Fixed Threshold Mixing Model (Draft)

Last updated: November 12, 2018

Contents

Chris: I am planning to first add all relevant figures to this doc so that we can then discuss which ones to highlight in a more finalized document – but let me know if you think of a better way to do this!

1 Overview

The goal of this investigation is to understand how varying one or more or the parameters of the fixed threshold model affects the behavior of single line (A or B) colonies and mixed colonies.

Here I think we might want to insert a list of specific patterns that (we think) we observe in the data:

- Different mean frequencies of task 1 performance between line A and B ants
- etc.

so that we can agree on what it is that we want the model to do.

2 Plan

2.1 Original model in Ulrich et al. [1]

Parameter	Definition	Model values	Notes
n	No. of individuals	$1 \leq n \leq 16$	
m	No. of tasks	$m = 2$	
δ_j	Task-specific demand rate	$\delta_j = \delta = 0.6$	Assumed to be the same across all tasks
α_j	Task-specific performance efficiency	$\alpha_j = \alpha = m(= 2)$	Assumed to be the same across all tasks
μ_j	Task-specific mean threshold	$\mu_j = \mu = 10$	Assumed to be the same across all tasks
σ_j	Task-specific threshold variation	$0 \leq \sigma_j = \sigma \leq 0.5$	Assumed to be the same across all tasks
η	Threshold stochasticity	$1 \leq \eta \leq 30$	
τ	Quit probability	$\tau = 0.2$	

Table 1: Parameterization of the fixed threshold model in Ulrich et al. [1]. Note that the model values only include those in Fig. 3 of [1].

2.2 *Varying* across lines and *fixing* across tasks

Parameter	Varied?	Model Value(s)	Notes / Biological Interpretation
n	Fixed	$n = 4, 16$	Based on colony sizes used in the mixing experiments
m	Fixed	$m = 2$	For simplicity; no compelling reason to change from [1]
δ	Fixed	$\delta = 0.6$	Stimulus increase rate should not depend on line
α	By line	$\alpha^A = 2, \alpha^B = 6$	Line B ants are be more efficient than line A ants at both tasks
μ	By line	$\mu^A = 10, \mu^B = 20$	Line B ants have higher mean thresholds than line A ants for both tasks; creates a bimodal distribution of thresholds in the mixed case
σ	By line	$\sigma^A = 0.1, \sigma^B = 0.3$	Line B ants have a greater range of internal thresholds than line A ants; seems unlikely since the variance in RMSD does not appear to differ between lines A and B, but included here for thoroughness
η	By line	$\eta^A = 7, \eta^B = 14$	Line B ants respond more deterministically to both stimuli than line A ants
τ	By line	$\tau^A = 0.2, \tau^B = 0.6$	Line B ants tend to spend less time on a given task than line A ants; could be correlated to their relative cycle lengths (A has slower cycles than B)

Table 2: Varying parameters by line.

2.3 *Fixing* across lines and *varying* across tasks

Parameter	Varied?	Model Value(s)	Notes / Biological Interpretation
n	Fixed	$n = 4, 16$	Based on colony sizes used in the mixing experiments
m	Fixed	$m = 2$	For simplicity; no compelling reason to change from [1]
δ	By task	$\delta_1 = 0.6, \delta_2 = 1.8$	Demand for task 2 increases more rapidly than that for task 1; δ could capture the difference between A larvae vs. B larvae?
α	By task	$\alpha_1 = 2, \alpha_2 = 6$	Ants are more efficient at task 2 than at task 1
μ	By task	$\mu_1 = 10, \mu_2 = 20$	The mean threshold for task 2 is higher than that for task 1
σ	By task	$\sigma_1 = 0.1, \sigma_2 = 0.3$	Ants vary more in their international thresholds for task 2 than those for task 1
η	Fixed	$\eta = 7$	Stochasticity in behavior is inherent to the ants, not tasks
τ	By task	$\tau_1 = 0.2, \tau_2 = 0.6$	Ants have a shorter period for task 2 relative to task 1 (e.g., task 2 is more taxing so they need to take more breaks)

Table 3: Varying parameters by task.

3 Results

3.1 Base case

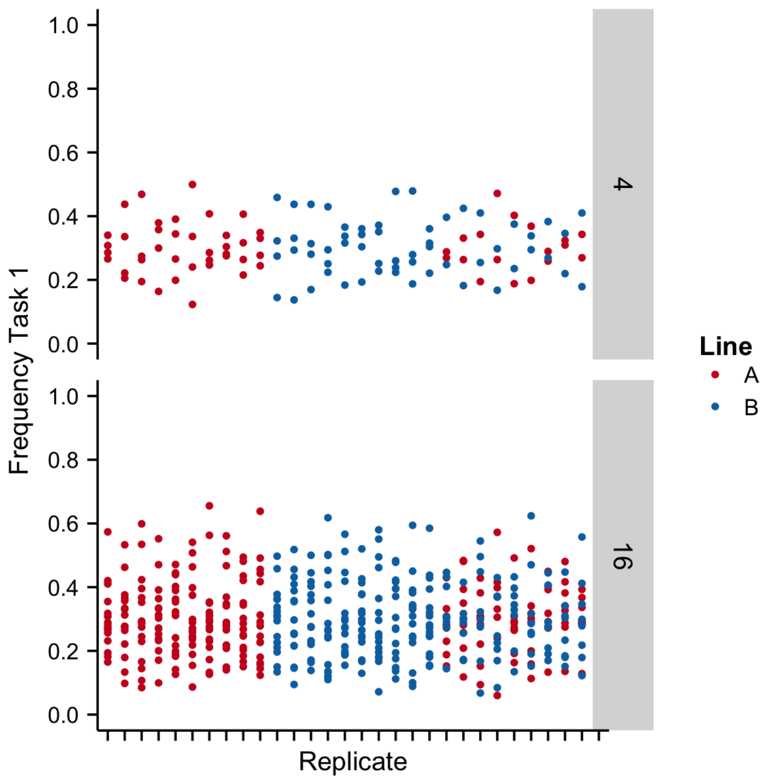

Figure 1: Base case. Parameter values for both tasks (task 1 and task 2) and lines (line A and line B) as as follows: $\delta = 0.6$, $\alpha = 2$, $\mu = 10$, $\sigma = 0.1$, $\eta = 7$, $\tau = 0.2$.

3.2 *Varying* across lines and *fixing* across tasks

3.2.1 Varying task performance efficiency α by line

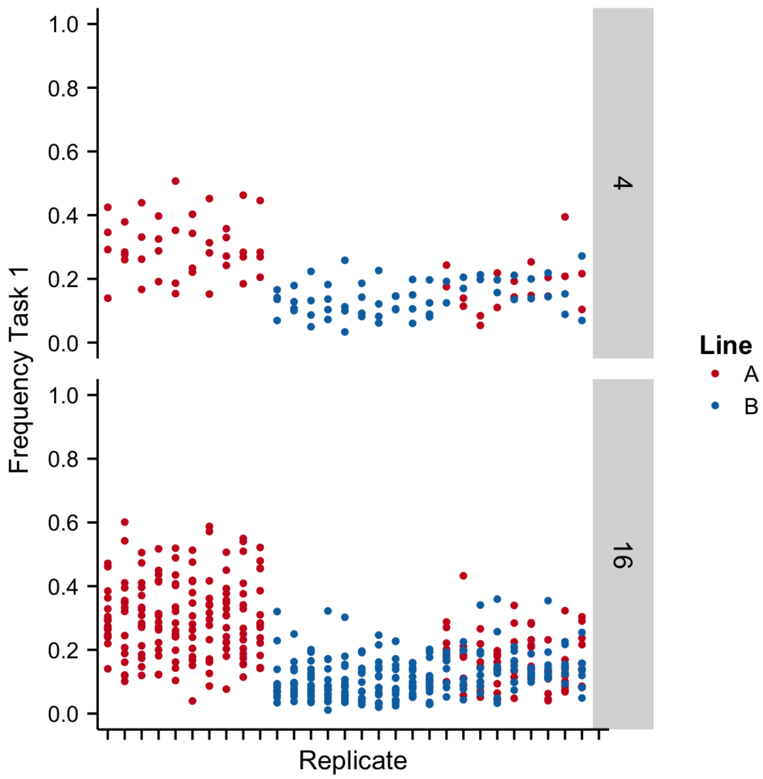

Figure 2: Varying task performance efficiency (α) by line. The parameter values are identical to those in the base case (Fig. 1) with the exception of line-specific efficiencies, $\alpha^A = 2, \alpha^B = 6$.

Interpretation: Given identical demand rate for the two tasks, B ants spend less time performing tasks because the stimuli decrease more quickly (only task 1 is shown here, but would expect the same relation between A and B for task 2). There seems to be some **'behavioral contagion'** (in Yuko's terms), i.e., the A and B ants become more similar in behavior.

3.2.2 Varying mean threshold μ by line

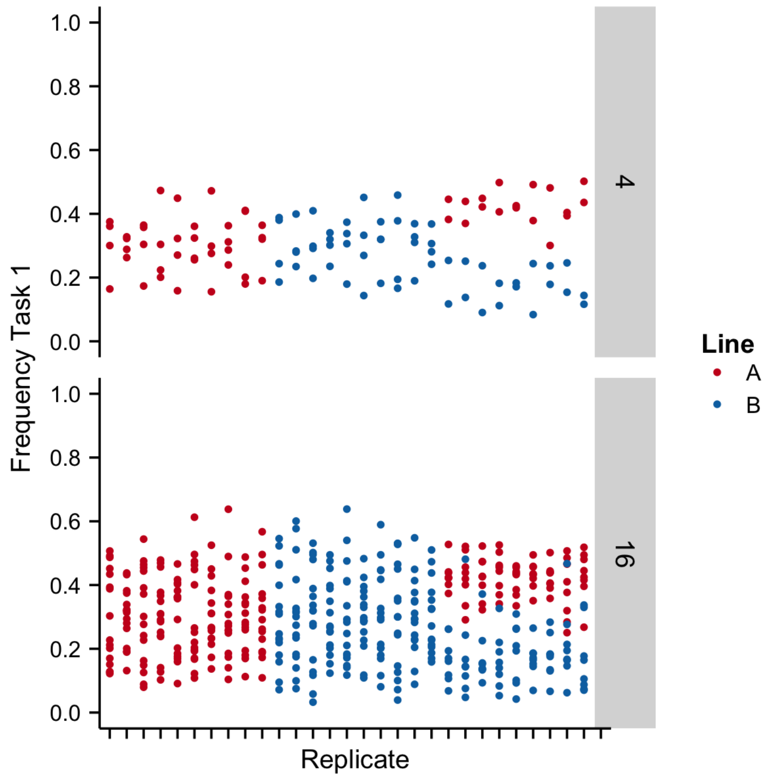

Figure 3: Varying mean threshold (μ) by line. The parameter values are identical to those in the base case (Fig. 1) with the exception of line-specific mean thresholds, $\mu^A = 10, \mu^B = 20$.

Interpretation: Changing the mean internal threshold by line **does not** change mean frequency of task 1 performance in single-line colonies. In the mixed case, we observe the expected increase in behavioral specialization.

3.2.3 Varying threshold variance σ by line

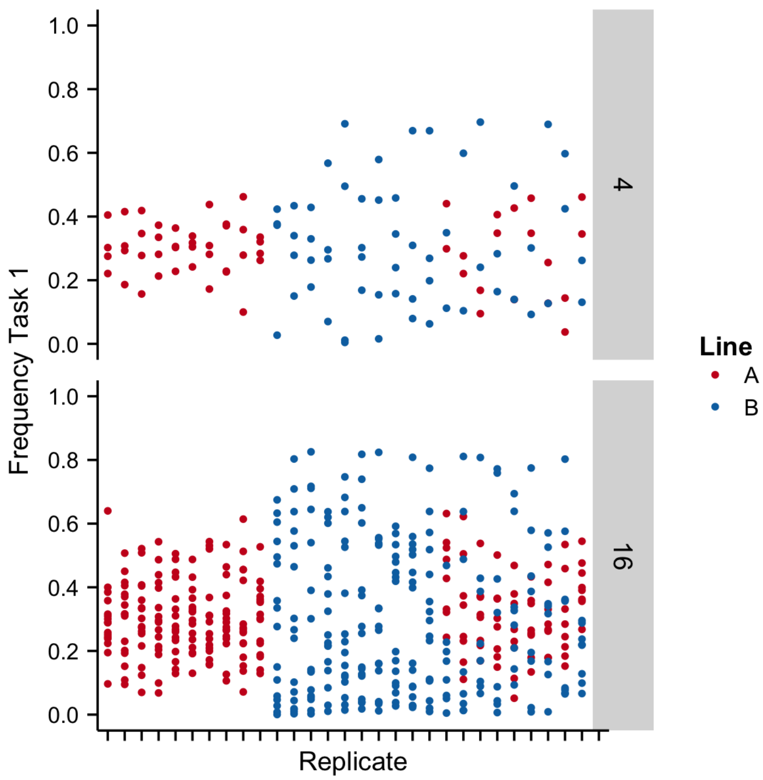

Figure 4: Varying threshold variance (σ) by line. The parameter values are identical to those in the base case (Fig. 1) with the exception of line-specific threshold variances, $\sigma^A = 0.1, \sigma^B = 0.3$.

Interpretation: Varying the threshold variance **does not** appear to alter the mean frequency of performing task 1. It is unclear from this particular plot if, in the mixed case, the mean of each line differs from the mean of the corresponding single-line colony (we would expect it to, since the line with higher variance is more likely pick up tasks, although this effect might be counterbalanced by those with high-end thresholds that don't perform tasks as often), but we could easily check this.

If we do not observe a difference in the variance of task performance between the two types of ants (in all three experiments), then it is unlikely that this parameter governs the behavior of the single-line vs. mixed colonies. Whether we observe such a difference or not should be able to be answered empirically (the data already there, additional statistical tests needed).

3.2.4 Varying threshold stochasticity η by line

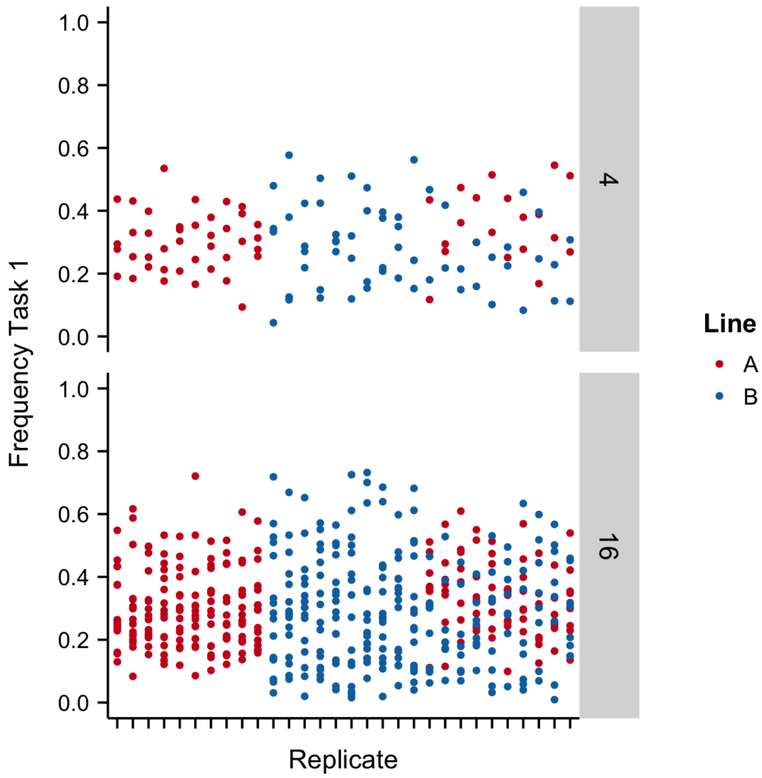

Figure 5: Varying threshold stochasticity (η) by line. The parameter values are identical to those in the base case (Fig. 1) with the exception of line-specific threshold slope parameters, $\eta^A = 7, \eta^B = 14$.

Interpretation:

3.2.5 Varying quit probability τ by line

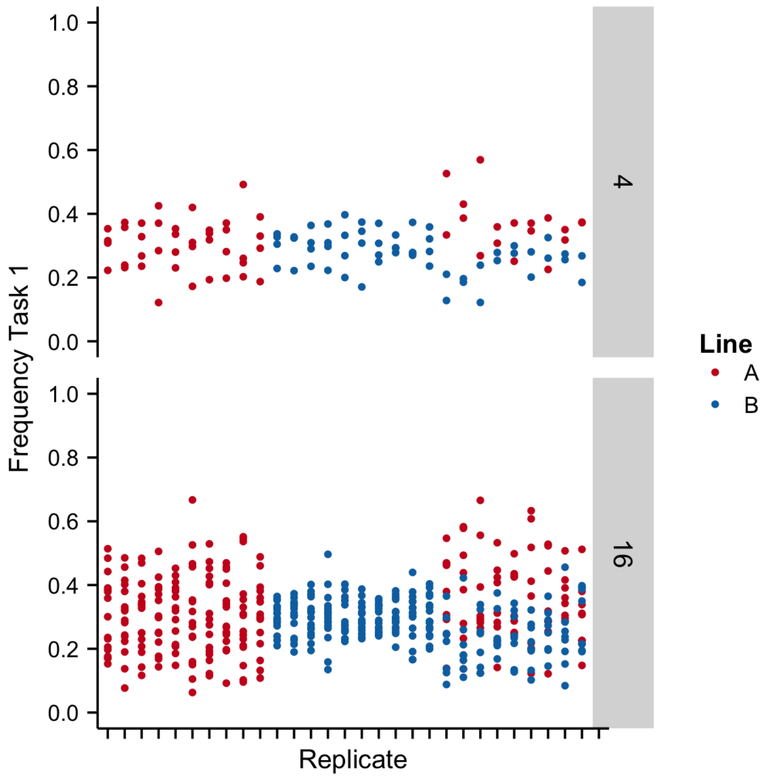

Figure 6: Varying quit probability (τ) by line. The parameter values are identical to those in the base case (Fig. 1) with the exception of line-specific quit probabilities, $\tau^A = 7, \tau^B = 14$.

Observation: Higher quit probability ($\tau^B = 0.6$) means that line B ants experience greater turnover rate, which results in smaller variance in frequency of performing task 1. If there is a way to count the number of times the ants "switch tasks" (i.e. go to and from the nest), then we could measure a proxy for the average period that the ants spend on one task. The quit probability can be estimated as its inverse.

3.3 *Fixing* across lines and *varying* across tasks

3.3.1 Varying task performance efficiency α by task

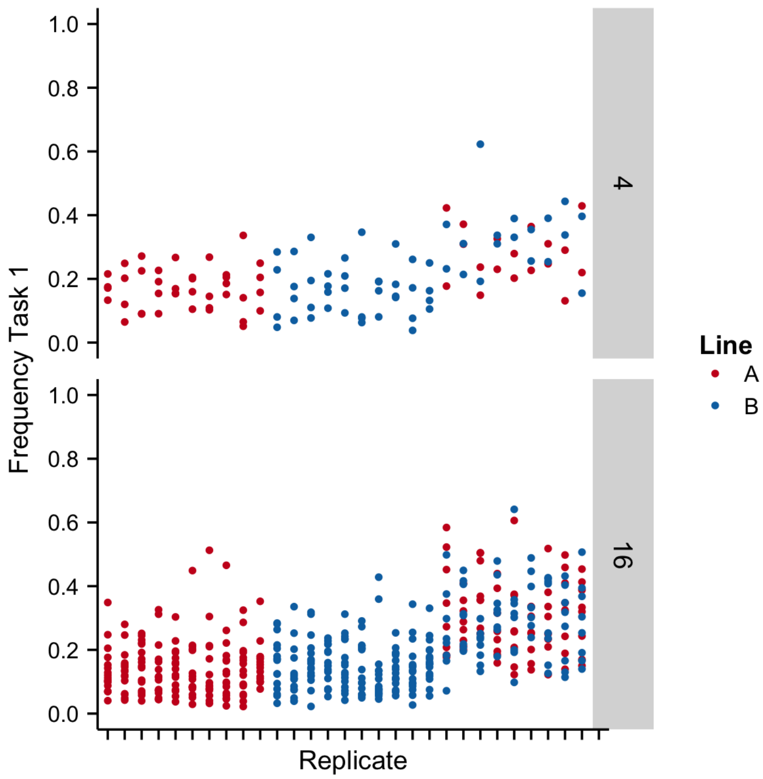

Figure 7: Varying task performance efficiency (α) by task. The parameter values are identical to those in the base case (Fig. 1) with the exception of task-specific efficiencies, $\alpha_1 = 2, \alpha_2 = 6$.

Observation: In the single-line cases, the average task 1 performance frequency decreases. This is counterintuitive because I expected that the ants would spend more time performing task 1 because they are less efficient...? Also, what is happening in the mixed case?

3.3.2 Varying mean threshold μ by task

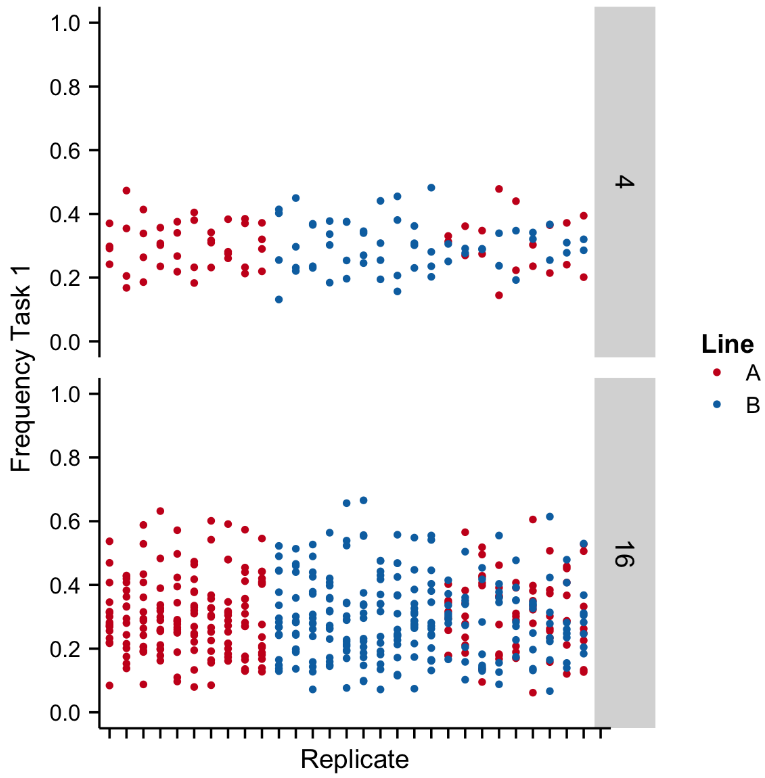

Figure 8: Varying mean threshold (μ) by task. The parameter values are identical to those in the base case (Fig. 1) with the exception of task-specific mean thresholds, $\mu_1 = 10, \mu_2 = 20$.

Observation: No visible change compared to the base case. My intuitive interpretation is that the stimulus for the task with the higher mean threshold (in this case task 2) decreases more slowly, which means that the ants have a smaller probability for performing that task (task 2) but over a longer period of time.

3.3.3 Varying threshold variance σ by task

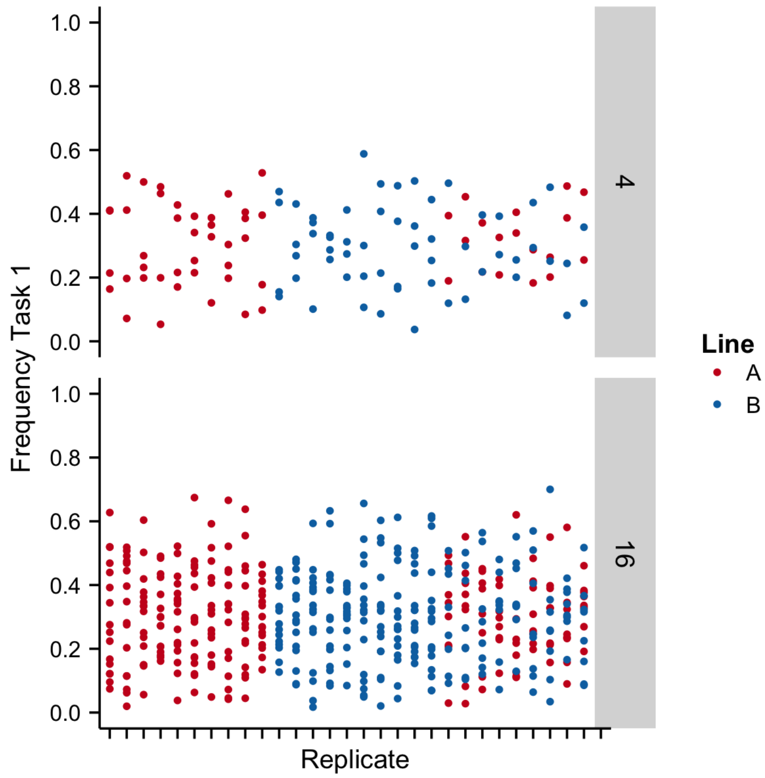

Figure 9: Varying threshold variance (σ) by task. The parameter values are identical to those in the base case (Fig. 1) with the exception of task-specific threshold variances, $\sigma_1 = 0.1, \sigma_2 = 0.3$.

Observation: Changing the threshold variance for one task (task 2 in this case) affects the performance frequency of the other task (task 1) as well, as expected. Variance in task 1 performance frequency is greater than in the base case.

3.3.4 Varying task demand rate δ by task

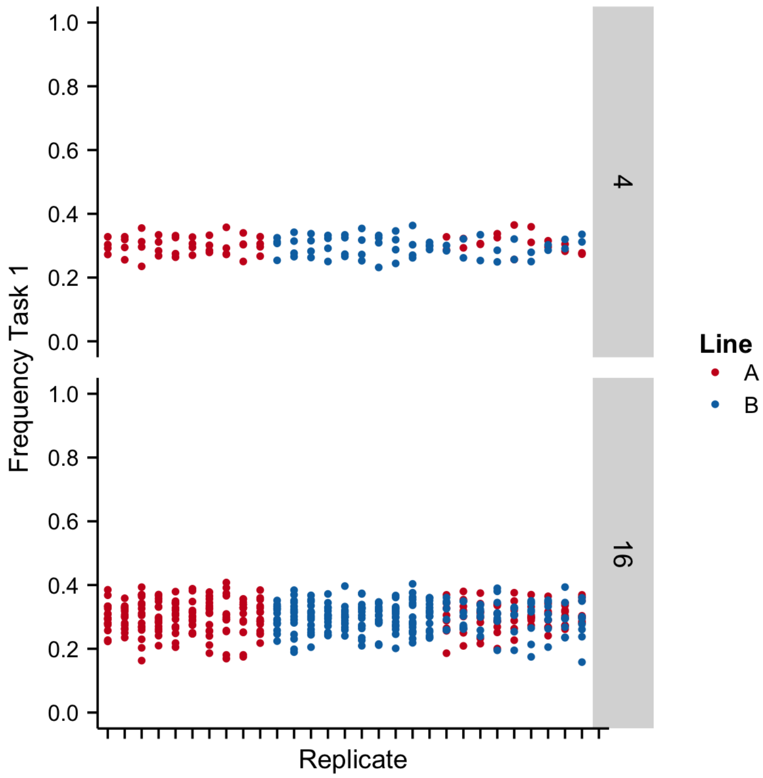

Figure 10: Varying task demand rate (δ) by task. The parameter values are identical to those in the base case (Fig. 1) with the exception of task-specific demand rates, $\delta_1 = 0.6, \delta_2 = 1.8$.

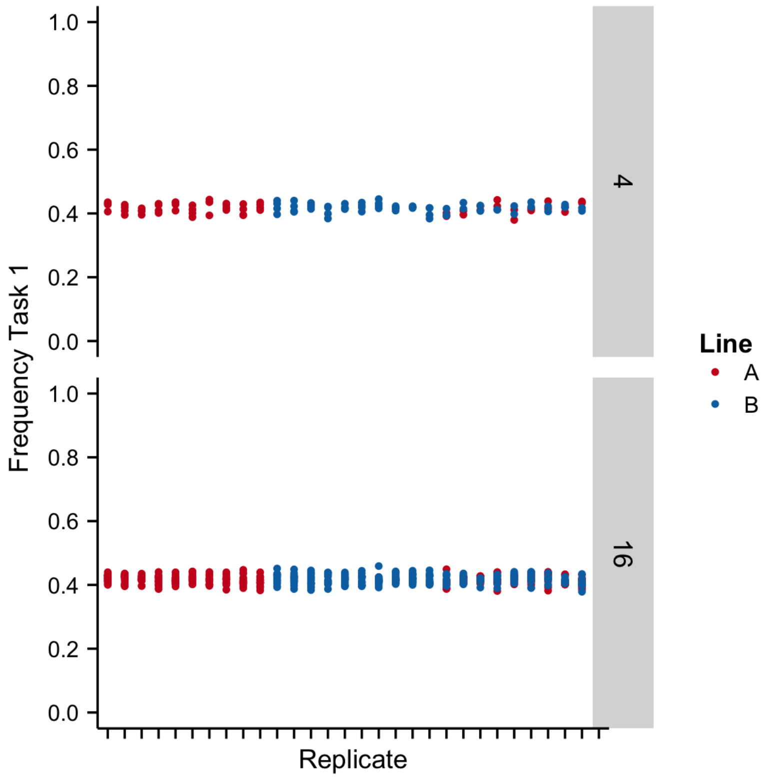

Figure 11: Higher task demand rate (δ) for both tasks compared to the base case, with $\delta_1 = \delta_2 = 1.8$.

3.4 *Varying* across lines and *Varying* across tasks

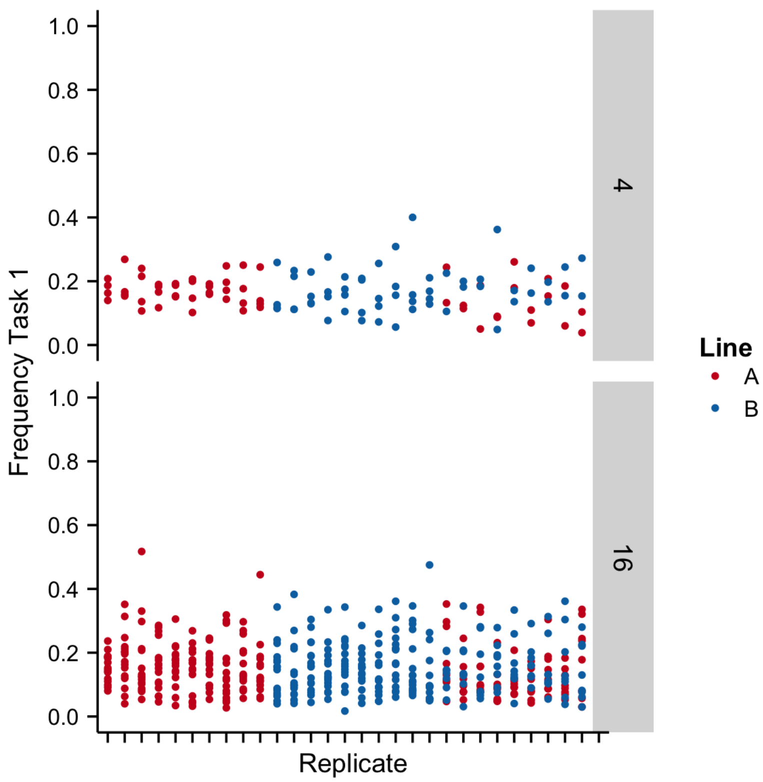

Figure 12: Varying task efficiency (α) by both line and task. The line-and-task-specific efficiencies are, $\alpha_1^A = 2,\ \alpha_2^A = 6,\ \alpha_1^B = 6,\ \alpha_2^B = 6$.

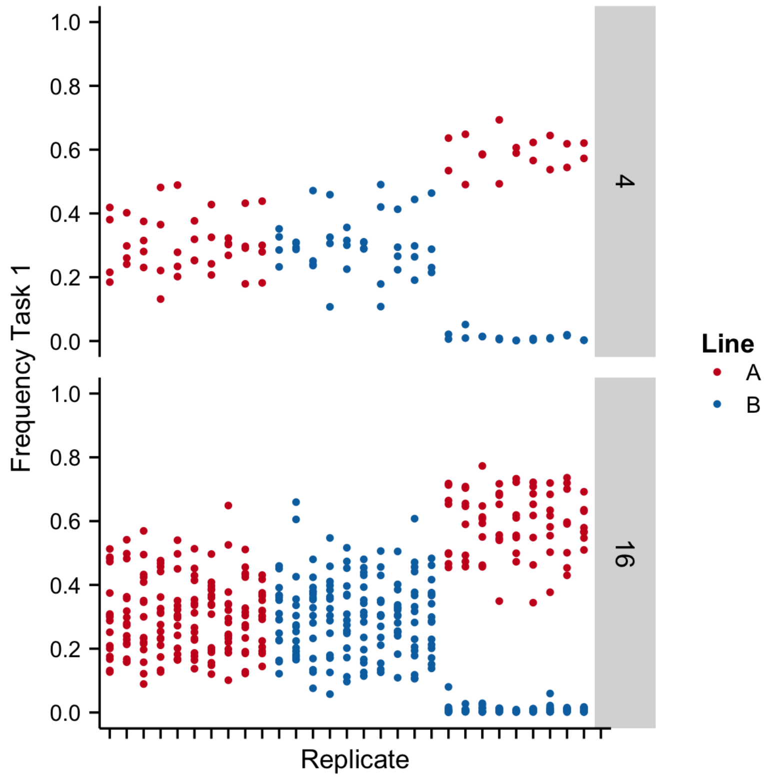

Figure 13: Higher task demand rate (δ) for both tasks compared to the base case, with $\mu_1^A = 10,\ \mu_2^A = 20,\ \mu_1^B = 20,\ \mu_2^B = 10$.

4 Conclusions so far

- Varying task performance efficiency (α) by line
  - produces different mean task 1 performance frequencies
  - produces the 'behavioral contagion' pattern
- Varying mean threshold (μ) and quit probability (τ) by line
  - does NOT produce different mean task 1 performance freq.
  - produces the 'behavioral amplification' pattern
- Seems biologically unlikely that the threshold variance (σ) varies by line

References

[1] Y. Ulrich, J. Saragosti, C. K. Tokita, C. E. Tarnita, D. J. C. Kronauer, "Fitness benefits and emergent division of labour at the onset of group living," *Nature*, vol. 560, pp. 635-638, Aug. 2018.