# Why is Disparity-Modulation Acuity so Low?

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## Purpose:

Spatial acuity for modulations of stereoscopic depth is much lower than acuity for luminance modulations.[1,2] To understand the causes of low disparity-modulation acuity, we examine four possible factors:

- Stimulus constraints (Figure 1),
- Disparity gradient limit (Figure 1),
- Front-end filtering (Figures 1 & 3),
- The correspondence problem (Figure 2 & model).

## Method:

**Stimulus**: RDS of disparity-modulated sinewave gratings. Orientation = +/-20 deg from horizontal, multiple dot densities, two amplitudes, random phase, two viewing distances.

**Task**: Forced-choice identification of orientation. No feedback.

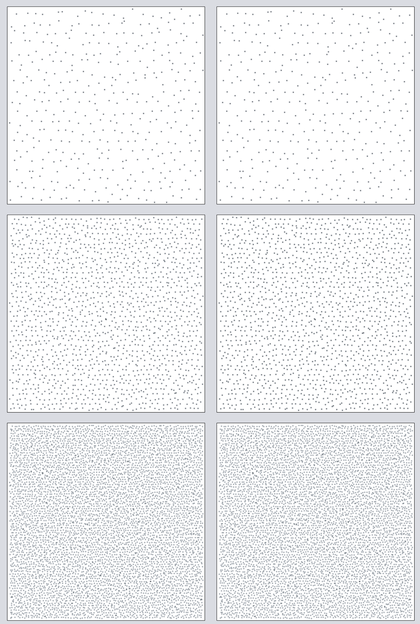
**Procedure**: Find the highest discriminable spatial frequency for each dot density using adaptive staircases.

## Demonstration: Sweep disparity gratings.

In each RDS, the frequency of disparity modulations decreases from top to bottom:

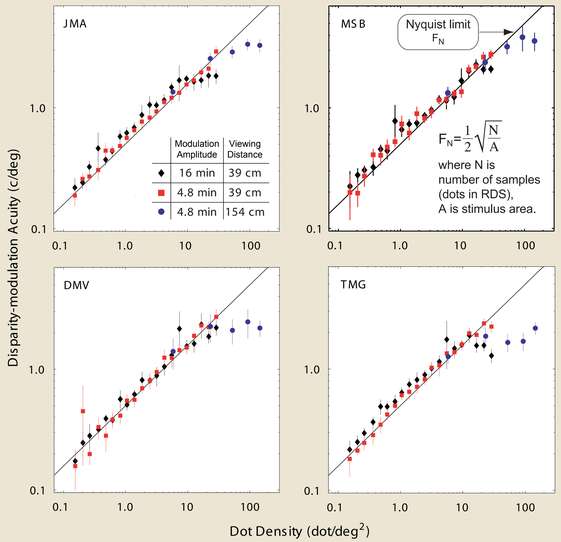
The RDSs differ in dot density. Find the highest frequency you can see in each RDS. Notice it's higher when density is higher.

**SCALE INVARIANCE**: The highest visible frequency scales with viewing distance. As you move farther from the demo, the row, corresponding to the highest frequency at which the grating is visible, doesn't change.



## Results

### Figure 1: Effects of Sampling Density and Modulation Amplitude



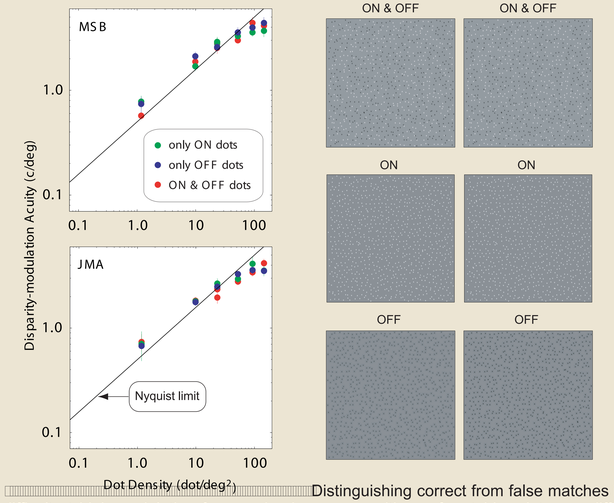

* Rising segment of the data:
- Across ~2 log units of dot density,
- Slope = 0.5; implies **SCALE INVARIANCE**,
- Predicted by the Nyquist limit $F_N$ of RDS,
- Thus, sampling density in the stimulus affects disparity-modulation acuity.

* Asymptotic segment of the data:
- Acuity asymptotes at 2-4 c/deg with corrected optics (**blue** data points),
- Could be caused by a minimal size of binocular cross-correlation window (as suggested by the model in the right panel).

**Black** data points at high densities correspond to a peak-to-trough disparity gradient of ~1.

Decreasing the modulation amplitude (**red** and **blue** points) decreases the gradient and acuity improves at high densities. Thus, the disparity gradient limit also affects acuity.

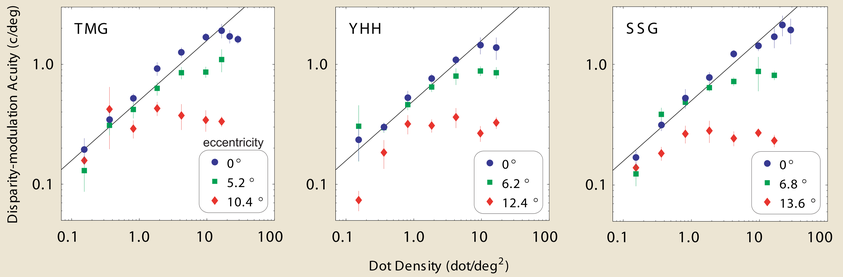
### Figure 2: Effect of the Contrast Polarity of Dots



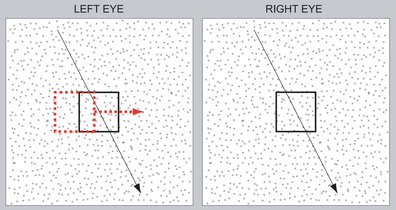

Distinguishing correct from false matches is difficult at high modulation frequencies because positions of matching dots can differ substantially in the two eyes. In theory, the correspondence problem is easier when dots have different contrast polarities.[3] This manipulation, however, does not affect disparity-modulation acuity.

### Figure 3: Effect of Eccentricity

Disparity waveform presented in circular patch ~8 deg diam. at different retinal eccentricities. Lower acuity in the periphery suggests that disparity-modulation acuity is also limited by low-pass filtering in front-end visual mechanisms.[4,5]




## Cross-correlation Model of Disparity-Modulation Acuity



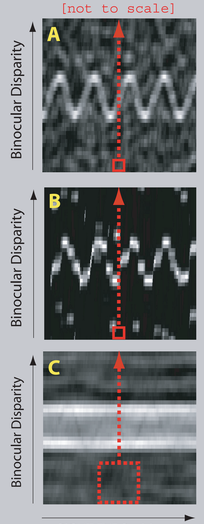

The cross-correlation window moves in direction orthogonal to grating orientation (the oblique **black arrow**). At each location along the path in the RIGHT EYE, cross-correlation is computed for multiple horizontally-offset locations of the window in the LEFT EYE (the **red arrow**). How does the window size affect model performance?

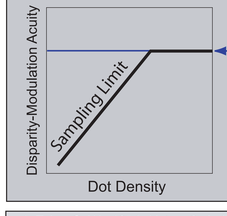
[not to scale]

**A. Small Correlation Window, High Dot Density:**
With an appropriate window size and sufficiently large number of dots, the cross-correlator signals the disparity waveform clearly.

**B. Small Correlation Window, Low Dot Density:**
With lower dot density, cross-correlator finds MORE FALSE MATCHES and disparity waveform is not signaled as clearly. Further decrease in dot density leads to failure to signal waveform altogether. Density at which failure occurs roughly follows Nyquist limit (Figure 1).

**C. Large Correlation Window, High Dot Density:**
Cross-correlation window too large to signal waveform. Corresponds roughly to the high-density acuity limit (**blue** data points, **Figure 1**).




Although the visual system presumably uses matching windows of multiple sizes, the model suggests that there is a smallest size that determines disparity-modulation acuity under optimal conditions.

## Conclusions:

Disparity-modulation acuity depends on the following four factors: **1. Sampling constraints of the stimulus:** in the task of identifying stereoscopic form, acuity is limited by the Nyquist frequency of the sampling pattern (Figures 1-3), **2. Disparity gradient** (Figure 1): when high, sets the limit of acuity, **3. Front-end low-pass filtering:** Disparity-modulation acuity depends on eccentricity (Figure 3), **4. Correspondence problem:** **The computational problem of finding correct binocular matches requires a size of binocular cross-correlation window that ultimately determines the highest acuity.**

1. Tyler, C. W., 1974. *Nature* **251**, 140-142.
2. Bradshaw, M. F. & Rogers, B. J., 1999. *Vis. Res.* **39**, 3049-3056.
3. Harris, J.M. and Parker, A.J., 1995. *Nature* **374**, 808-811.
4. Campbell, F.W. & Green, D.G., 1965. *J. Physiol.* **181**, 437-445.
5. Banks, M.S., Sekuler, A.B., & Anderson, S.J., 1991. *JOSA A* **8**, 1775-1787.

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