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# Neural Circuit Dynamics of Primary Visual Cortex

## Testing Neural Circuit Mechanisms Underlying Visual Illusions of Texture Border and Size

## Laboratory Report

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**Abstract**

How does the human brain recognize and localize objects? One strategy is to localize the borders between distinct visual textures. Li's (2000) neural circuit model of primary visual cortex (V1) proposes that texture borders are localized through lateral neural interactions in V1, specifically iso-oriented inhibition and co-linear excitation. However, Popple (2003) measured border localizations which are inconsistent with the biases predicted by the V1 model. So far, it remained unclear if the limitations of Popple's psychophysical experiment, specifically central viewing and prolonged stimulus duration of 150 ms, allowed confounding feedback from visual areas beyond V1. In this experiment we test if the biases in localizing borders between orientation textures contradict the V1 model even in the case of stimuli presented for durations as short as 20 ms in peripheral vision. We replicate and extend Popple's experiment, and compare our results with predictions simulated by a replicated version of the V1 model. The biases measured in this experiment might falsify the V1 model explanation and support alternative neural mechanisms of visual texture segmentation. Else, the V1 model and our results predict a new visual size illusion inverse to the well-known Helmholtz illusion (1867). Future comparative study of both illusions might open up a new experimental and theoretical avenue to understand the contributions of V1 and higher visual areas to not only visual texture segmentation but also size perception.

# 1 Introduction

- Scientific issue: How objects recognized and localized? One startegy: localize border between textures. Neural mechanisms? - [1] model: neural circuits in V1 through iso-oriented inhibition and co-linear excitation, see Fig. 1.I - [2] experiment: measured border localization inconsistent with bias predicitons by model -> limited in stimulus duration without visual backward masking -> confounding feedback from higher visual areas [**something_about_feedback_speed?**, 2, 3] -> limited in central viewing -> confounding feedback from higher visual areas [4] - objectives of study: 1. replicate V1 model 2. test predictions of model 3. replicate and adapt experiment for borders in periphery, shown only 20ms with visual backwards masking

# 2 Methods

1. V1 model replication: - implemented available at `https://github.com/iakioh/V1SH_model` - using Euler method for simulation time of $T = 12\alpha$ where $\alpha$ denotes membrane time constant, with a typical step size of $\delta t = 0.01\alpha$ - model parameters as documented for original model [5, 6] - exception: orientation-unspecific normalization for excitatory pyramidal cell, following notation with location $i$ and tuned to orientation $\theta$ as

$$I_o = 0.85 - 2.0 \left[ \frac{\sum_{j \in S_i} \sum_{\theta'} g_x(x_{j\theta'})}{C} \right] \tag{1}$$

with $C = 16$ following the original implementation, not documentation where $C = \sum_{j \in S_i} 1 = 25$ using a Manhatten grid for sampling visual input - initial condition: resting state for no visual input (without top-down feedback)

$$y_0 = I_c/\alpha = 1.0 \tag{2}$$

$$x_0 = \left( I_o - g_y(y_0) \cdot \sum_{\theta'} \psi(\theta') \right) /\alpha = -1.65 \tag{3}$$

2. predictions: - border saliency = highest saliency of grid column close, i.e. maximally 3 columns distance, to border. Saliency of grid columns = average saliency of all column locations. Saliency of a location = highest (temporally averaged) pyramidal response to inputs at this location. Z-scored over all locations $i$. - border localization bias = distance between most salient column close to border and actual border, i.e. midpoint between textures. Positive if bias towards orientation texture parallel to border, else negative.
3. experimental design: - see Fig. 2.I - TODO: add ...

# 3 Results

1. Model replication: - successful replication of V1 model verified by visualization of all model parameters, including connections, and comparison with expectation and original model [5] as well as replication of - model responses to calibration inputs, see Fig. 1.II,

- filling-in and avoiding leaking-out [6, 7] - temporal evolution of responses to texture border [6], - the figure ground and medial axis effect [6, 8] - summation curve for grating disc inputs showing cross-orientation enhancement [6, 8], - dynamical properties of reduced two-point EI network [6, 9]
2. Predictions: - see Fig. 2.II, for medium to high input intensities - for higher number of rows border localization bias positive, i.e. towards texture parallel to border, confirming simulation by [1], but negative for lower number of rows; confirming simplified argument by [2] - additionally, saliency of border higher for higher number of rows, because for lower rows co-linear excitation of texture vertically oriented to border dominates over iso-oriented inhibition between small number of rows

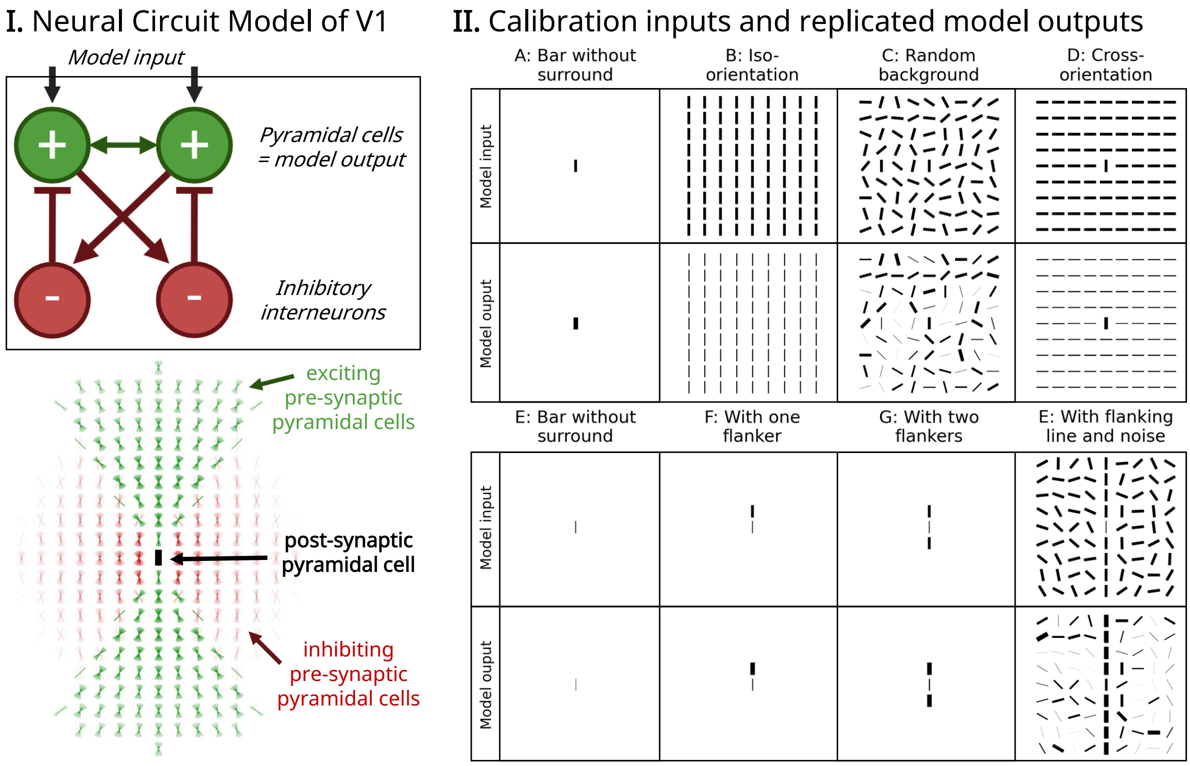


Figure 1: Model replication. I. Sketch of neural circuit model of primary visual cortex (V1). Top: The model consists of two cell types, excitatory pyramidal cells, which are the in- and output of the model, and inhibitory interneurons. Bottom: Orientation and location of bars depict tuning and receptive field of edge / bar detector neurons in V1. The excitatory co-linear and inhibitory iso-oriented interactions mediate contextual influences underlying saliency computations in V1. II. Inputs and replicated outputs for model calibration. A-D show contextual effects dominated by iso-orientation supression. E-H show contextual effects dominated by co-linear facilitation.

# 4 Discussion

- important findings: - V1 model successfully replicated, with minor improvements to documentation - confirmed switch in localization bias and predicted decreased saliency

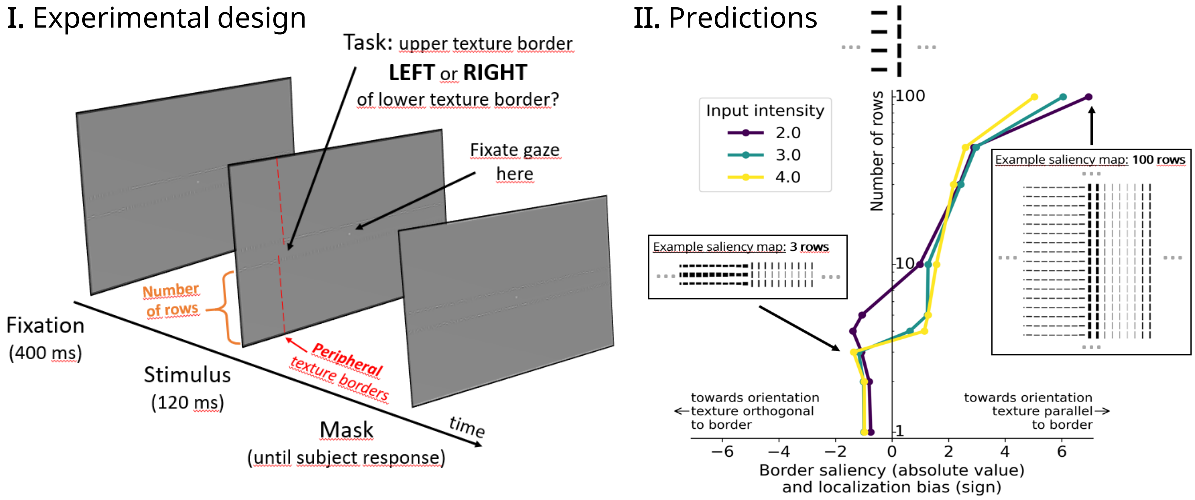


Figure 2: Experimental design and predicitions. I. One example trial of the proposed experiment. After subjects fixate for 400 ms, the stimulus with two texture borders of varying horizontal displacement and number of rows is shown in the periphery for 120 ms. Visual backward masking afterwards reduces confounding extrastriatal feedback. Subjects are forced to decide between two alternative choices: is the upper texture border left or right of the lower texture border? II. Predicted saliency and localization of borders given orientation textures of varying height. The absolute value and sign of the x-axis show border saliency (z-scored, here found to be positive for all predictions) and the direction of the localization bias as indicated by the sketched texture border above the y-axis, respectively. The y-axis shows the number of rows of the input texture, with examplatory predicted saliency maps for the case of 3 and 100 rows. For medium to high input intensity and increasing number of rows, the border saliency increases after a sign switch of the border localization bias. Due to wrap-around boundary conditions and an model input size of 100 rows, 100 rows indicates the case of texture ends beyond the visual input field.

of texture border - designed improved experiment to test this prediction
- limitations: - leaking-out in replicated and original model in dependence of numerical accuracy - predictions made for approximate case, not real stimuli - missing data collection and analysis
- implications of the work, open questions / future studies: - biases and sensitivity might falsify V1 model explanation -> support alternative neural mechanisms, e.g. in higher visual areas - else, assuming visual size estimation consistent with border localization, model predicts visual size illusion inverse to well-known Helmholtz illusion [10] - future comparative study of both illusions for new experimental and theoretical avenue to understand contributions of V1 and higher visual areas to visual texture segmentation and size perception

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