Multi-stage sequential sampling models: A framework for binary choice options Part 3

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March 18 – 22, 2019

Overview

- Part 1
  - Motivation – 3 Examples
  - Basic assumptions of sequential sampling models (as used here)
  - Multi-stage sequential sampling models
- Part 2
  - Time and order schedules
  - Implementation
  - Predictions
  - Impact of attention time distribution
  - Impact of attribute order
- Part 3
  - Applications

Example 3, revisited

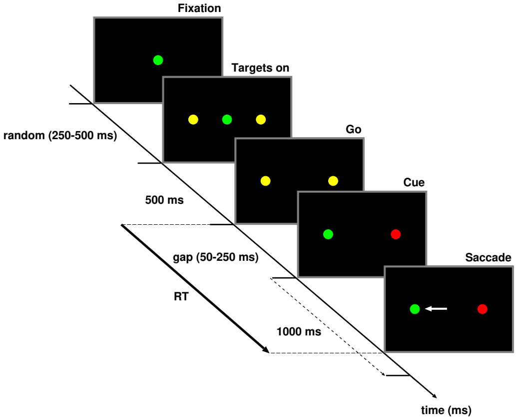
Perceptual decision making in less than 30 milliseconds

Terrence R Stanford, Swetha Shankar, Dino P Massoglia, M Gabriela Costello & Emilio Salinas

In perceptual discrimination tasks, a subject's response time is determined by both sensory and motor processes. Measuring the time consumed by the perceptual evaluation step alone is therefore complicated by factors such as motor preparation, task difficulty and speed-accuracy tradeoffs. Here we present a task design that minimizes these confounding factors and allows us to track a subject's perceptual performance with unprecedented temporal resolution. We find that monkeys can make accurate color discriminations in less than 30 ms. Furthermore, our simple task design provides a tool for elucidating how neuronal activity relates to sensory as opposed to motor processing, as demonstrated with neural data from cortical oculomotor neurons. In these cells, perceptual information acts by accelerating and decelerating the ongoing motor plans associated with correct and incorrect choices, as predicted by a race-to-threshold model, and the time course of these neural events parallels the time course of the subject's choice accuracy.

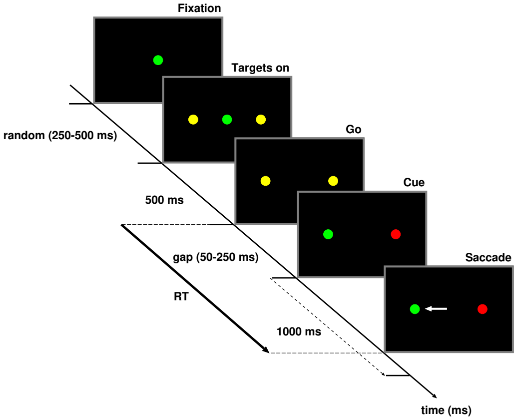
Nature Neuroscience 2010

Timeline of events in the compelled-saccade task



- The fixation circle indicates the color of the target (green).
- The participants must initiate a saccadic response (left or right) when the fixation circle disappears (Go).
- Target and distracter colors and positions are revealed after a gap of 50 - 250 ms (Cue).

Timeline of events in the compelled-saccade task



- A trial is correct if the participant makes an eye movement to the peripheral location that matches the color of the fixation circle (green).
- Response time is defined from the offset of the fixation circle to initiating a saccade.

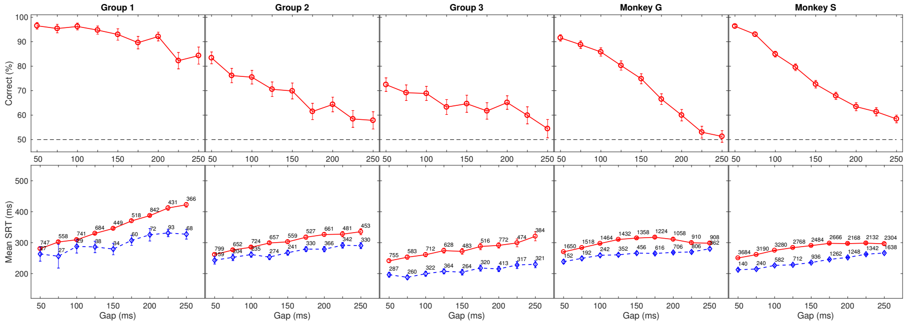
Ideas behind the compelled-saccadic task

- Separating perceptual decision making and motor-planning stages by always instructing the participant when to respond (go)
- Motor response is triggered first (go) $\rightarrow$ mean RT should be approximately constant
- Perceptual performance is expected to change systematically as a function of gap but motor performance is not

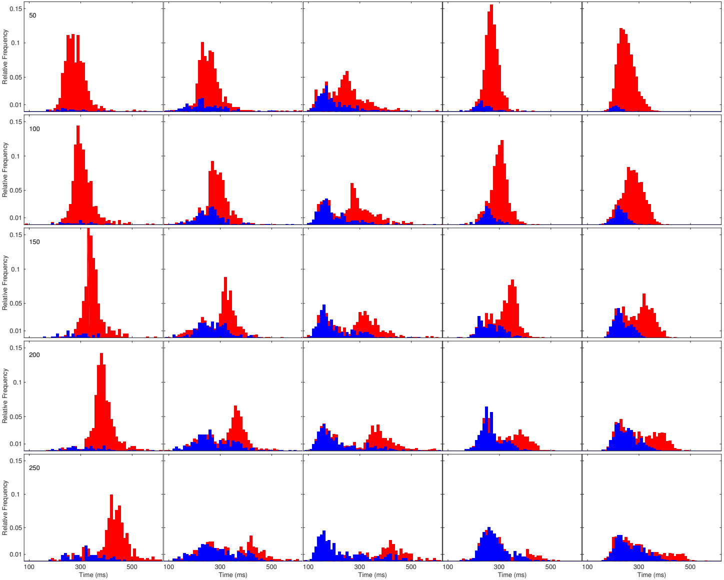
Experiments

- Data from 2 monkeys (Stanford et al. 2010, Nature Neuroscience)
- 8 participants from Jacobs University – three groups (clustered according to choice frequency patterns)
- Saccadic onset times (SRT) – recorded with Eyelink1000 Eye tracking System (SR Research); mobile camera, which recorded monocular gaze data from the left eye at a sampling rate of 1000 Hz.

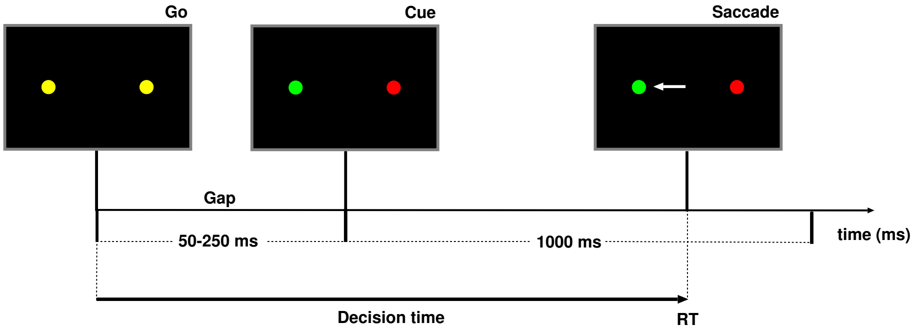
Percentage of correct responses and mean choice SRT



SRT distributions



Timeline, revisited



Two-stage model

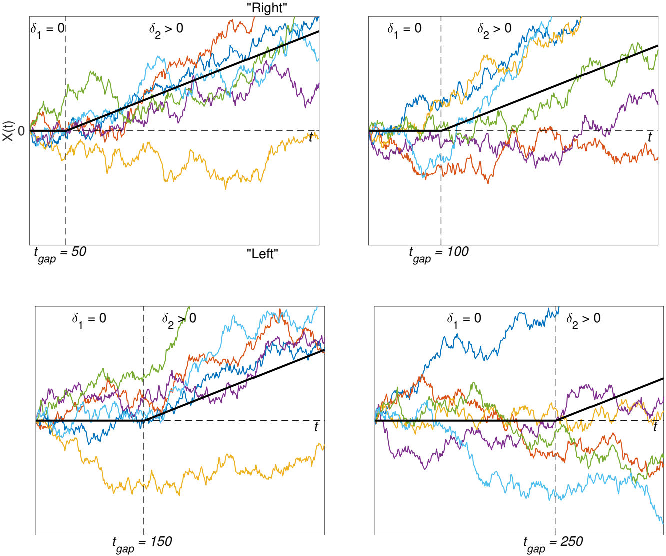
- The first stage includes the processes from onset of go signal to the onset of the cue.

$$\mu(x, t) = \mu_1 = 0$$

- The second stage includes the processes from the onset of the cue until a decision is made.

$$\mu(x, t) = \mu_2$$

Two-stage model

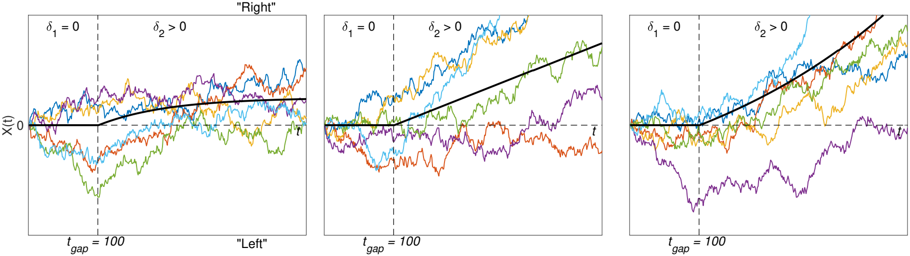


Two-stage model

- Or, as an alternative for the second stage

$$\mu(x, t) = \delta - \gamma x$$

Two-stage model



Deterministic time and order schedule

2 attributes (stages); fixed attention time – gap time; $n = t/\tau$

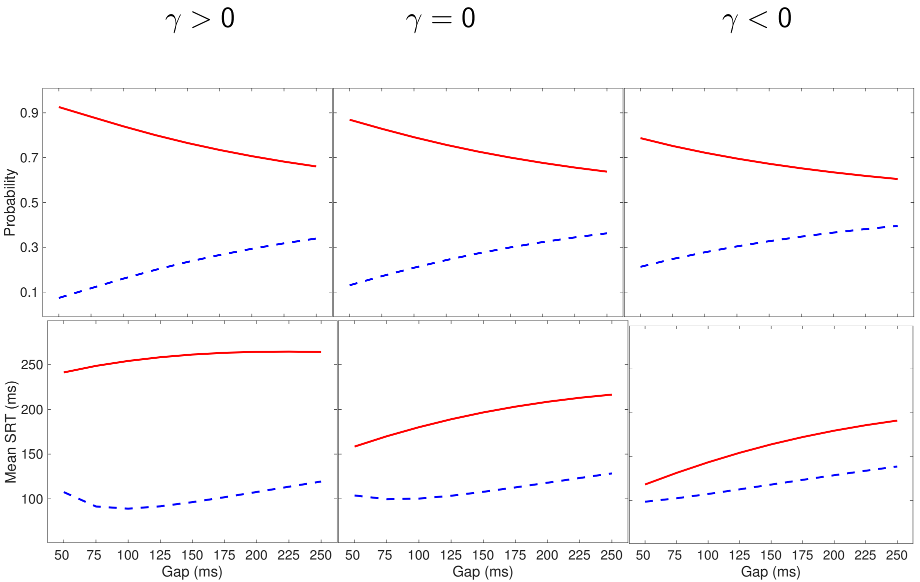
- **Probability** to choose A

$$p_A = Z' \sum_{i=1}^{n_1} Q_1^{i-1} R_{A_1} + Z' Q_1^{n_1} \sum_{i=n_1+1}^{\infty} Q_2^{i-(n_1+1)} R_{A_2}$$

- **Mean RT** to choose A

$$ET_A = \frac{\tau}{p_A} \left[Z' \sum_{i=1}^{n_1} i Q_{k_1}^{i-1} R_{A_1} + Z' Q_1^{n_1} \sum_{i=n_1+1}^{\infty} i Q_2^{i-(n_1+1)} R_{A_2} \right].$$

Model predictions – choice probability and mean choice RT



Recall

- For $\delta_1 < \delta_2$: model predicts always fast errors

Distribution

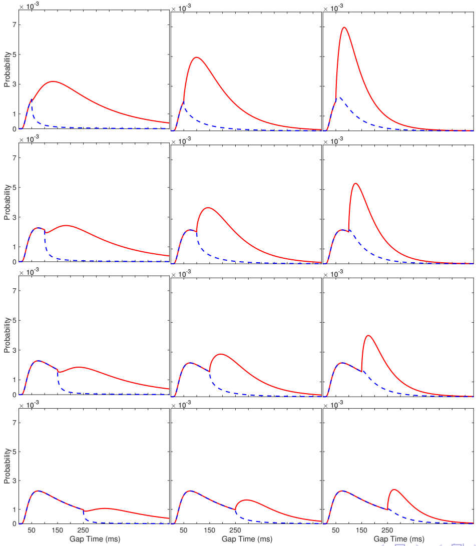
$n = t/\tau$

$$Pr[T < n_1 \cap \text{choose } A] = Z' \sum_{i=1}^{n_1} Q_1^{n-1} R_{A_1}$$

$$Pr[n_1 \leq T \cap \text{choose } A] = Z' Q_1^{n_1} \sum_{i=n_1+1}^{\infty} Q_2^{i-(n_1+1)} R_{A_2}$$

Model predictions – probability distributions

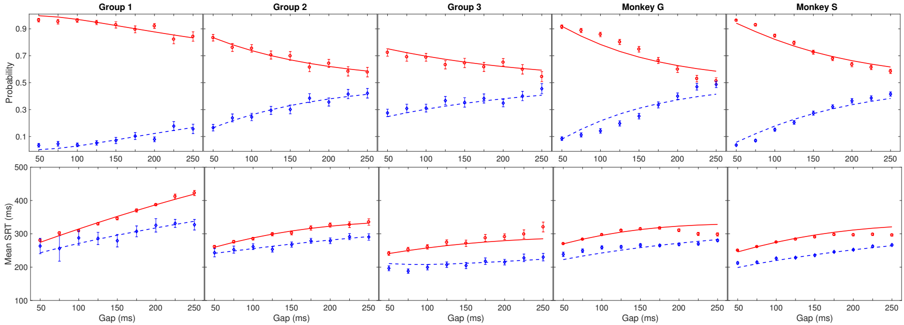
$\gamma > 0$ $\gamma = 0$ $\gamma < 0$



Parameter estimations

- 3 (4) parameters (Wiener: boundary θ; drift rate δ_2; non-decision time T_{ND}: OUP plus γ)
- 9 gap times $\rightarrow$ 9 choice frequencies; 18 mean choice response times $\rightarrow$ 27 data points
- Objective function: Σ((observed-predicted)/observed std error)^2
- Matlab fminsearchbnd

Model accounts - choice probabilities and mean choice SRT



Estimated parameters

	θ	δ	γ	T_{ND}	χ^2	AIC
G1	22	0.7172	–	0.2070	140	104
	21	1.1569	0.0359	0.2114	138	112
G2	11	0.6917	–	0.2072	93	57
	13	0.2293	−0.0237	0.1852	33	7
G3	14	0.0638	–	0.0841	166	130
	15	0.0594	−0.0023	0.0724	144	118
G	12	0.3043	–	0.1942	428	392
	12	0.5346	0.0451	0.1931	401	374
S	13	0.3358	–	0.1684	524	488
	13	0.5848	0.0428	0.1682	466	440

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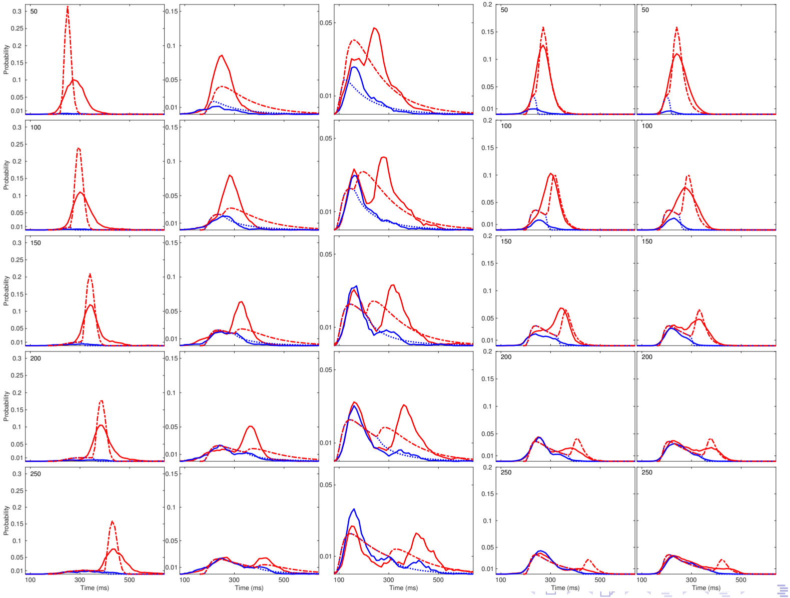
Predicting the distributions – same parameters

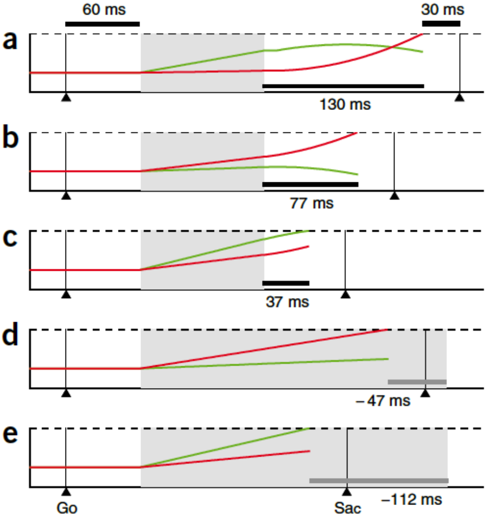


Problem – your advise is appreciated

- How to estimated the density function?
- Appropriate bins
- Vectors of different lengths
- Times scale
- ...

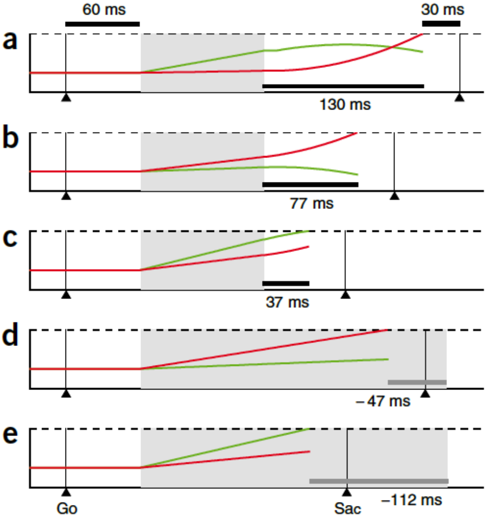
- Stanford et al. 2010; Shanker et al. 2011, approach

Accelerated race-to-threshold model – 5 trials



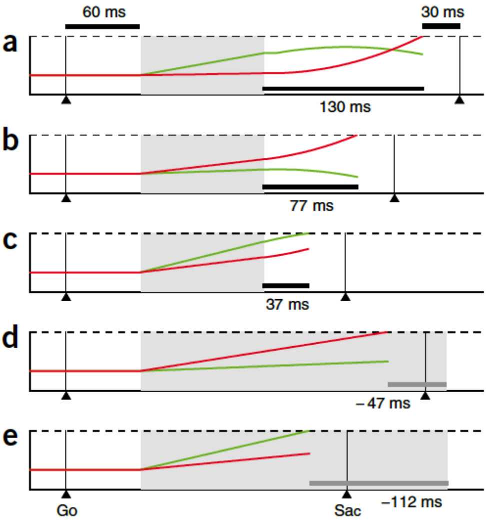
- Two competing variables, x_L and x_R represent the mean activity of neurons that trigger eye movements to the left and to the right.
- The one reaching a certain fixed threshold first (the winner of the race) determines the direction of the saccade occurring a short efferent delay after that.

Accelerated race-to-threshold model



- Two different stages must be distinguished:
  - one in which no cue information is yet available and
  - another in which the cue boosts one of the motor plans and suppresses the other.

Accelerated race-to-threshold model



- This information build-up assume build-up rates r_R and r_L of x_L and x_R, respectively drawn from a bivariate Gaussian distribution.
- Constant
- After the cue information arrives showing, e.g., the target is on the right side, the build-up rate of x_R accelerates and x_L decelerates (again at *constant* rates) until a target value is reached.

Race parameters: free (Shanker et al. 2011 version)

- r_G: mean of bivariate normal distribution for build-up rates for r_R and r_L; constant within one trial: $d_{x_R}/d_t = r_R, d_{x_L}/d_t = r_L$
- σ_G: standard deviation of bivariate normal distribution for build-up rates for r_R and r_L
- ρ correlation coefficient; correlation between r_R and r_L
- r_T “direction changer“ for target: $d_{r_R}/d_t = (r_T - r_R)/\tau$
- r_D “direction changer“ for distractor: $d_{r_D}/d_t = (r_T - r_D)/\tau$
- τ time to reach the final values of r_T and r_D
- T_1: start of interrupt time relative to cue (ms)
- T_2 : end of interrupt time relative to cue (ms)
- T_{ND}: non-decision time (afferent and efferent)
- sdT_{ND}: SD of non-decision time (afferent and efferent)
- p_e: small error probability

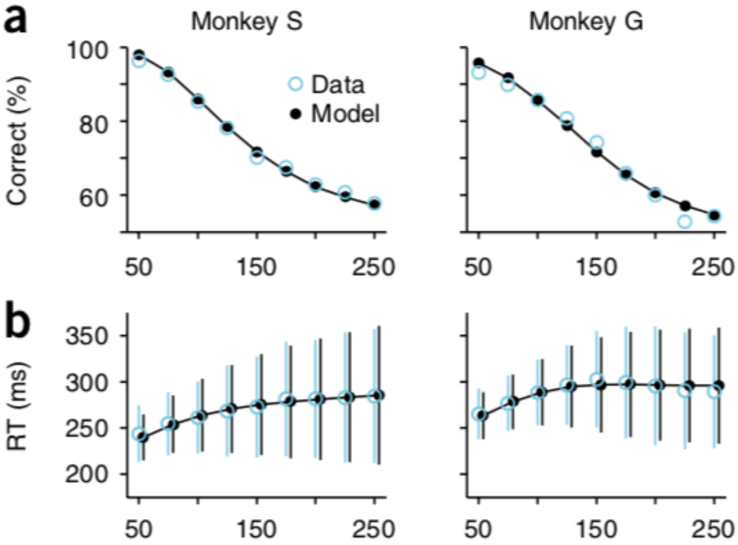
Fixed

- ΔT: variability in the afferent delay ($N(0, 100)$)
- Decision boundary: 1000 units

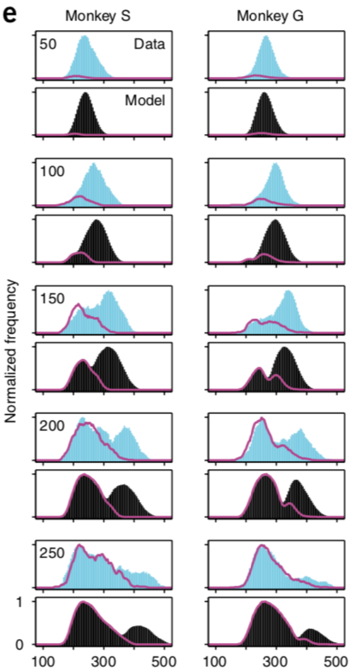
Other model parameters: fixed

Nit = 5000;	number of races in one shot
x0_R = 0;	relative offset in R starting point
x0_L = 0;	relative offset in L starting point
RTcut = 600;	RT cutoff (in ms)
Twait = 0;	to simulate the monkey waiting for the cue
Teff = 20;	mean efferent delay (to limit variability only)
Taff_min = 20;	minimum afferent delay
Taff = Tnd - Teff;	mean afferent delay (to limit variability only)
xdip = -Inf;	minimum allowed activity level

Results



a
Monkey S
Monkey G
Correct (%)
100
80
60
Data
Model
50
150
250
50
150
250
b
RT (ms)
350
300
250
200
50
150
250
50
150
250


e
Monkey S
Monkey G
50
Data
Model
100
150
200
250
Normalized frequency
1
0
100
300
500
100
300
500

References

- Shankar S, Massoglia DP, Zhu D, Costello MG, Stanford TR, Salinas E (2011) J Neurosci 31(23):8406–8421.
- Stanford, T. R., Shankar, S., Massoglia, D. P., Costello, M. G., & Salinas, E. (2010). Perceptual decision making in less than 30 milliseconds. *Nature neuroscience*, 13(3), 379-385. doi: 10.1038/nn.2485