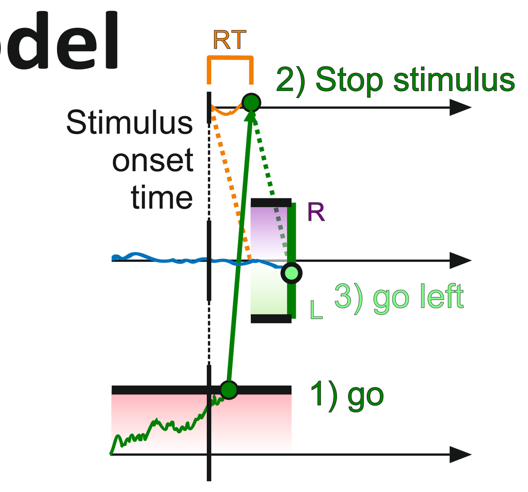
RTs are determined by the faster among two independent integrators: an urgency integrator and a stimulus integrator. However, **choices are always set by the stimulus integrator** as the sign of the Decision Variable (DV).



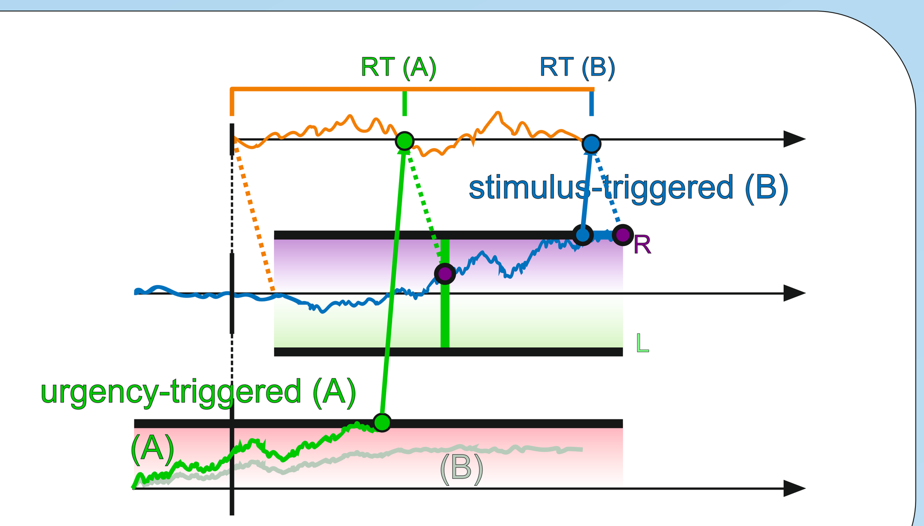
Fixation Breaks [urgency-triggered only]

Fixation Breaks: unfinished fixation periods due to invalid early responses (before stimulus onset).

Express responses: urgency-triggered responses after stimulus onset but before any posible stimulus-triggered responses.



Express responses [urgency-triggered only]



Longer responses [urgency (A) or stimulus (B) triggered]

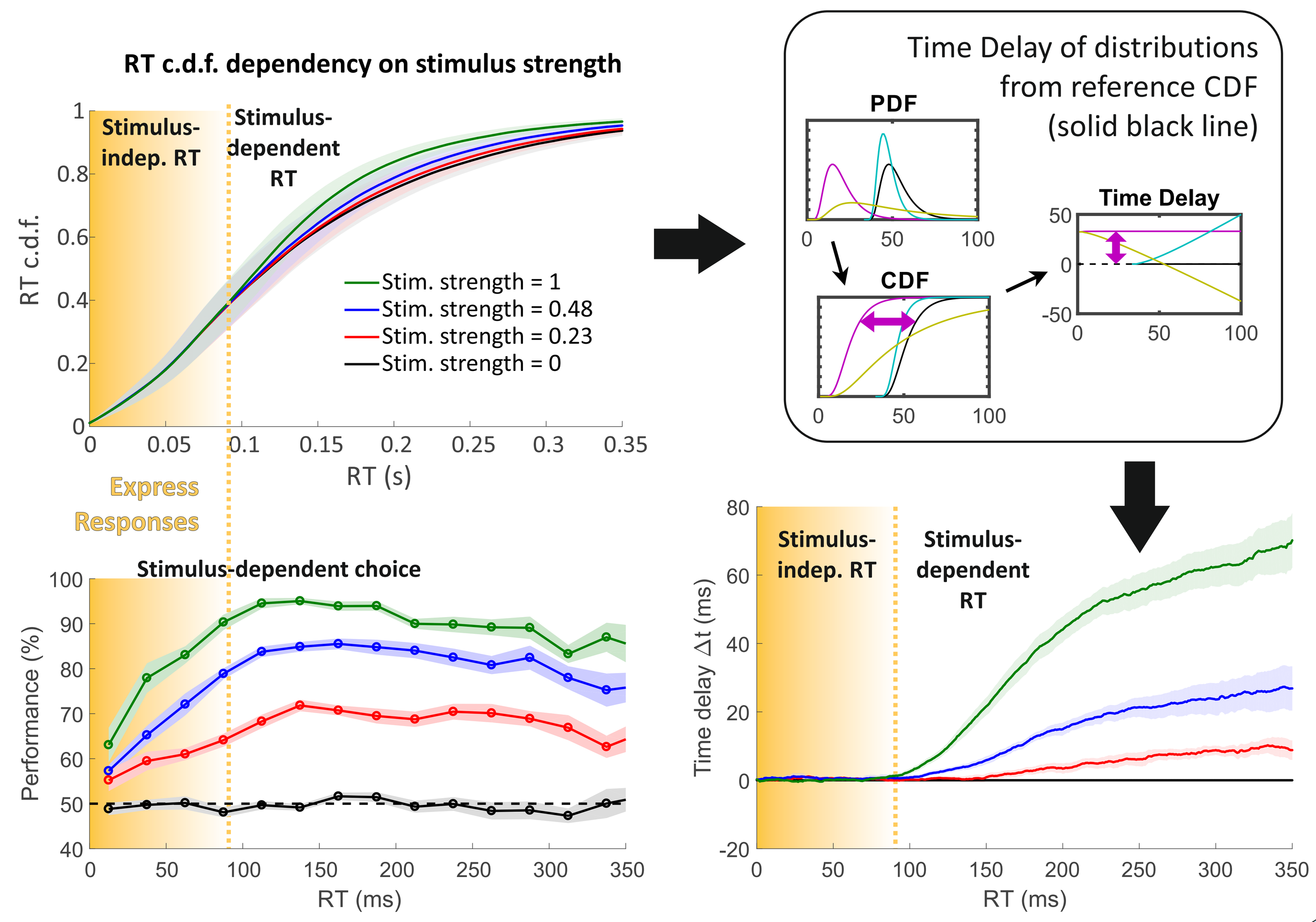
RTs arise from two independent processes

Express RTs (<80 ms) are totally **independent of the stimuli** [Pardo-Vazquez et al., 2018].

Longer RTs are modulated by stimulus strength.

Express choices' **accuracy** (RT<80 ms) **depends on the stimuli and increases with RT.**

Longer choices' accuracy depends on the stimuli but is constant with RT.

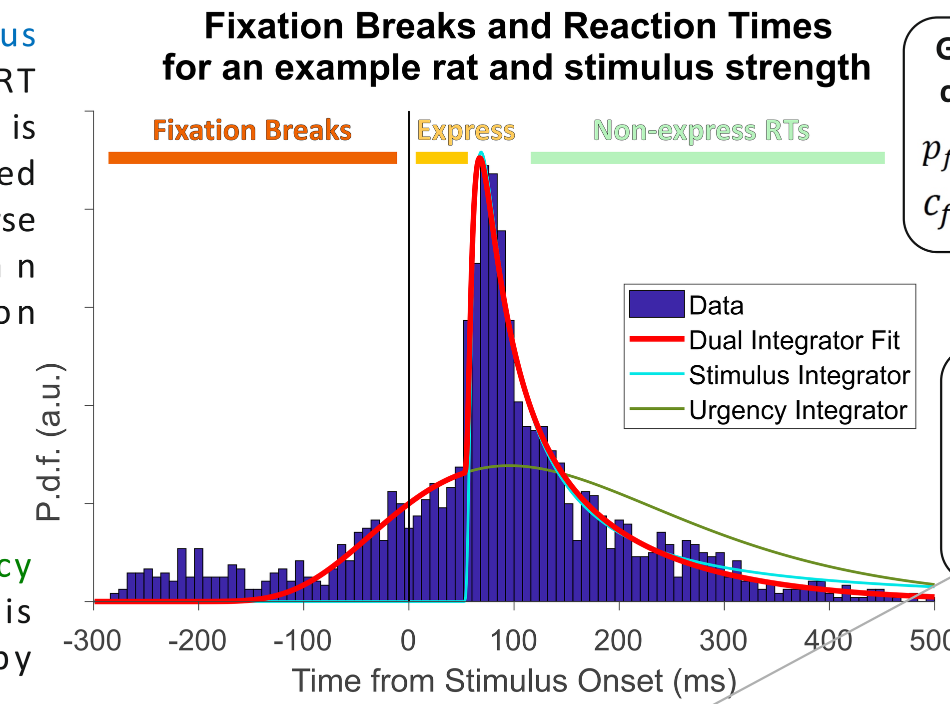


Dual model predicts Fixation Breaks and RTs

The FB-RT distribution is governed by the first integrator (urgency integrator or stimulus integrator) that hits the threshold, on a trial-by-trial basis. Both processes are modelled as drift-diffusion processes.

The Stimulus integrator RT distribution is approximated by an Inverse Gaussian distribution (IG).

The Urgency Integrator is modeled by another IG.



General expressions for the p.d.f. and c.d.f. of the fastest-of-two processes:

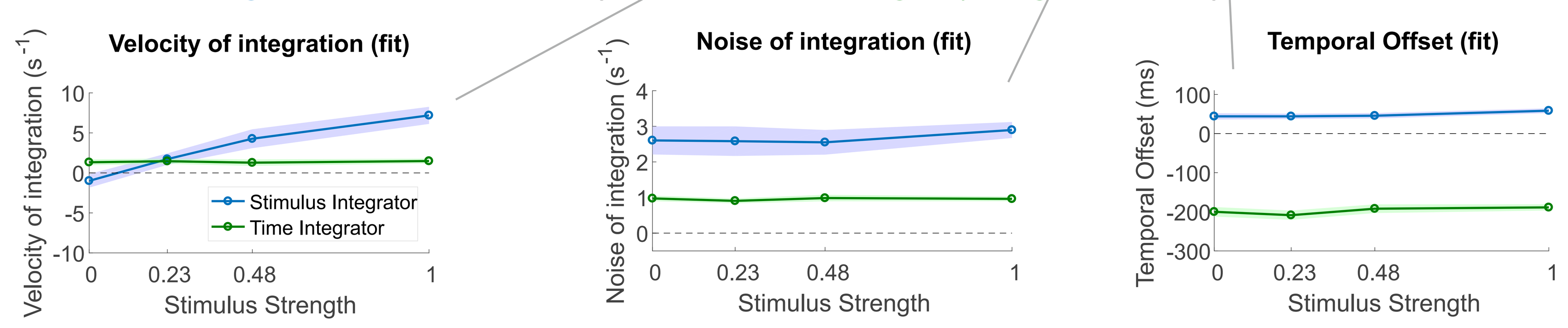
$$p_{fastest} = p_1 \cdot (1 - c_2) + p_2 \cdot (1 - c_1)$$

$$c_{fastest} = c_1 + c_2 - c_1 \cdot c_2$$

P.d.f. of an IG distribution:

$$IG(t|v, \sigma, t_0) = \frac{e^{-\left(\frac{v}{\sigma}\right)^2 \frac{\{(t-t_0)-1/v\}^2}{2\cdot(t-t_0)}}}{\sigma\sqrt{2\pi\cdot(t-t_0)^3}}$$

The Stimulus integrator drift is **stimulus-dependent.** The Urgency Integrator is **independent of the stimulus.**

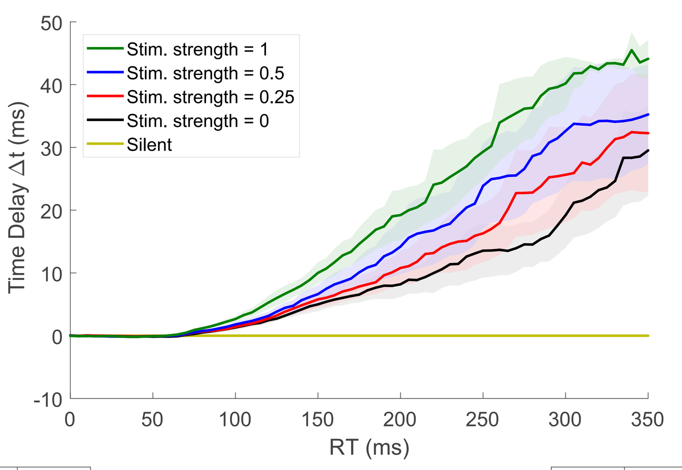


The Dual Model is **consistent with the experimental data.**

Dual Model predicts RTs in silent trials task

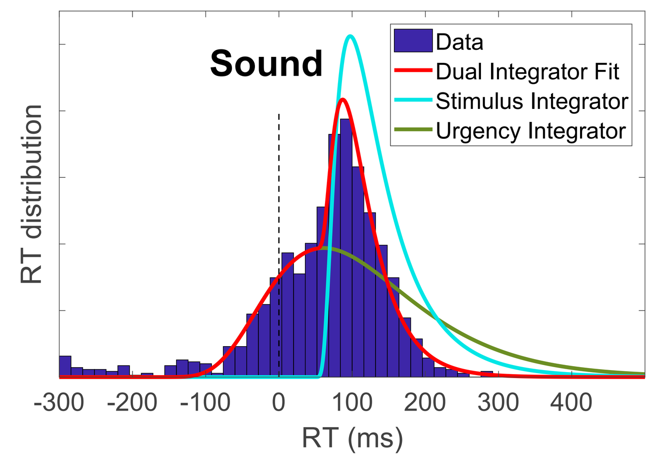
Rats (N=3) also performed a **lateral intensity discrimination task** with **10% silent random catch trials** (no stimulus) to test the Dual Model.

Rats also show **express responses** (RT<75ms) for this lateral intensity discrimination task, with **earlier impact of the stimuli** on RTs.

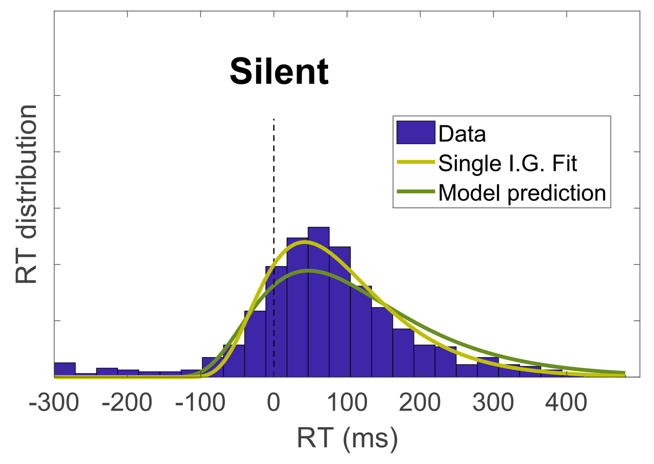


As expected, **express RTs** for standard sound trials and **for silent trials are indistinguishable.**

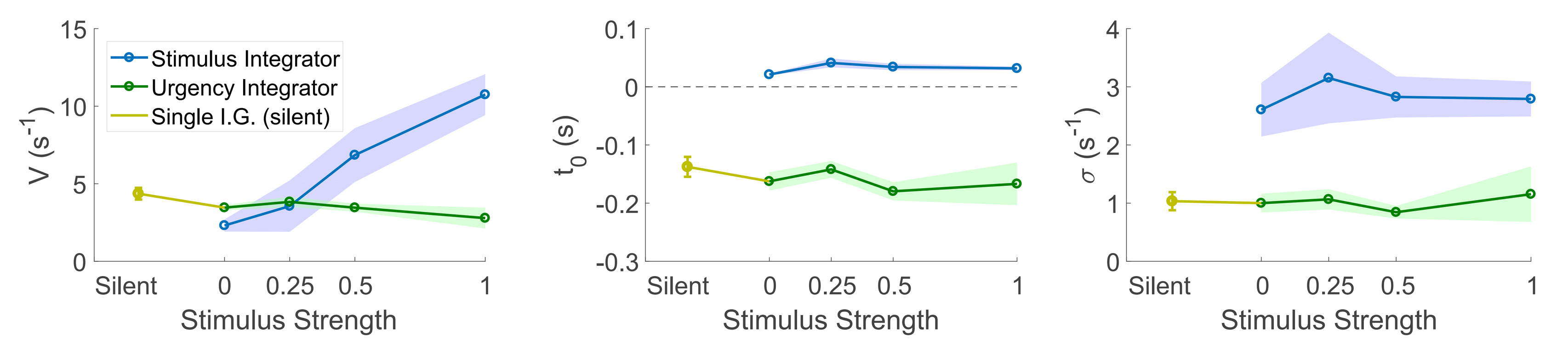
Silent stimuli slow down long RTs with respect to sound trials.



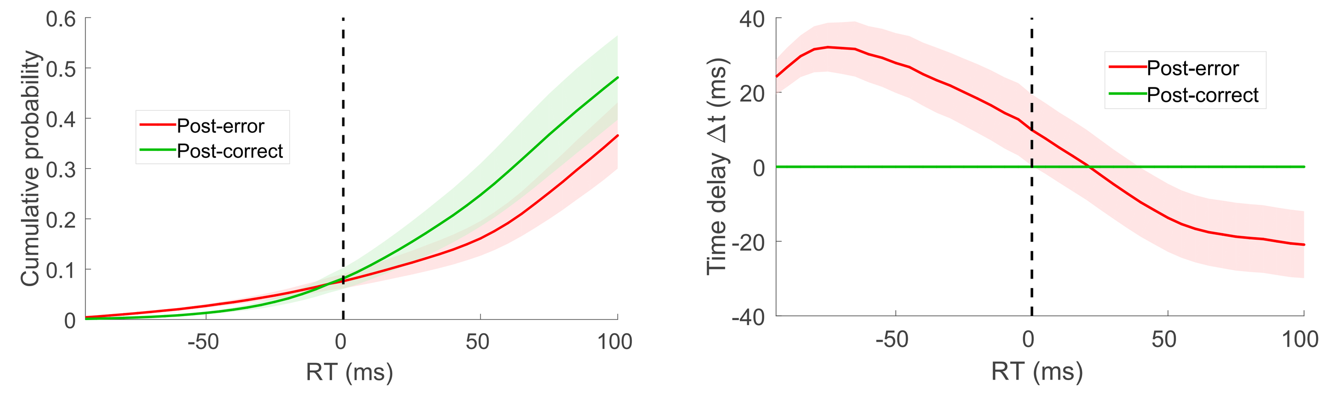
The **Dual Model** also **captures standard sound trials' RTs** in this second task.



The **Dual Model predicts that silent trials' RTs only arise from the urgency integrator**, which can be estimated from standard sound trials. The model predictions are **consistent with the experimental data**.



Previous errors and trial index impact urgency

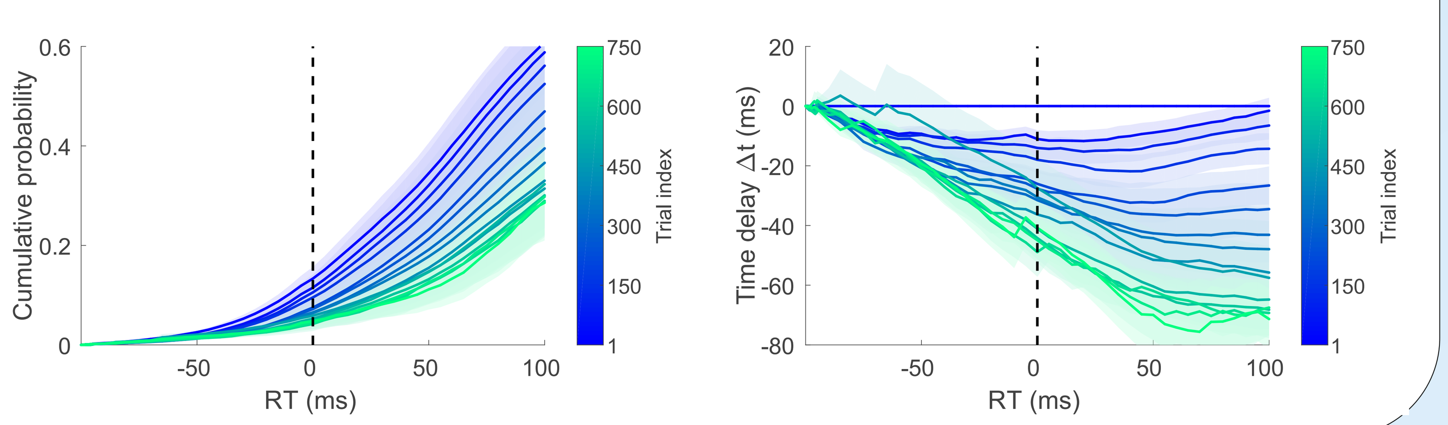


The **urgency integrator strongly contributes to the post-error slowing.**

Post-error slowing is consistent with the combination of an **early temporal onset** and a **slower drift of integration**.

Trial index slows down the urgency integrator, probably due to rats' tiredness and satiety.

The impact of **trial index** on the urgency integrator is consistent **with a slowing of its drift of integration.**



Conclusions

I. In reaction time perceptual task in rats, **RTs arise from two distinct integration processes:** a stimulus-independent **urgency integrator** anticipating stimulus onset, and a standard **stimulus integrator** accumulating evidence.

II. A second task with **silent catch trials unveils** the full RT distribution of the **urgency integrator**, which can be **predicted from standard sound trials**.

III. The **urgency integrator** strongly **contributes to** the **post-error slowing** effect **by lowering its drift**, which is **also modulated by tiredness and satiety**.

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