Plan, initiate and update: a model for rats' choice trajectories in 2AFC task

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1. Introduction

Standard decision-making models postulate that a response is triggered once the accumulated evidence reaches a decision bound. We have recently shown that rats in a free reaction time (RT) auditory discrimination task trigger their response before stimulus is processed or even presented in a considerable fraction of trials (express responses). To explain this behavior our group proposed a model where evidence and action accumulators act in parallel (PSIAM,[1]). However, it is limited in the sense that it predicts the choice and RT but other nuances of the decision-making process are out of its limits. To our best knowledge, alternative models that predict further choice features, fail to explain express responses.

Here, using rats' snout coordinates recorded during the task, we will build on PSIAM to be able to explain and reproduce trajectories exhibited by subjects in both kinds of responses predicted by the model, proactive and reactive. Briefly, we propose that reactive responses show a ballistic movement while proactive start with a slow reaching trajectory based on the decision variable at the movement onset which will be updated on-the-go if there is incoming sensory information.

We will attempt to reproduce several features of rats' trajectories with PSIAM predictions and minimum jerk trajectories while exploring prior history and stimulus contribution in both kinds of trajectories. Finally, we show how this model can account for changes of mind, although it still requires some tuning.

2. Methods

18 male Long-Evans rats performed a free reaction time (RT) two-alternative forced choice (2AFC) intensity discrimination task. After 300ms fixation, a stimulus was presented (broadband noise) until they initiated their response. Correct responses were rewarded with 25 µl of water and incorrect ones punished with 2s timeout.

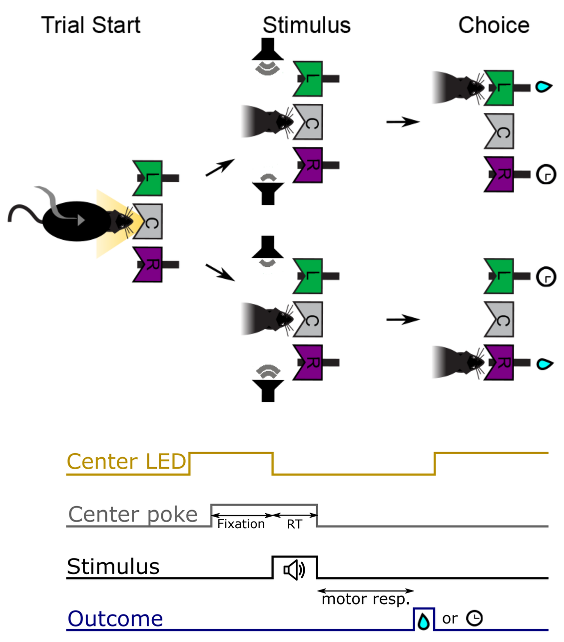
Trials were distributed in repeating and alternating blocks of 80 trials, in which the probability to repeat the rewarded port was 0.8 and 0.2, respectively. Stimulus strength was chosen randomly from {0, 25, 50, 100} possible values. For sake of clarity we will represent a single subject.

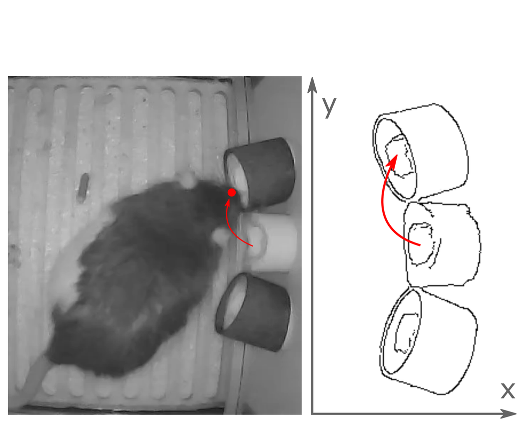
Their biases were assessed by fitting a GLM described in [2]

$$\begin{cases} p(R_t = +1|\omega, \boldsymbol{\pi}, \beta) = \pi_R + (1 - \pi_L - \pi_R)\ \Phi(y_t) \\ y_t = \sum_f \omega_f^S S_{t,f} + \sum_k \omega_k^A S_{t-k}^{sum} + \sum_{k,o} \omega_{k,o}^L L_{t-k}^o + (\sum_{k,o,q} \omega_{k,o,q}^T T_{t-k}^{o,q})\ R_{t-1} + \beta \end{cases}$$

Snout position was extracted from videos using DLC [3]. We will focus on the trajectory exhibited in y-axis and the time they take to reach arbitrary thresholds.

Trajectories were generated using minimum jerk trajectories, which solely depend on total time and boundary conditions (position, velocity and acceleration) [4]. Total motor time and boundary coefficients were obtained by a linear fit using i) trial index, ii) transition bias and iii) lateral bias as regressors.

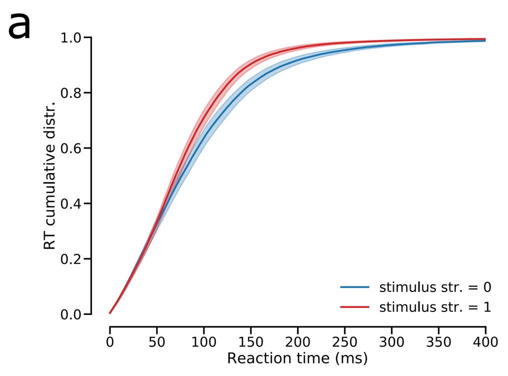




3. Express responses & motor response time

Express responses are those responses which fall in a short RT regime that is not modulated by stimulus strength (below ~90ms, panel **a**). However, in trials under that regime, stimulus is integrated, showing an increase of accuracy when it is informative (tachometric curves, panel **b**). Those RT are hard to explain by a canonical drift diffusion process, hence Hernández-Navarro *et al.* 2020 [1] proposed a dual model (action & evidence accumulators which operate in parallel) able to explain those RT distribution and accuracy. Figures below come from trials after an error where the bias contribution is reduced [2] (N=12, 82k trials).

a



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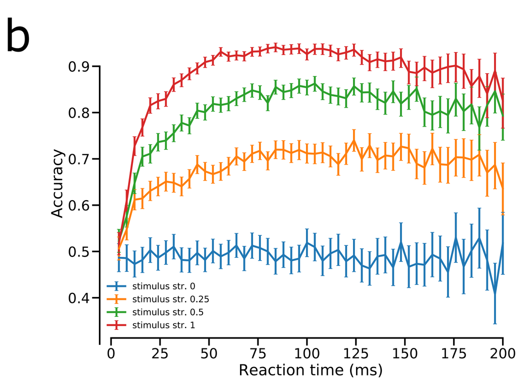
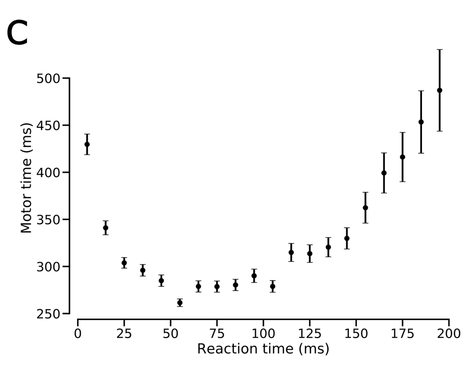


Unlike trials with long RT, express response trials show a negative relationship between RT and the time taken to reach the response port (motor time to make a choice, panel c). This encouraged us to assess how these trajectories look like and why are they slower. We will attempt to reproduce this profile using a model based on PSIAM, minimum jerk trajectories and few extra parameters

c

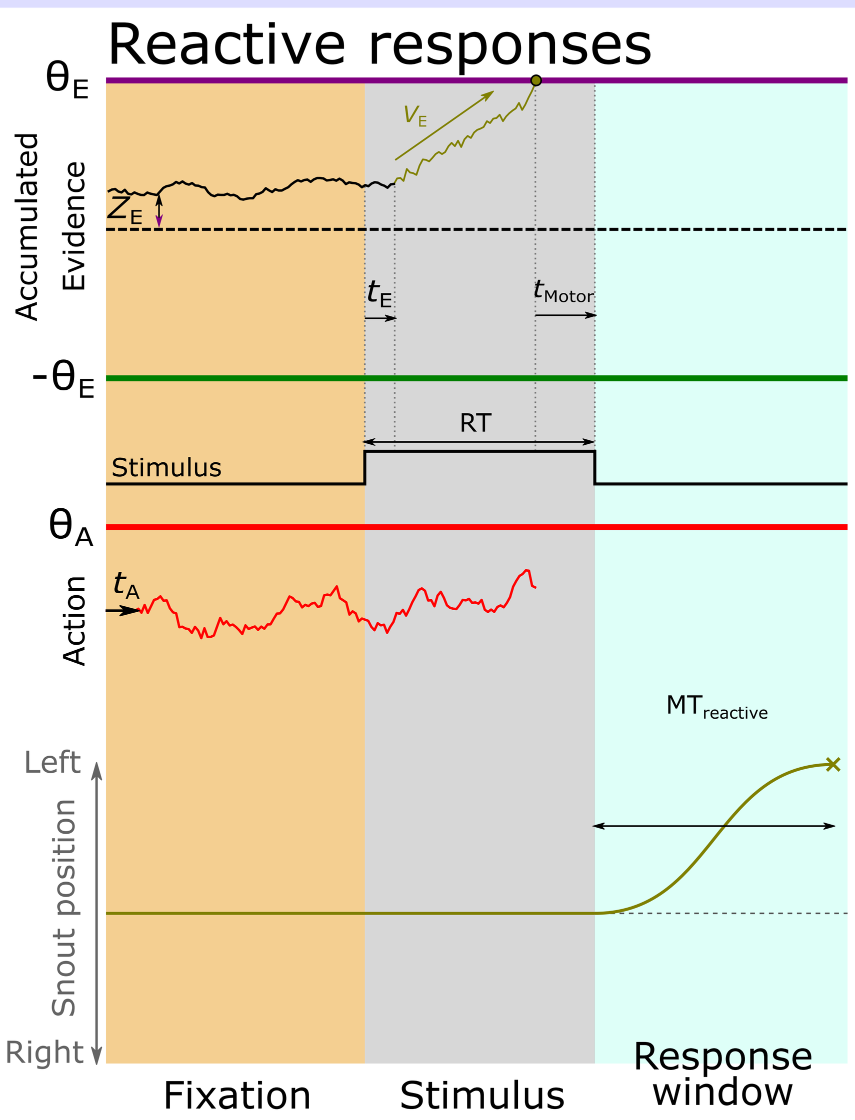


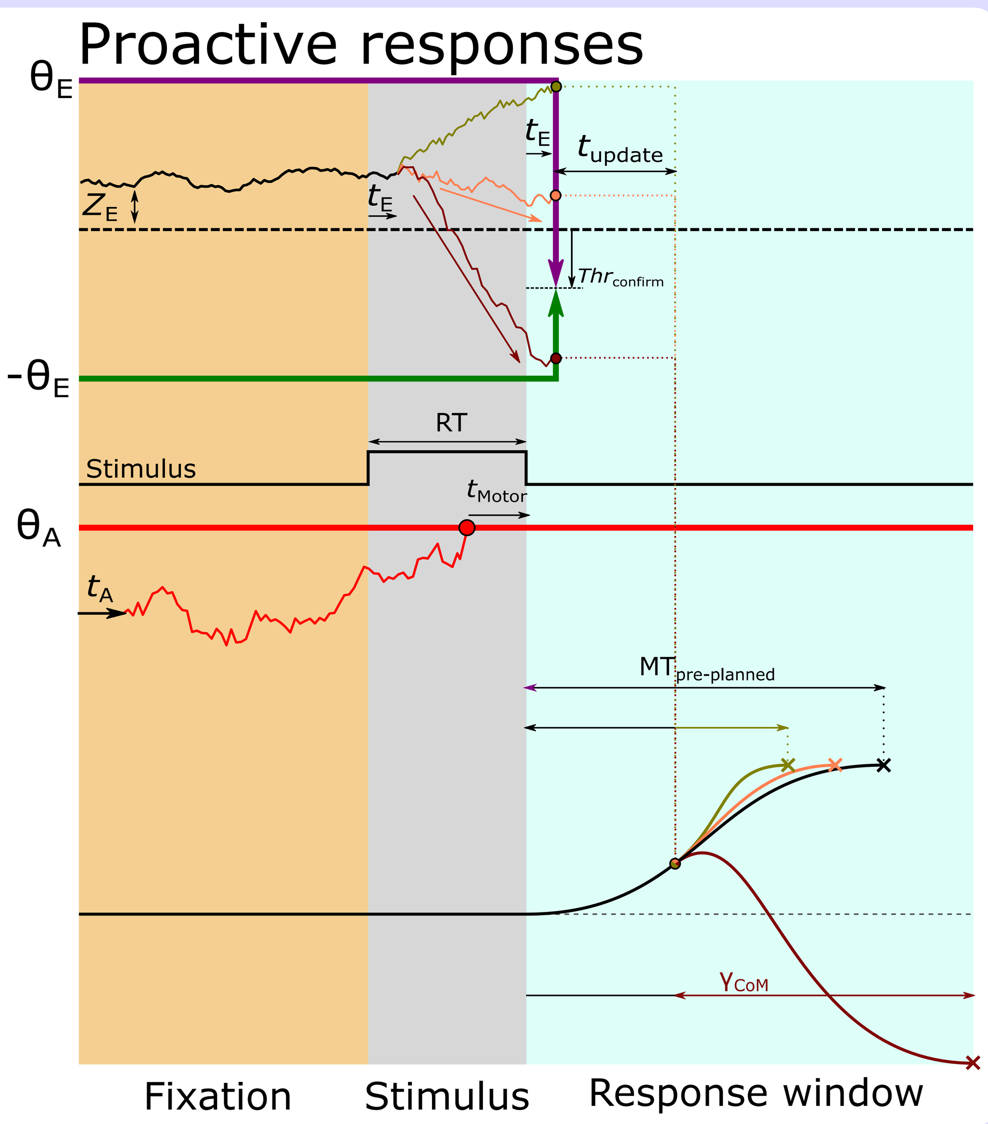
4. Model

Extended from [1].

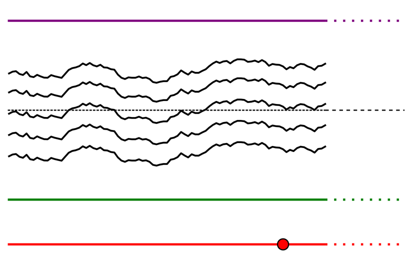
Evidence accumulator and action initiator operate in parallel. **Reactive responses** are those triggered by evidence accumulator. In those responses, the stimulus is integrated after some sensory delay (t_E) starting from an initial offset based on biases (Z_E). After the bound is reached and some extra motor delay (t_{Motor}), the motor response is started with a ballistic trajectory. Alternatively, action initiator hits the bound first, triggering a **proactive response** and evidence bounds collapse after movement onset + t_E. Concomitant motor response trajectory is based on the prior (Z_E) value and begins after t_{Motor} (grey dashed line). If the evidence integrator hits a bound during the motor response, the trajectory gets updated. This can lead to confirmation of the pre-planned choice, increasing peak velocity and linearly decreasing the preplanned motor time (e.g. olive), or a rebuttal after hitting the opposite bound (maroon), reversing the initial choice.

Z_E : choice bias
V_E : mean stimulus drift
t_E : sensory delay
θ_E : evidence bound
θ_A : action (go) bound
t_{Motor} : motor delay
RT: reaction time
MT : motor time
$Thr_{confirm}$: threshold (biased)
t_{update} : delay to update trajectory
Y_{CoM} : extra motor time after reversing updates



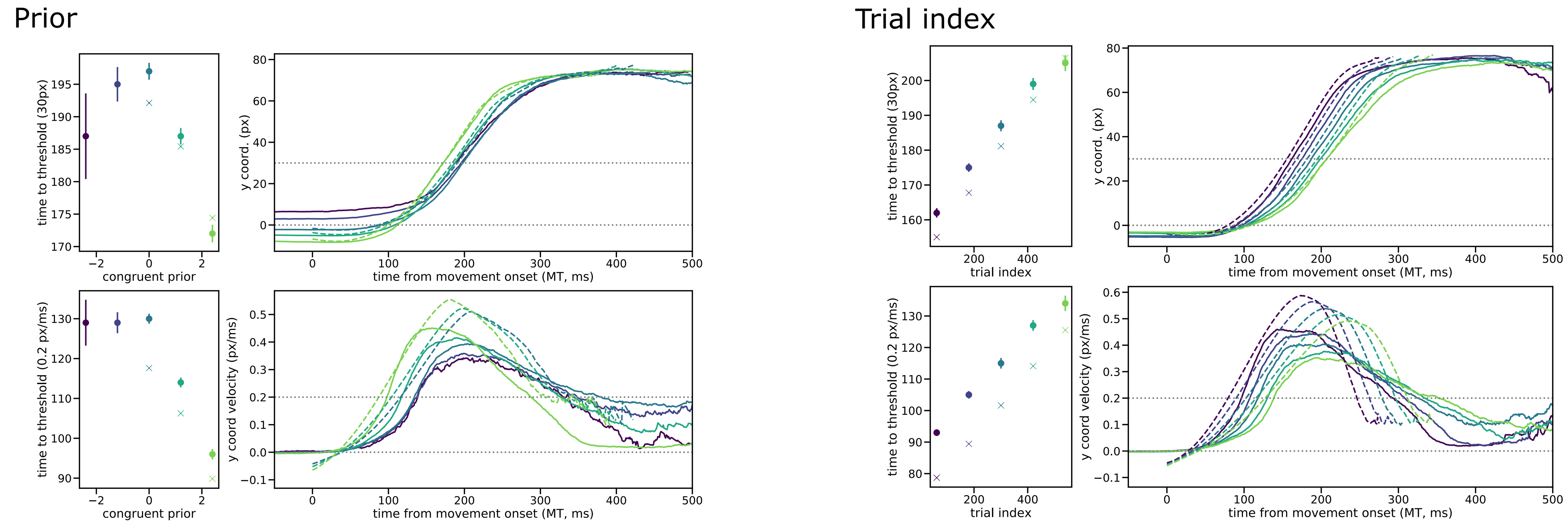


5. Expectations quicken reaching trajectories, trial index slows them

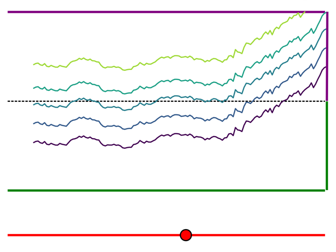


10% of silent catch trials were interleaved randomly during the sessions in a subset of subjects. Biases congruent to final choice modulate trajectories by reducing the latency to show vertical movement (y-axis) resulting in reduced time to reach a threshold and increased peak velocity. Trial index shows opposite effect.

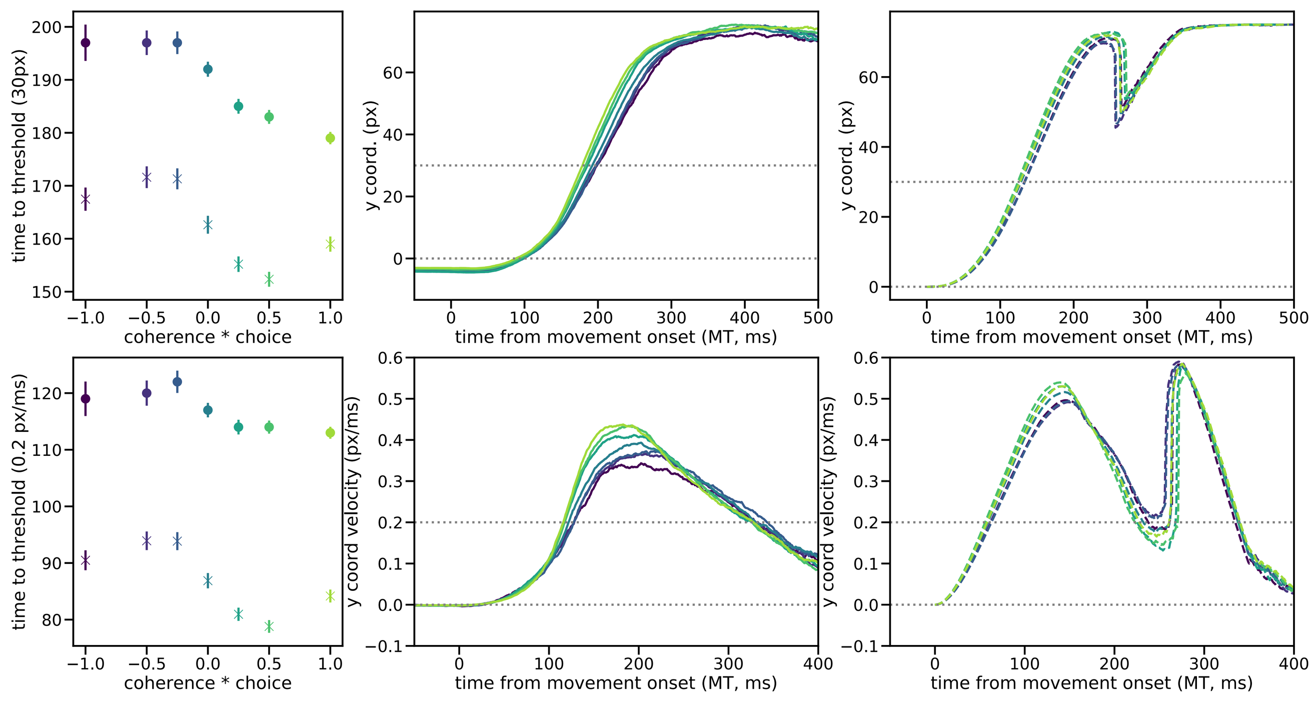
Then, we assume that their pre-planned trajectory depends on them linearly. We reproduce those pre-planned trajectories using a minimum jerk trajectory (dashed lines) whose initial and final conditions depend linearly in bias and trial index. We do the same for preplanned motor time. Because there is no sensory information we assume that trajectories in these trials do not get updated. We can recover mean trajectories of silent trials fairly well with using trial index, transition bias and lateral bias.

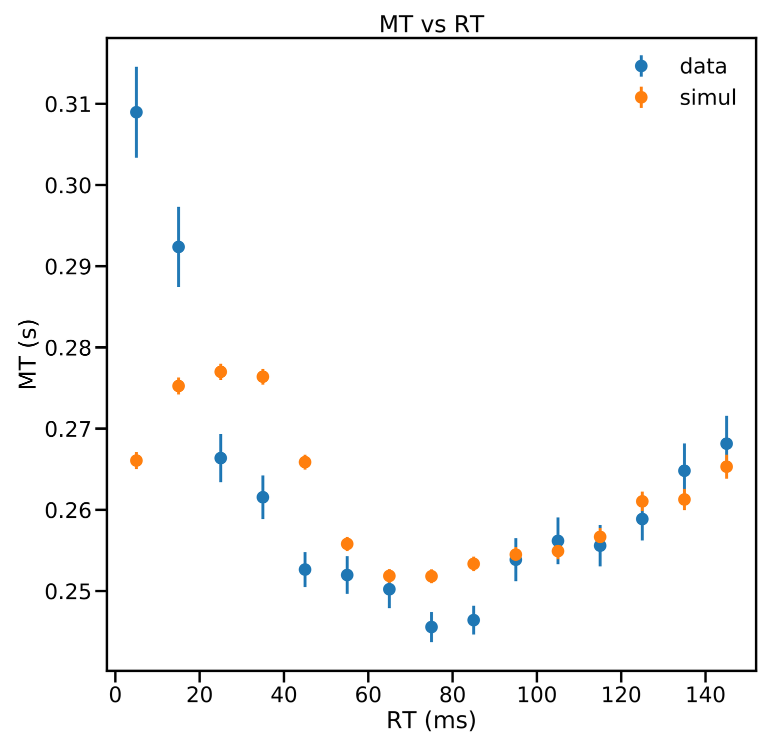


6. Stimuli quicken trajectories after a certain amount of time which depends on RT



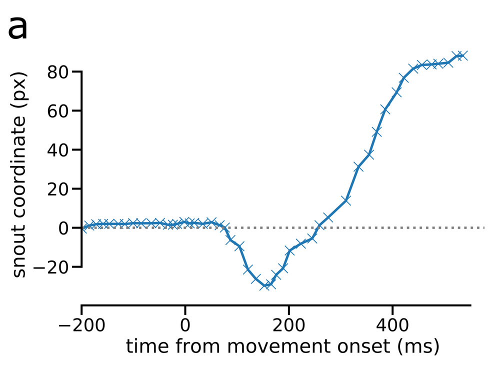
In proactive trials, rats begin their pre-planned trajectory after action initiator hits the bound. If a stimulus is played in that trial, t_{update} time after movement onset, the trajectory gets updated. The more congruency between final choice and the stimulus, the faster they reach an arbitrary threshold. In trials where the preplanned choice category is the same than final choice, we capture this feature by making motor time reduction linearly dependent on the accumulated evidence until bounds collapse. Otherwise, a fix amount of motor time is added to account the time it takes to switch targets and reach opposite port. Altogether, it results with a u-shaped MT *vs.* RT curve.





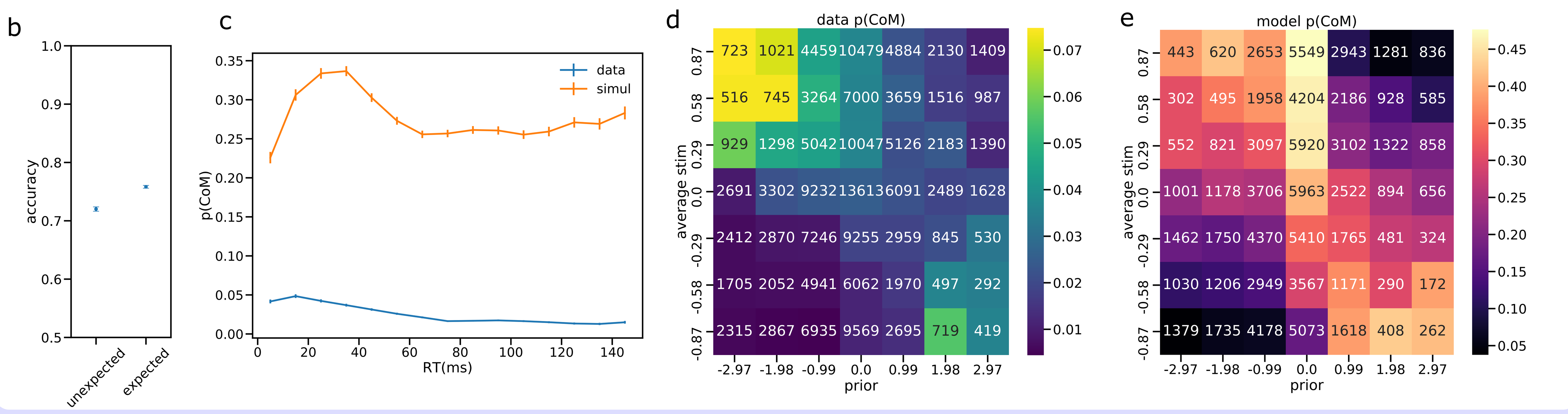
7 Changes of mind shown by rats are consistent with pre-planned trajectories which get updated on the air

a



In a small fraction of trials (~2%), rats reverse their initial choice (change of mind, CoM, e.g. fig. **7a**). This low chance to show a CoM is inconsistent with the accuracy shown in trials where the stimulus is unexpected (**7b**). Therefore we might not be able to detect most of them, either because of sensitivity (camera and framerate) or because the trajectory is updated while leaving central port.

From our model's perspective, CoM will happen in proactive responses where the initial choice is driven by the prior and the stimulus presented evokes a trajectory update in opposite direction while the rat is executing the initial response. Therefore we expect to find a higher p(CoM) RTs that contain mainly proactive responses (**7c**). It will become more obvious - increased p(CoM) probability - when the prior and stimulus are highly non congruent (**7d**). The model is capturing this trend (**7c**, **e**), however we need to work further on designing a CoM classifier that does not get biased due to the high resolution of synthetic trajectories.



8. Conclusions

Together with PSIAM, trajectories hint a non-ballistic approach from our rats. Few bullets:

- Motor time taken to reach a threshold or a target port in absence of stimuli, seems to be related linearly with prior history and trial index. Those trajectories can be reproduced using minimum jerk trajectories using the same factors as coefficients.
- Using sensory information to accelerate proactive response trajectories after a fixed amount of time (t_{update}) can account for the non-monotonic MT *vs* RT relationship observed in the data
- This model can easily capture CoMs due to incongruent prior/stimulus. However, as it is now, it cannot capture CoMs due to stimulus fluctuations.
- Aberrant over-representation of CoM might arise from flawed model (parameters) or a non-robust CoM classification.
- The fixed amount of extra time for CoM trials destroys median trajectory profile.

References

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