Differential effects of stimulus strength and volitional control on dominance durations in bistable perception

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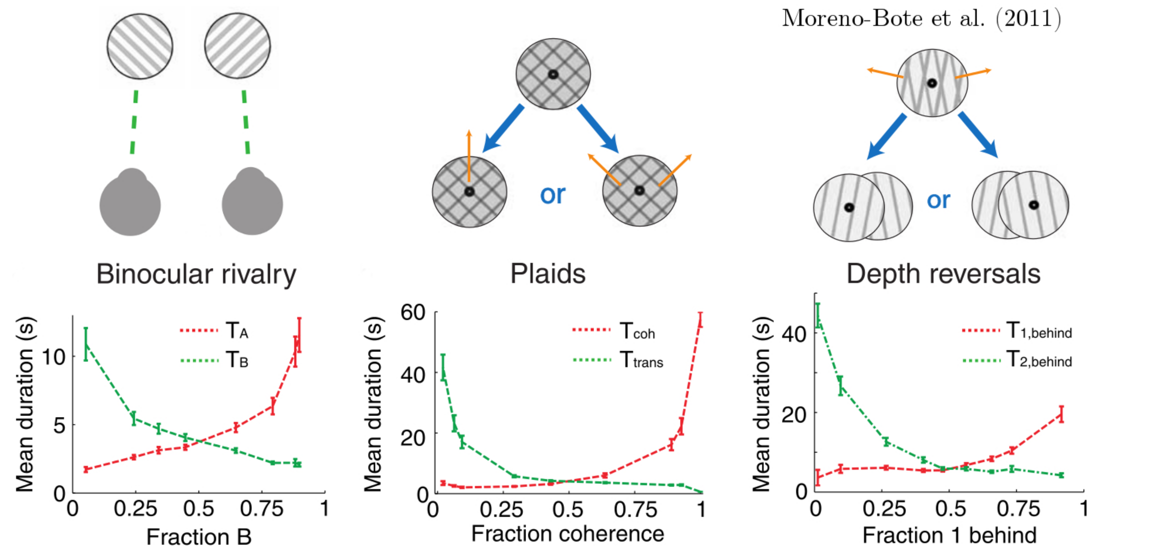
Poster summary: Bistable perception has been widely studied in the visual system and, more recently, in the auditory system where ambiguity in sensory information leads to spontaneous shifts in perception. Common dynamical characteristics have been found across different sensory cues and different sensory modalities, however, the different way in which stimulus strength manipulations and volitional control affect dynamics are not fully understand. We study this aspect of perceptual bistability with reduced rate models.

Motivation and previous results

Input strength modulation: visual bistable stimuli

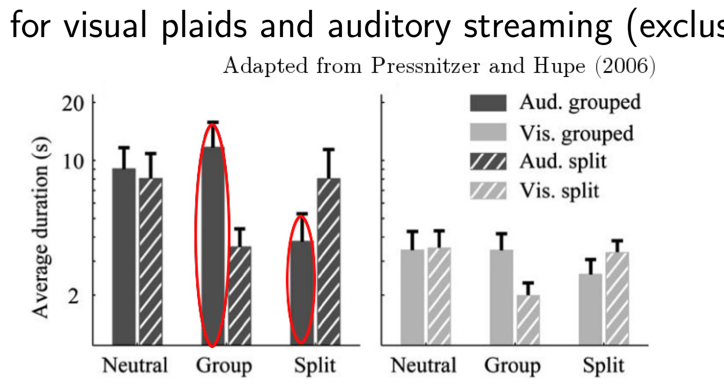
Stimulus strength manipulations about equidominance behave consistently across three different visual cues [1]:



Generalised Levels II: The mean dominance duration of the stronger percept changes more than that of the weaker percept

Volitional control: visual plaids and auditory streaming

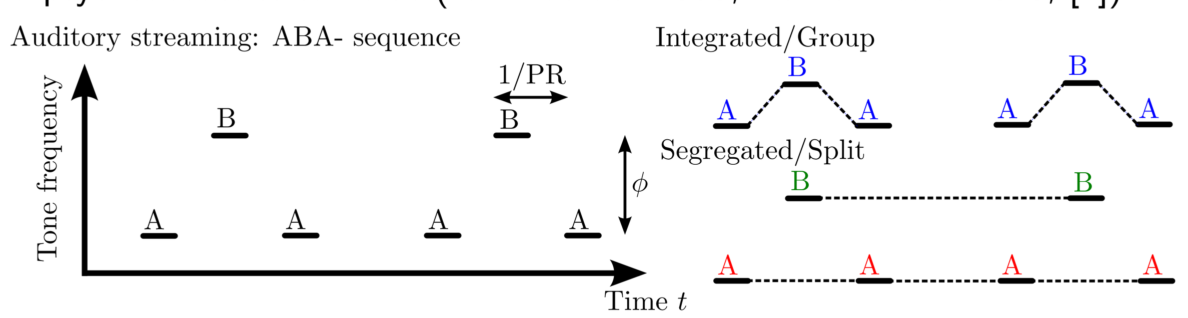
Bistability between an integrated/grouped and a segregated/split percept share common characteristics for visual plaids and auditory streaming (exclusivity, randomness, inevitability) [2].



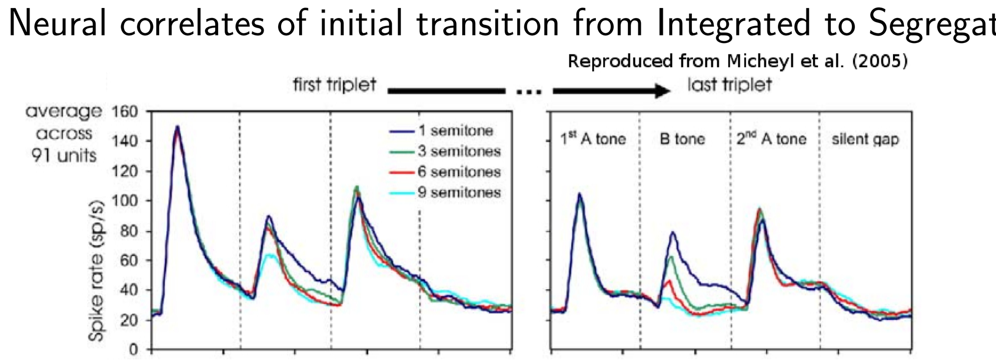
- Study also looked at the affect of volitional control (e.g. "attend integrated")
- Not accounted for by adjusting input strengths.
- **Mean dominance duration of the unattended percept changes more than that of the attended percept**

Auditory streaming paradigm

A widely studied psychoacoustics stimulus (van Noorden 1975, Denham et al 2010, [2]):



Neural correlates of initial transition from Integrated to Segregated [4]:



- Single unit recordings in awake rhesus monkey A1
- Initially integrated, later, segregated.
- Observations are consistent with human psychoacoustics.

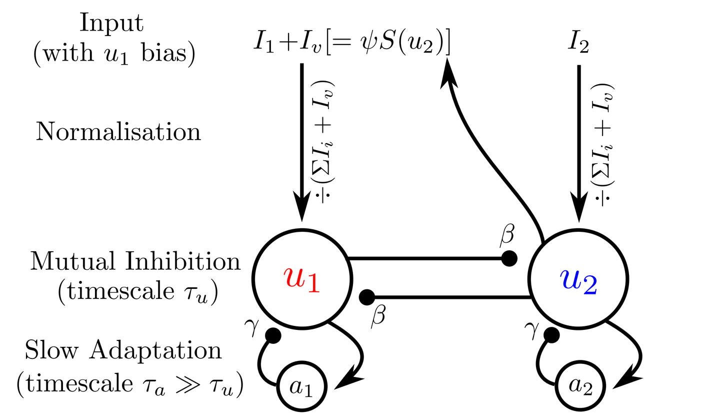
Our goals

1) Propose a new mechanism to account for the difference between **input strength** manipulations and the effect of **volition**.
2) Develop a model for the auditory streaming case where the inputs are **periodic**.
3) First test the mechanism in a **canonical rivalry model**, then in our **auditory streaming model**.

Models and parameter study

Rivalry model with mutual inhibition, slow adaptation and normalised inputs

Introduce **normalisation** of inputs [1] to standard, widely-studied model:

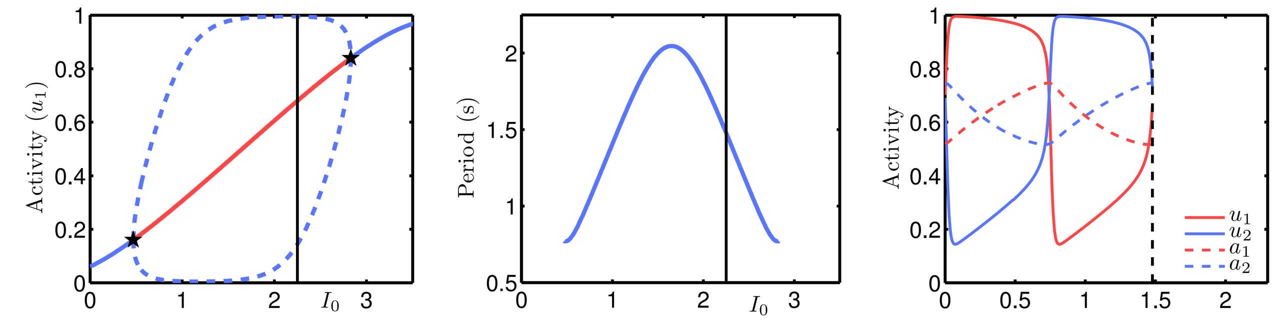


Model equations are given by

$$\tau_u \dot{u}_1 = -u_1 + S_f\left(-\beta u_2 d_1 - \gamma a_1 + \hat{I}_1\right),$$
$$\tau_u \dot{u}_2 = -u_2 + S_f\left(-\beta u_1 d_2 - \gamma a_2 + \hat{I}_2\right),$$
$$\tau_a \dot{a}_1 = (-a_1 + u_1),$$
$$\tau_a \dot{a}_2 = (-a_2 + u_2),$$

where S_f is a sigmoidal firing rate function.

Bifurcation diagram (see [3] and others) for **symmetric** input I_0 and no volition $\psi = 0$:

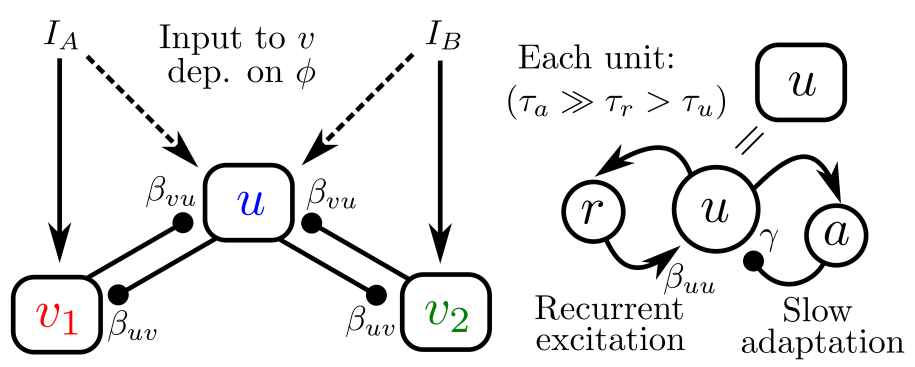


With a bias to pop. #2 ($\psi > 0$), inputs given by:

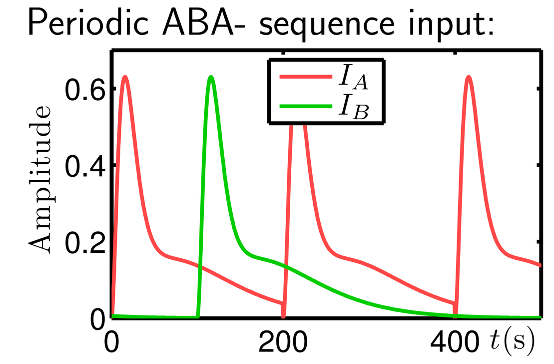
$$I_v = \psi S_v(u_2), \quad \hat{I}_1 = I_0\left(\frac{I_1 + I_v}{I_1 + I_2 + I_v}\right), \quad \hat{I}_1 = I_0\left(\frac{I_2}{I_1 + I_2 + I_v}\right).$$

Auditory streaming model with recurrent excitation

Each of three populations receives a different proportion of input dependent on the frequency separation ϕ between two tones A and B.



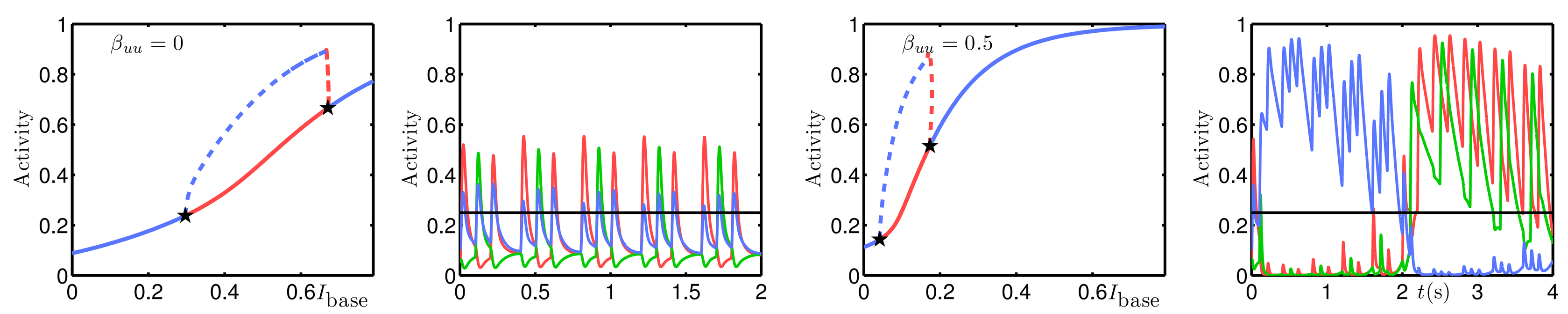
Periodic ABA- sequence input:



$$\tau_u \dot{u} = -u + S_f(\beta_{uu} r_u - \beta_{vu}(v_1 + v_2) - \gamma a_u + S_\phi(I_A + I_B)),$$
$$\tau_a \dot{a}_u = (-a_u + u), \quad \tau_r \dot{r}_u = (-r_u + u),$$
$$\tau_u \dot{v}_1 = -v_1 + S_f(\beta_{uu} r_1 - \beta_{uv} u - \gamma a_1 + I_A),$$
$$\tau_a \dot{a}_1 = (-a_1 + v_1), \quad \tau_r \dot{r}_1 = (-r_1 + u),$$
$$\tau_u \dot{v}_2 = -v_2 + S_f(\beta_{uu} r_2 - \beta_{uv} u - \gamma a_2 + I_B),$$
$$\tau_a \dot{a}_2 = (-a_2 + v_2), \quad \tau_r \dot{r}_2 = (-r_2 + u).$$

- Input I_A to the "A" population v_1 and I_B to the "B" population v_2
- For increasing ϕ, less input to the "AB" population u as controlled by a sigmoid function S_ϕ
- A **recurrent ndma excitation** r keeps activity up when input is low or silent.

- Bifurcation study with constant $I_A = I_B = I_{\text{base}}$,
- Simulations with $I_{\text{base}} = 0$ and periodic input shown above:



Recurrent excitation allows for a sustained response with "AB" (integrated) or "A" + "B" (segregated) dominant populations.

Numerical methods

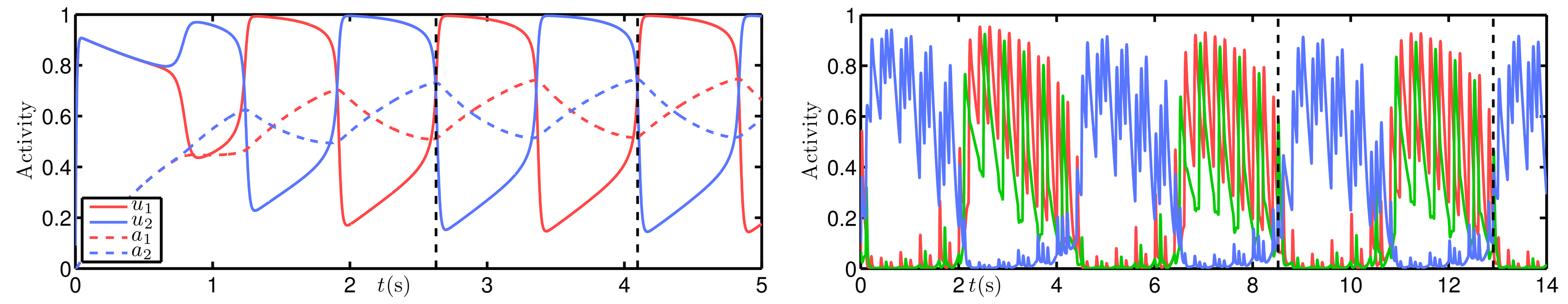
- Constant-input cases studied directly with AUTO07P.
- Periodic-input cases using MATLAB's ode23t with reduced RelTol and MaxStep.

Differential effects of stimulus strength and volitional control

Set parameters in both models for equidominance

As in [1] and [2] we tune the parameters in both models for equidominance:

- between u_1 and u_2 in the canonical model ($T_1 = T_2$)
- between the integrated and segregated states in the auditory model ($T_{\text{int}} = T_{\text{seg}}$)



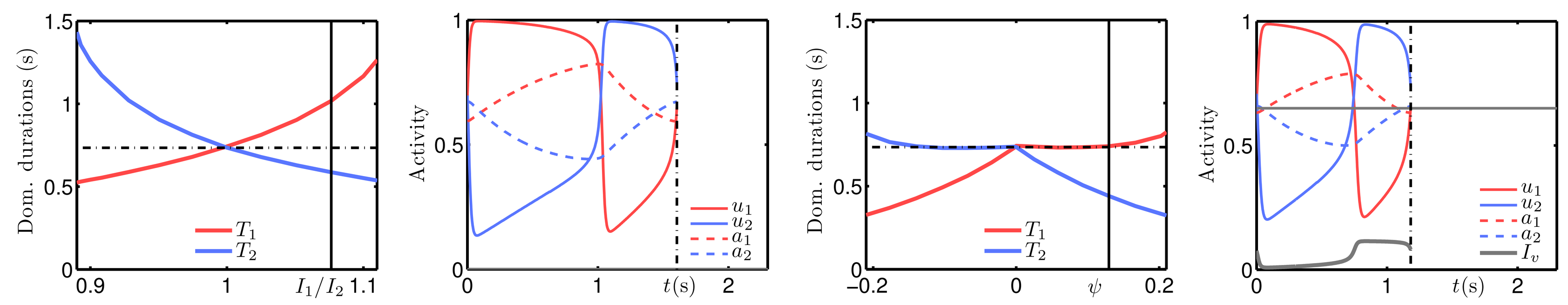
Input and control manipulations for the canonical rivalry model

For stimulus strength manipulations the dominant state is affected the most, as in [1].

With volitional bias towards one state, the other duration is affected the most, as in [2].

Increase input to pop. #1: $I_1/I_2 > 1$

Attend to state #1: $\psi > 0$



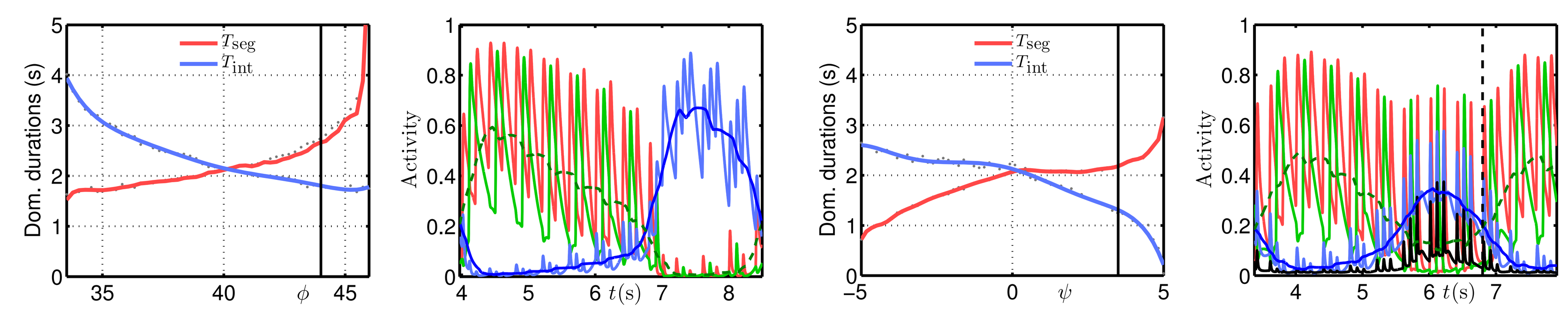
Input and control manipulations for the auditory streaming model

With a bias to integrated the inputs to the u-, v_1-, and v_2-equations become

$$I_u = (1 + \psi S_v([v_1 + v_2]/2) S_\phi(I_A + I_B), \quad I_{v_1} = I_A, \quad I_{v_2} = I_B.$$

Increase input to integrated: $\phi > 40$

Attend to integrated: $\psi > 0$



Same result holds for the auditory model.

Key results:

- The proposed volitional mechanism with state-dependent inputs resolves the apparent conflict by accounting for differences between direct input strength manipulations and top-down attention.
- A three-population model with periodic inputs for the auditory case has been presented, to which our general result extends.
- **Our modeling results can explain important differences between input strength and attention that generalize across sensory modalities.**

[1] Moreno-Bote R, Shpiro A, Rinzel J and Rubin N, **Alternation rate in perceptual bistability is maximal at and symmetric around equi-dominance.** *J. Vision* 2010
[2] Pressnitzer D, and Hupé, JM, **Temporal dynamics of auditory and visual bistability reveal common principles of perceptual organization.** *Current Biology* 2006
[3] Shpiro A, Curtu R, Rinzel J and Rubin N, **Dynamical characteristics common to neuronal competition models.** *J. Neurophys* 2007
[4] Micheyl, C, Tian B, Carlyon RP and Rauschecker JP, **Perceptual organization of tone sequences in the auditory cortex of awake macaques**, *Neuron* 2005

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