# The brain benefits of super-resolution displays

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# **Benefits** of super-resolution display from the viewpoints of brain science

1. Reduces information loss in pixelated displays

→ More realistic perception

2. Improves dynamic SNR of the image

→ Less load to the brain & immersion in the contents

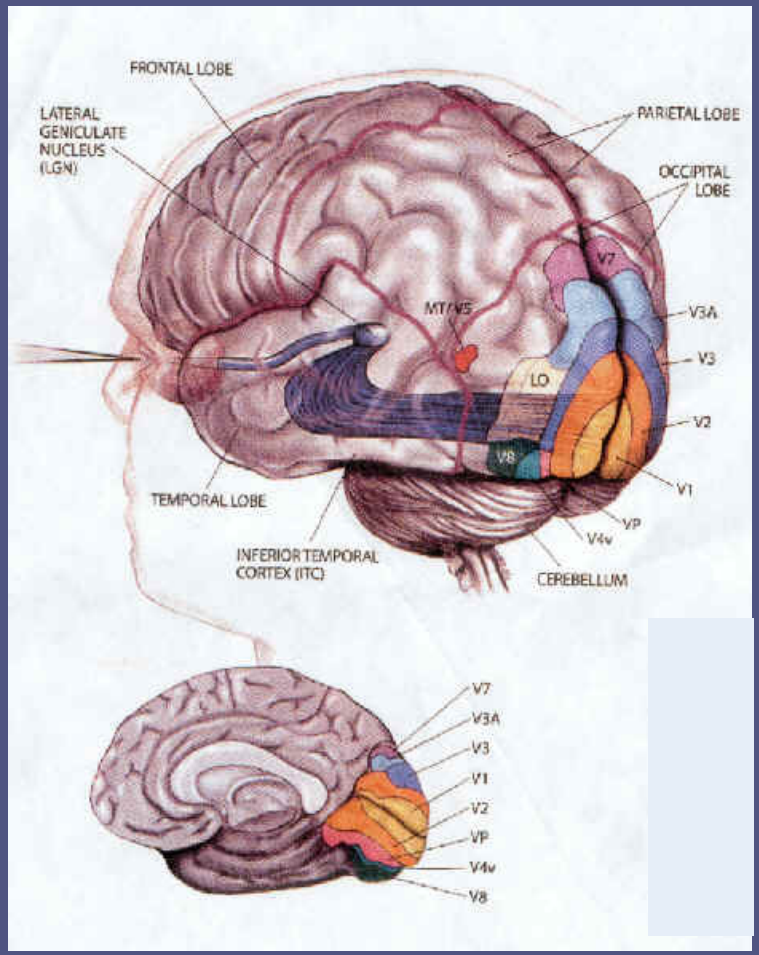
3. Widens the field-of-view while preserving image quality

→ More natural visual experience

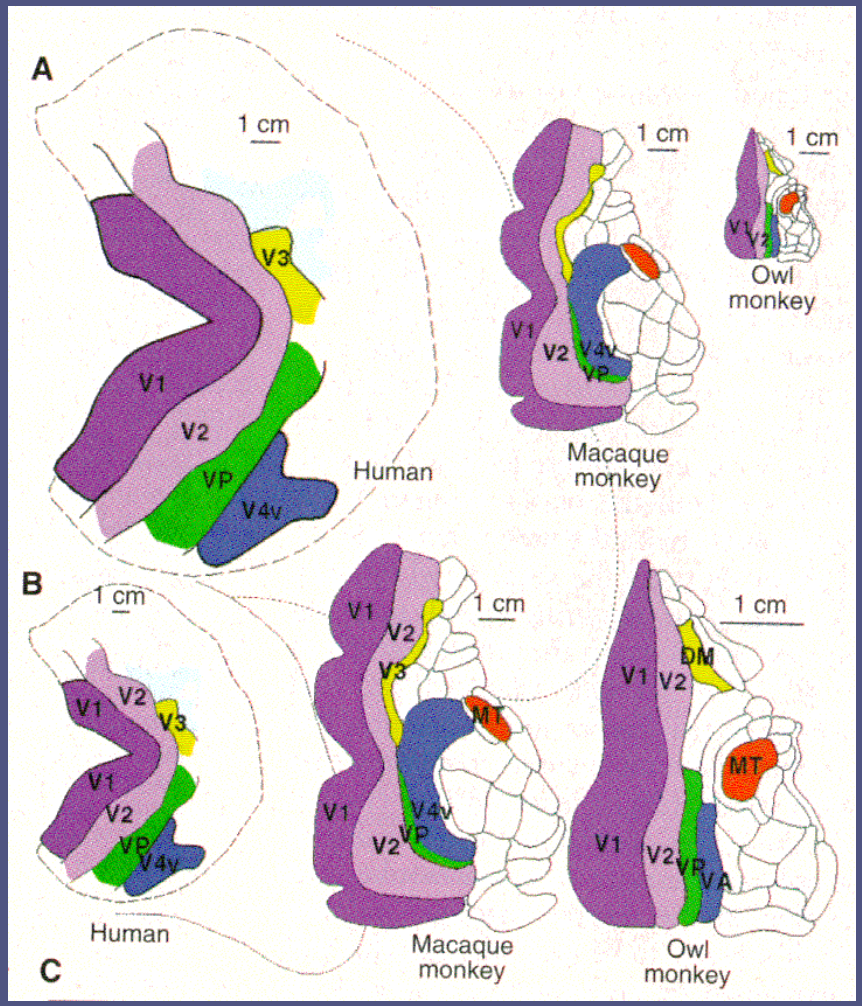
# Relevant concepts in brain and cognitive sciences

- **Accurate and efficient image processing in the brain**
  - Object perception improves with high resolution
    - Provides fine details
    - Reproduce texture quality
  - Depth perception improves with high resolution
    - Smoother luminance gradient (shading)
    - Higher spatial frequency gradient = slanted texture
- **Image SNR and viewer comfort**
  - Low spatial-frequency aliases activate the M channel.
  - Low temporal-frequency beats interferes with P processing.
  - Low SNR increases attention load.
  - Unexpected noise distracts attention.
  - Attention load and distraction increase brain fatigue.
- **Enriched visual experience with wider field-of-view**
  - Immersion is stronger with the wider spatial context.
  - Spatiotemporal continuity is essential in immersion.
  - Anxiety is reduced with peripheral vision.

# Multiple visual systems in the brain

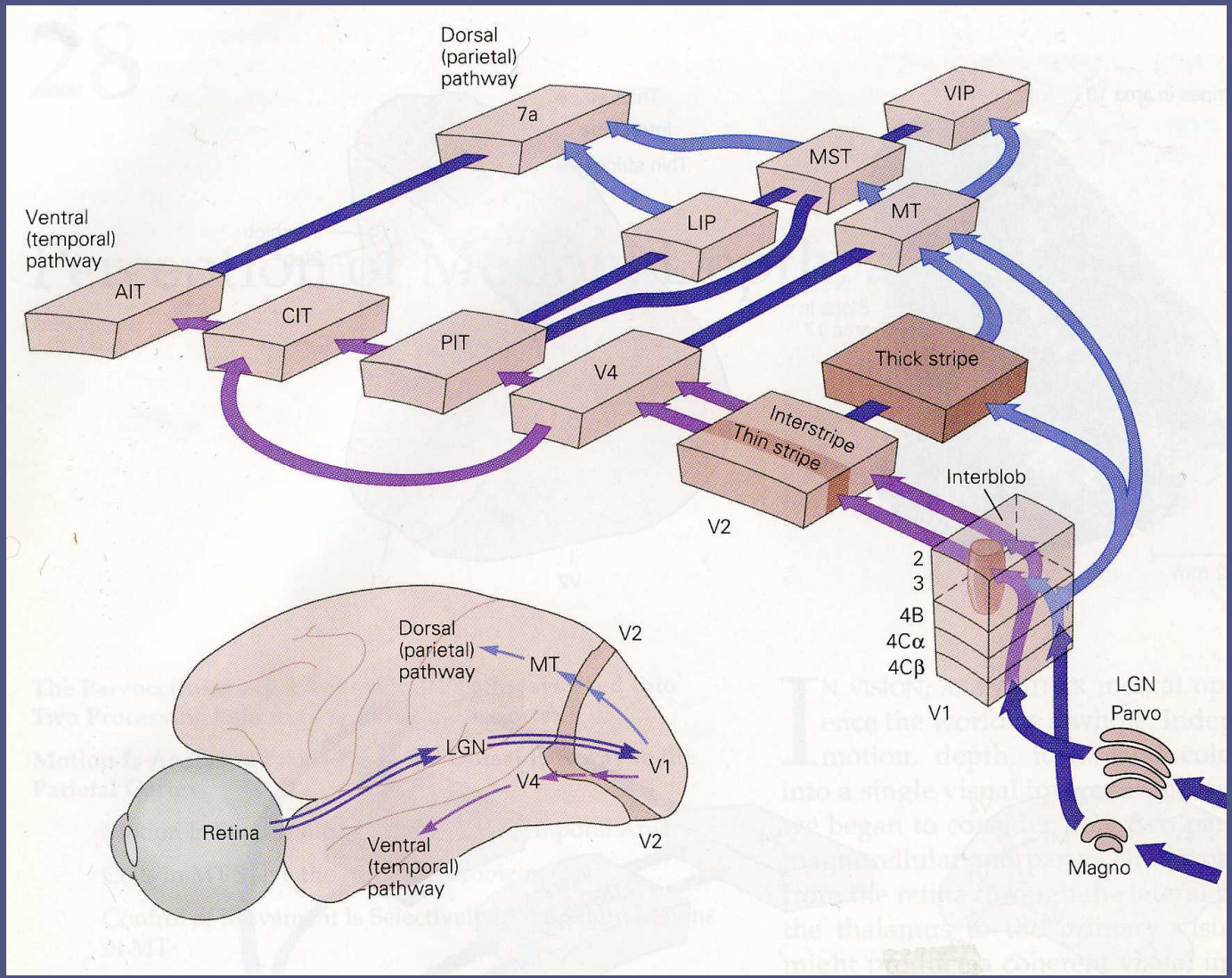



Logothetis et al., 2004




Tooltell et al., 1995

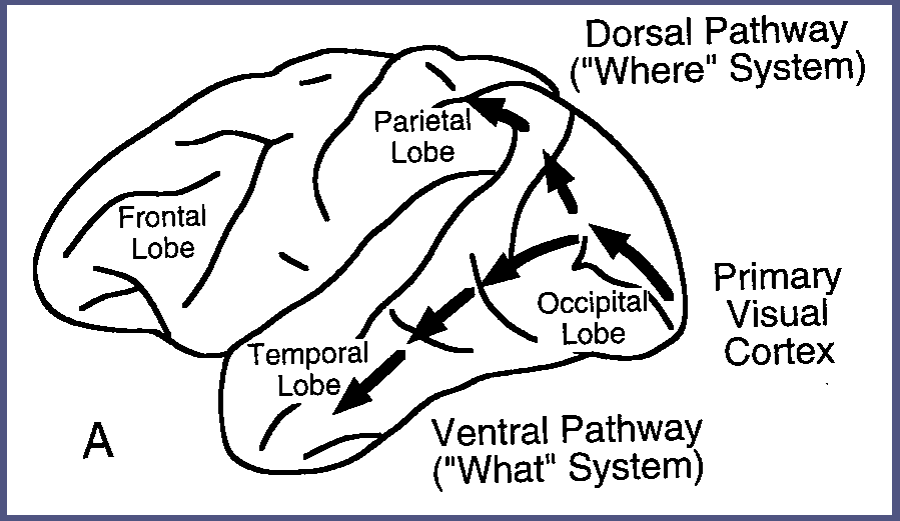
# Parallel and hierarchical connections of P and M pathways

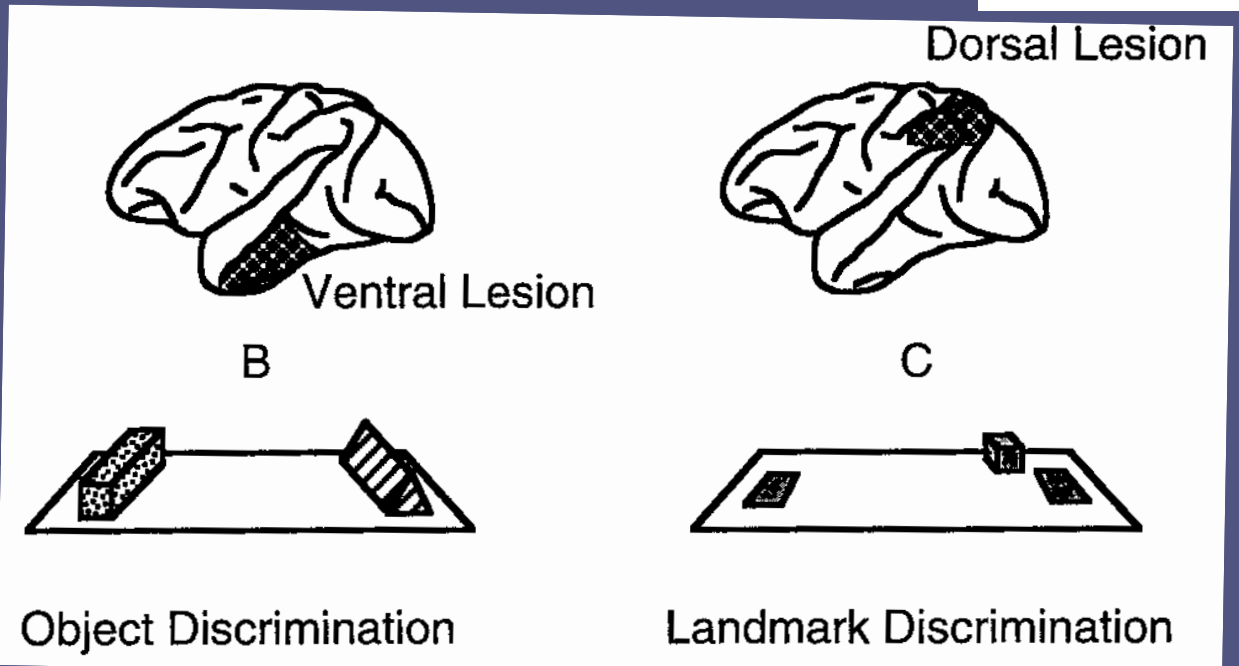



Kandel et al., *Principles of neural sciences*

# Functional roles of P and M pathways:

## According to Ungerleider and Mishkin, …

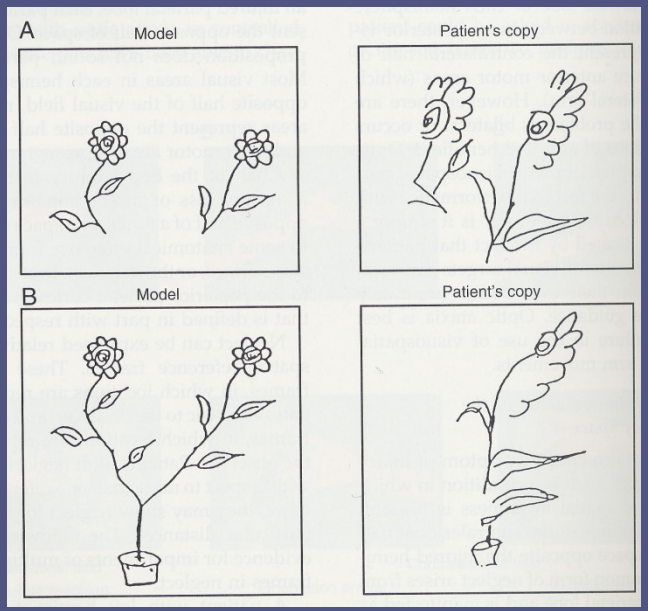


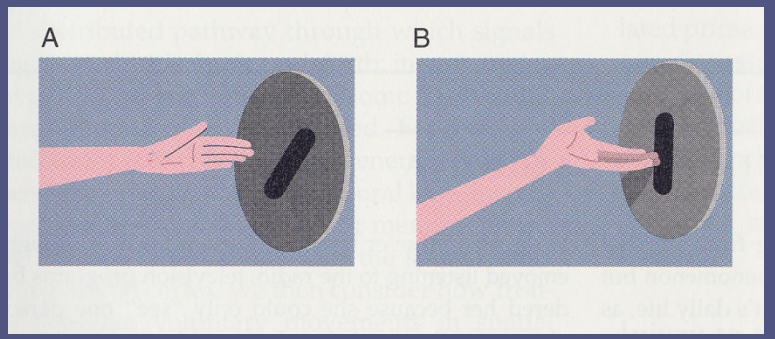



# According to Goodale and Milner, …

- Dorsal pathway for visuomotor action

Dorsal lesion causes visuomotor incoordination (= optic ataxia).

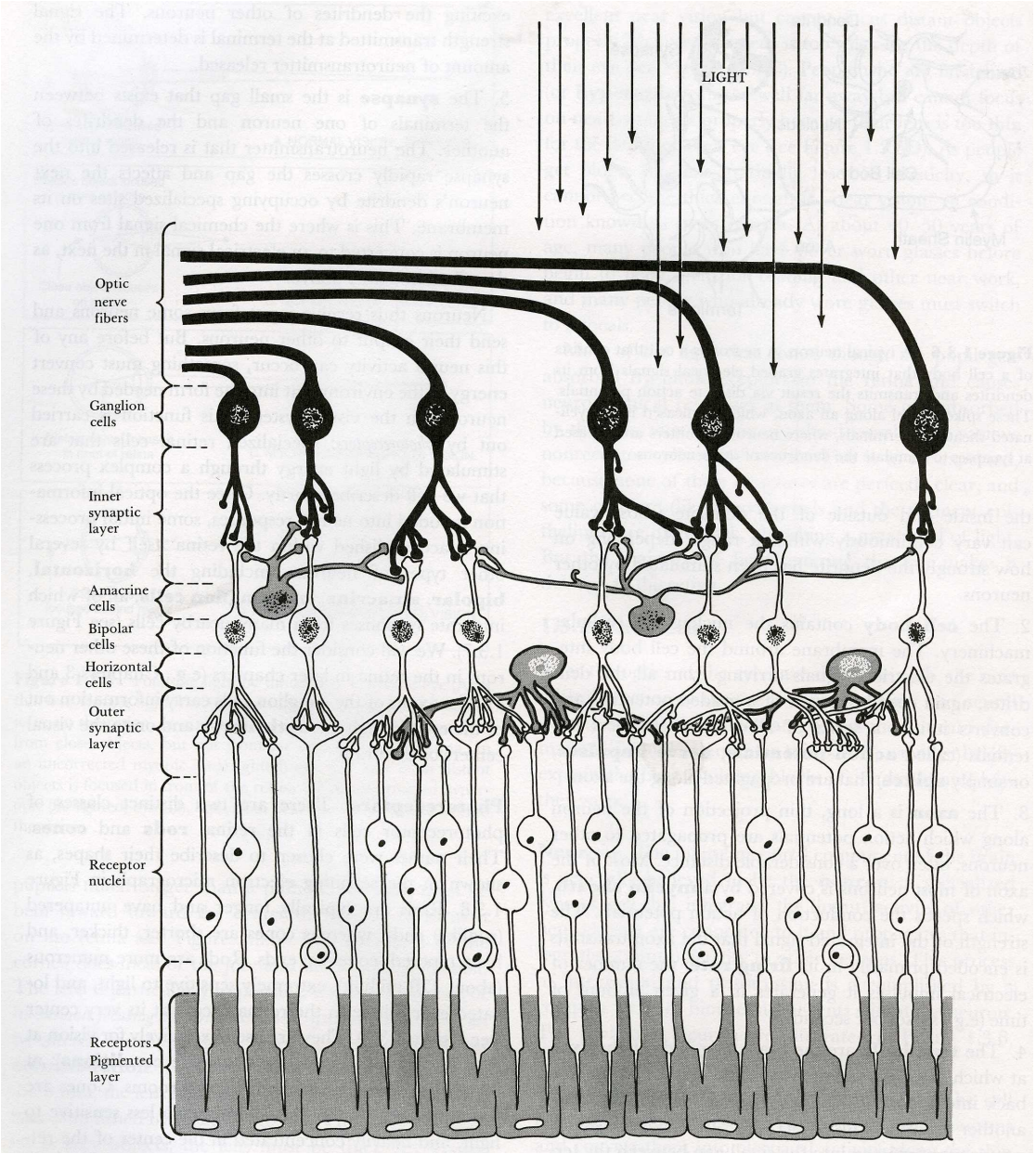


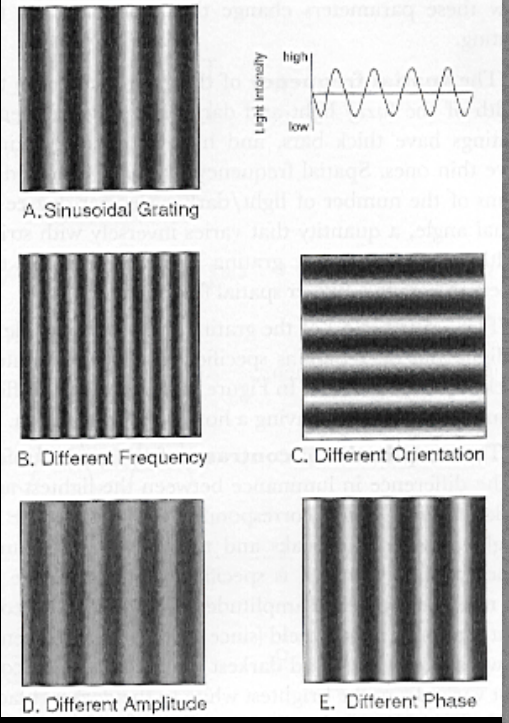

- Ventral pathway for conscious perception

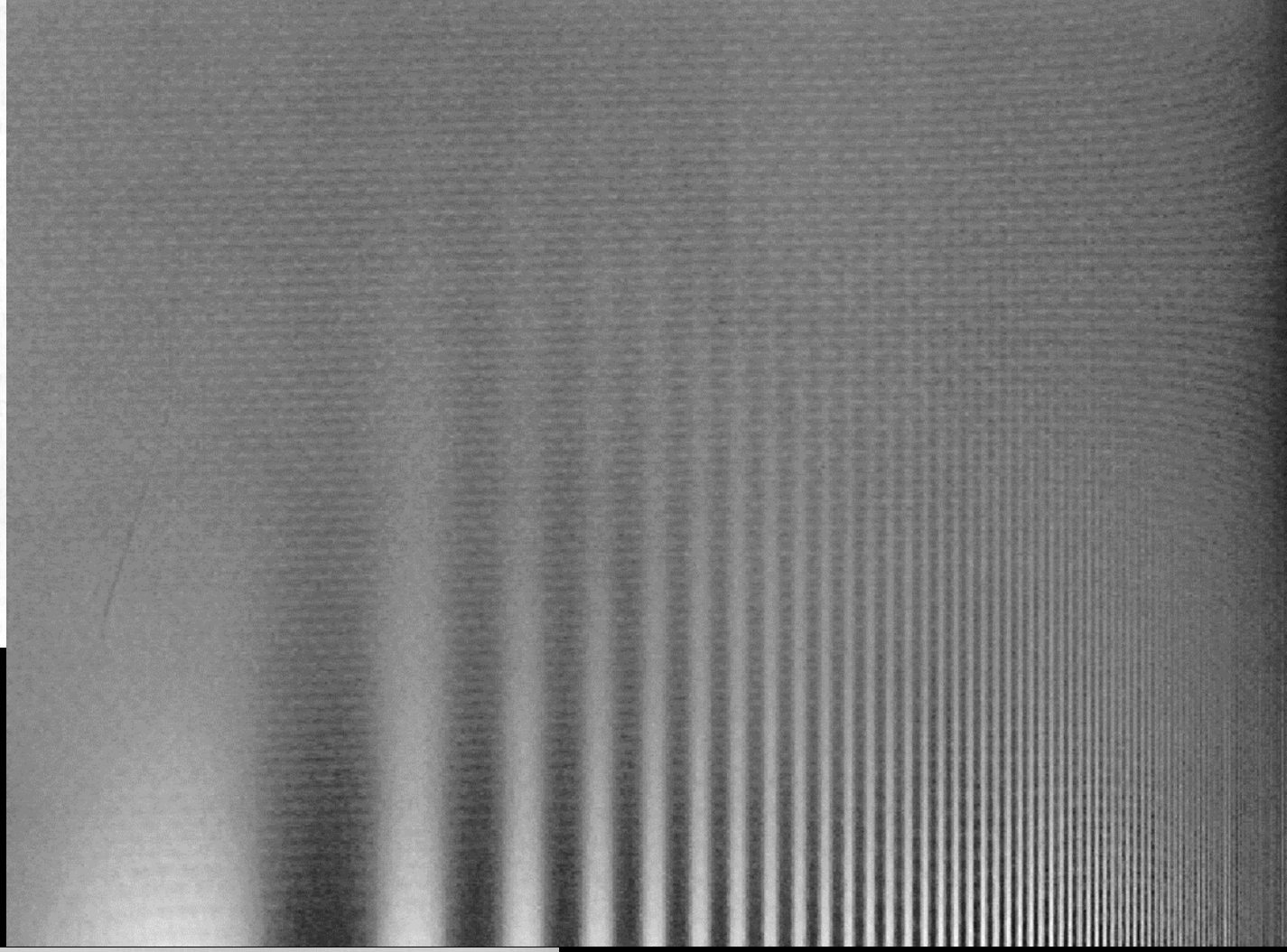
Ventral lesion causes perceptual unawareness (= visual agnosia).

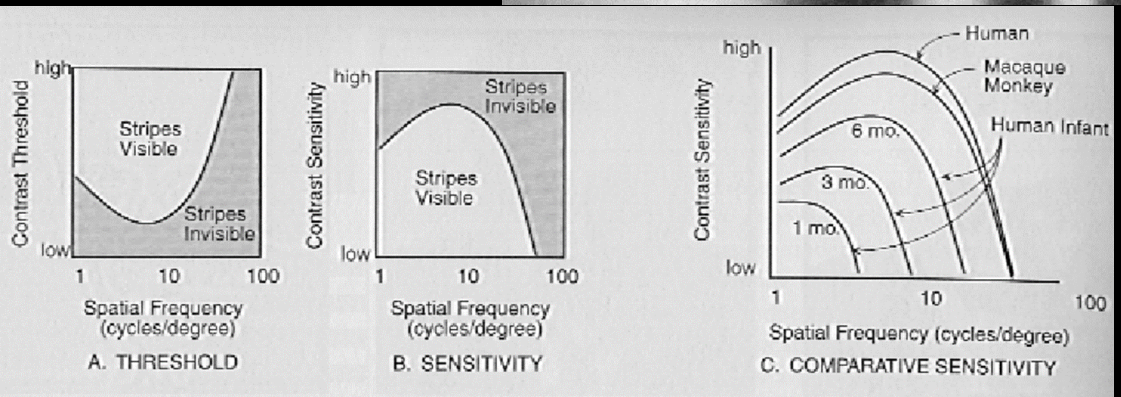
# Cell types in the retina




Palmer, *Vision science*♪

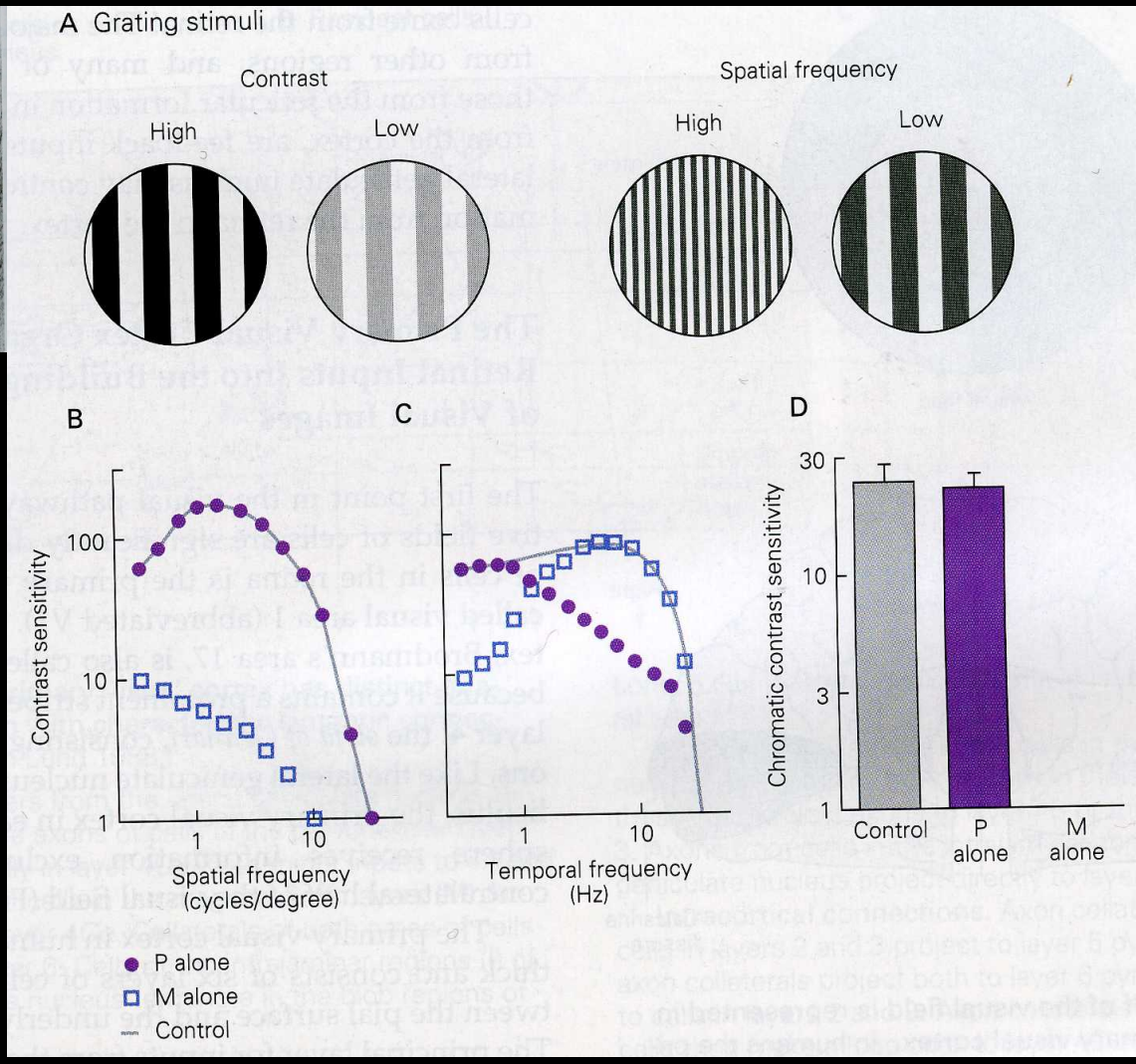





Palmer, SE, *Vision Science*, MIT Press, 1999

# The functional role of P and M pathways: Effects of selective lesions in the LGN


Palmer, SE, *Vision Science*, MIT Press, 1999

# Benefits of super-resolution display (1/3)

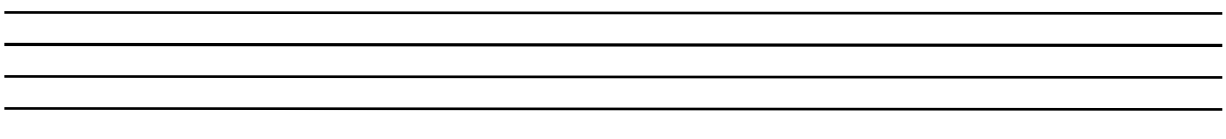
1. **Reduces information loss by pixelation**
   - Hyperacuity
   - Accurate object perception
   - Vivid depth perception

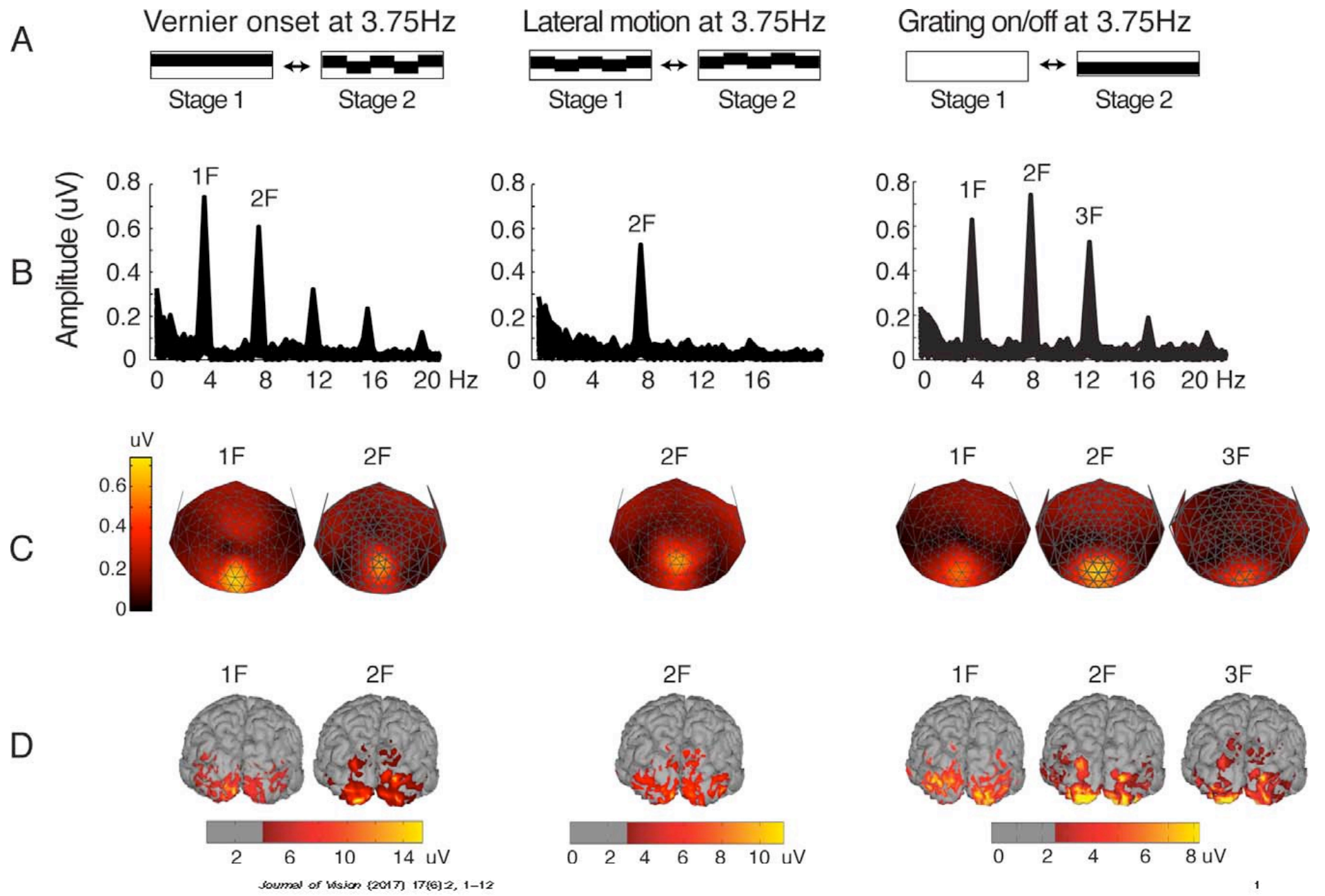
→ **More realistic perception**







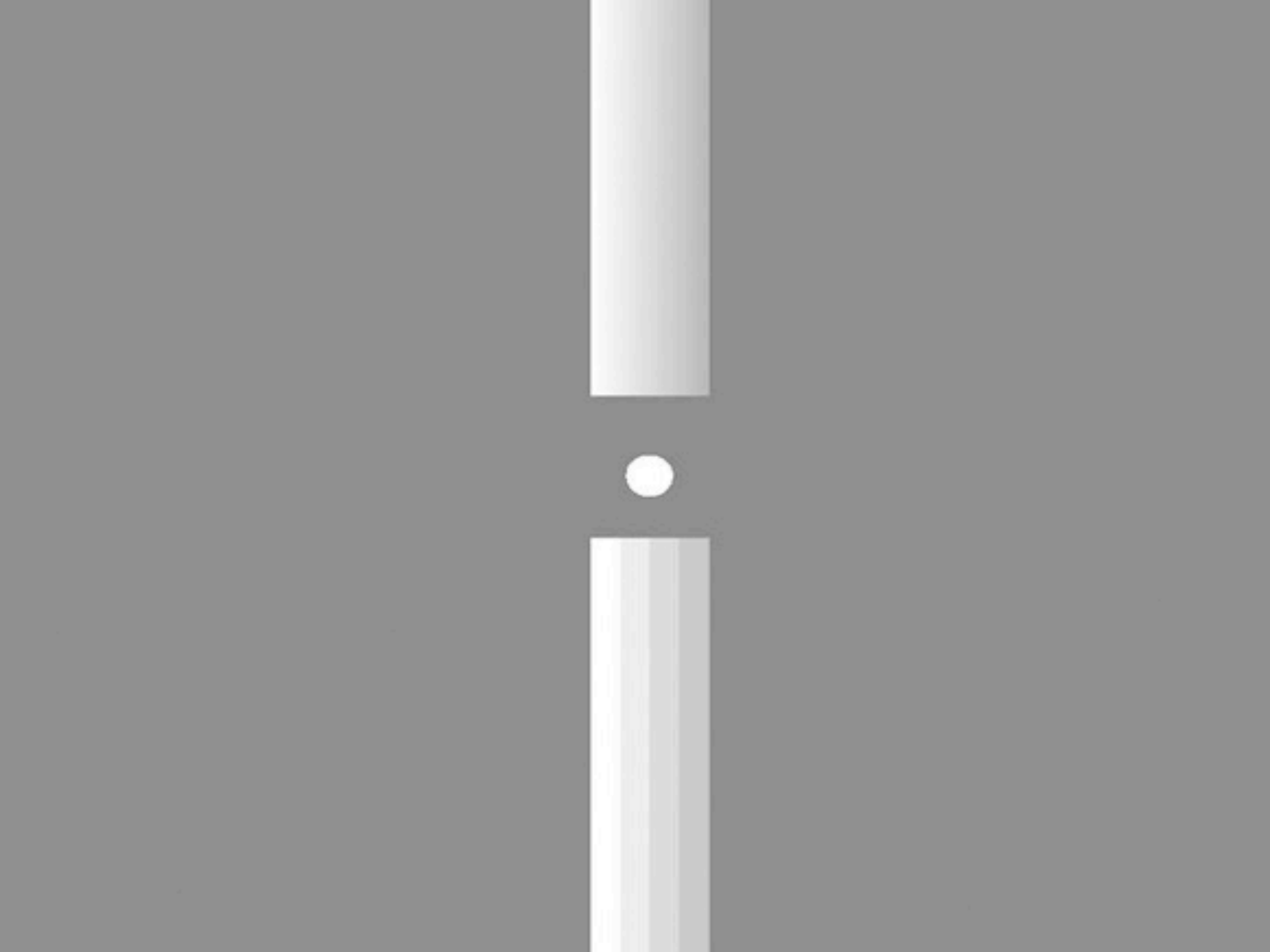




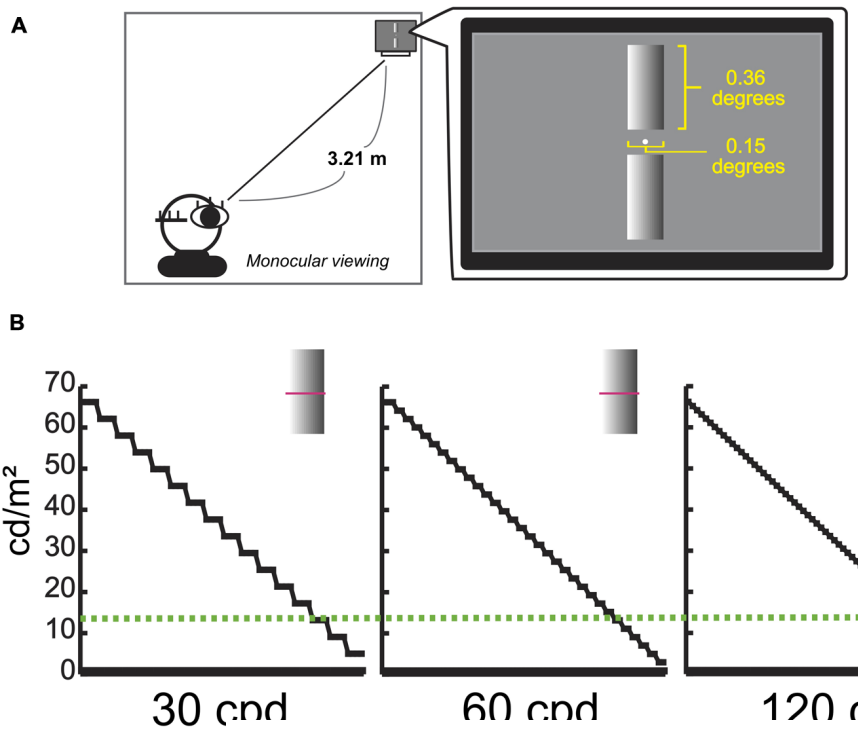

Journal of Vision (2017) 17(6):2, 1–12

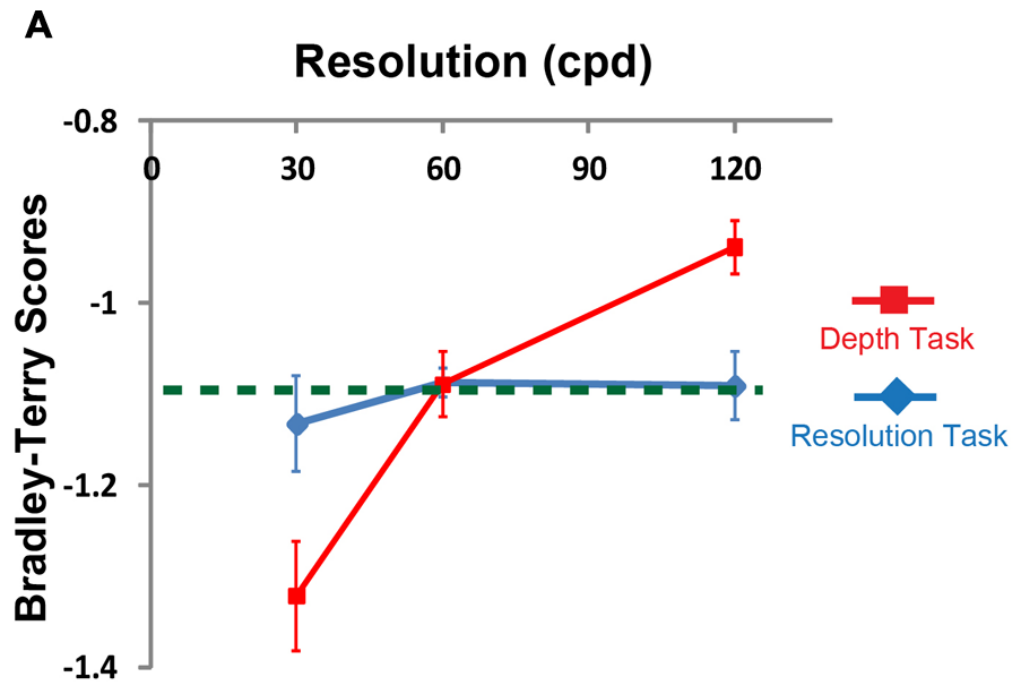


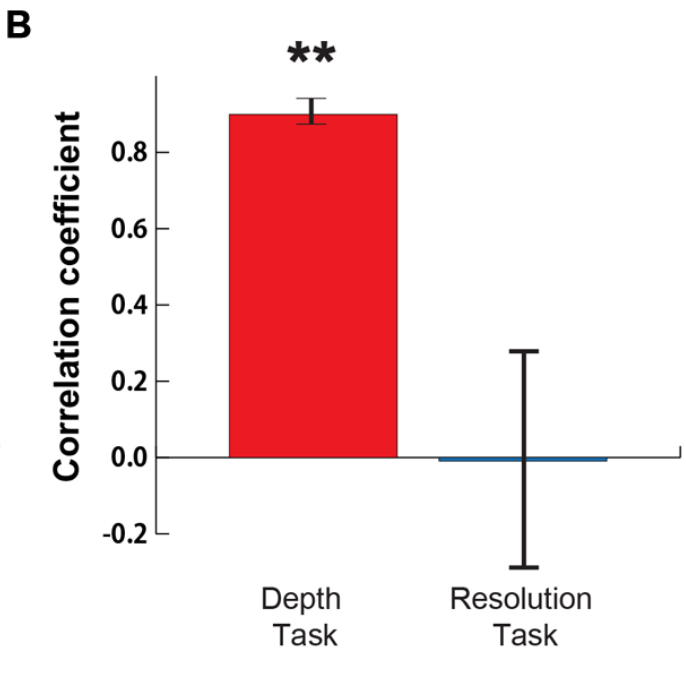
**Cortical sources of Vernier acuity in the human visual system: An EEG-source imaging study**



Tsushima *et al*.
Undetectable Changes in Image Resolution of Luminance-Contrast Gradients Affect Depth Perception
*Frontiers in Psychology* 2016 Vol 4 Article 242



PLOS | ONE

RESEARCH ARTICLE

# Shading Beats Binocular Disparity in Depth from Luminance Gradients: Evidence against a Maximum Likelihood Principle for Cue Combination

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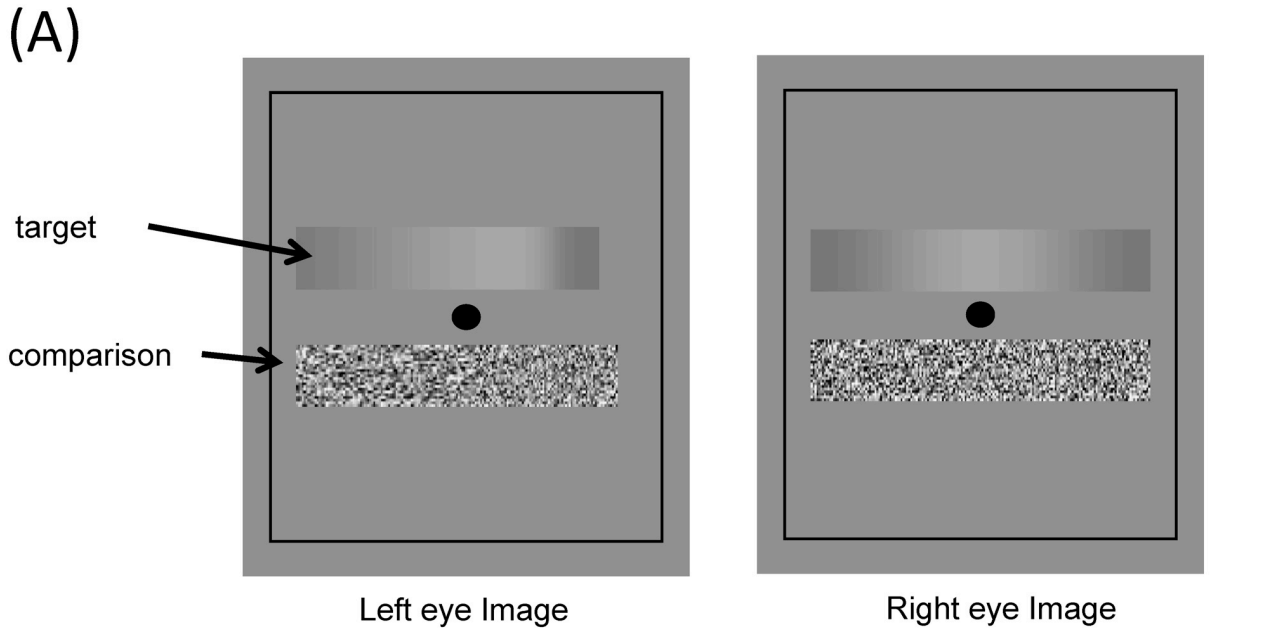
**Editor:** Samuel G. Solomon, University College

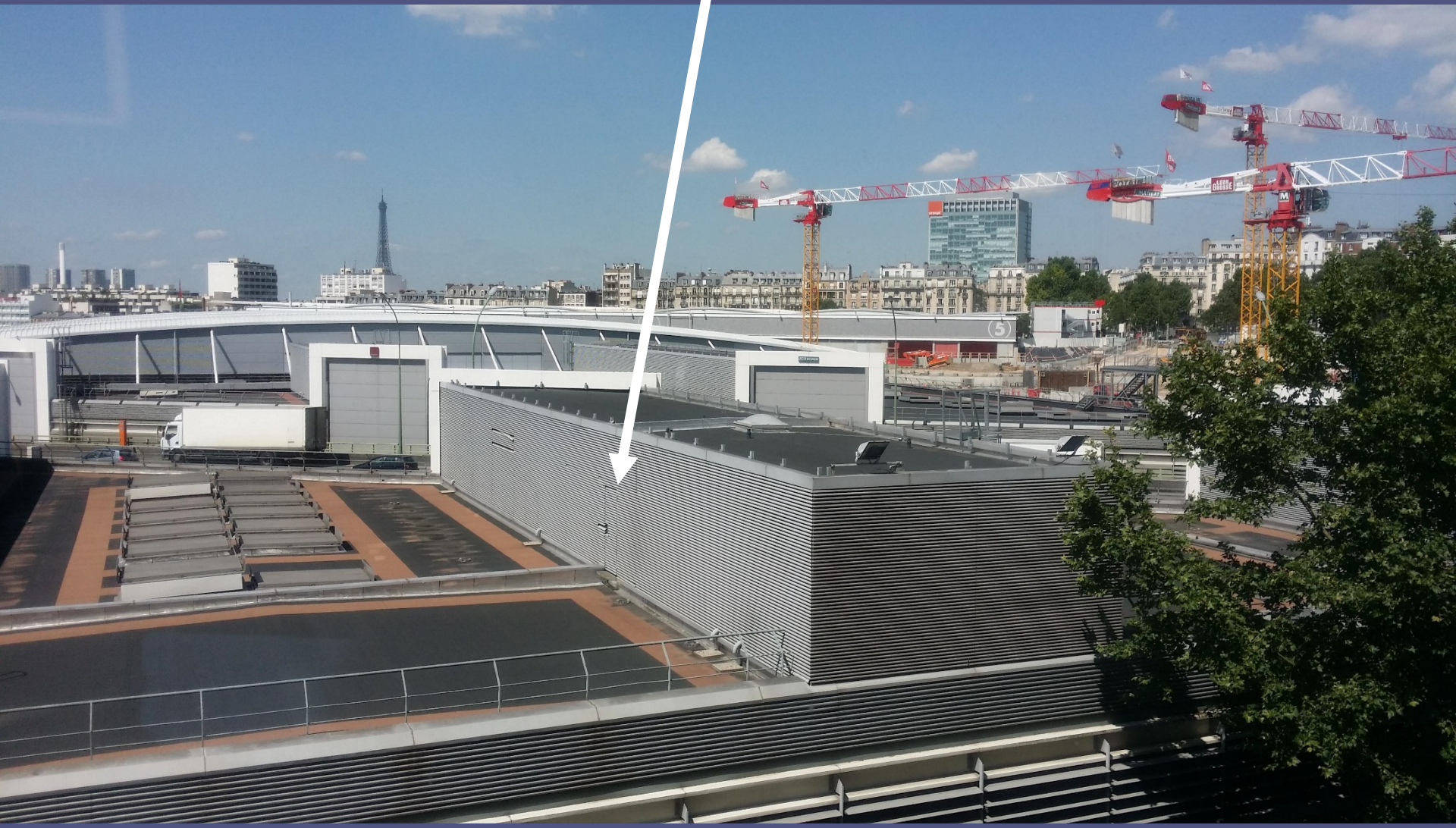
## Abstract

Perceived depth is conveyed by multiple cues, including binocular disparity and luminance shading. Depth perception from luminance shading information depends on the perceptual assumption for the incident light, which has been shown to default to a diffuse illumination assumption. We focus on the case of sinusoidally corrugated surfaces to ask how shading and disparity cues combine defined by the joint luminance gradients and intrinsic disparity modulation that would occur in viewing the physical corrugation of a uniform surface under diffuse illumination. Such surfaces were simulated with a sinusoidal luminance modulation (0.26 or 1.8 *cy/deg*, contrast 20%-80%) modulated either in-phase or in opposite phase with


(A)
target
comparison
Left eye Image
Right eye Image
(B)
(C)

4K

# Slanted surface: Texture and Depth



*Journal of Vision* (2015) 15(2):14, 1–24 http://www.journalofvision.org/content/15/2/14 1

# Perceptual biases and cue weighting in perception of 3D slant from texture and stereo information

**Jeffrey A. Saunders** Department of Psychology, University of Hong Kong, Hong Kong, Hong Kong SAR

**Zhongting Chen** Department of Psychology, University of Hong Kong, Hong Kong, Hong Kong SAR

*Journal of Vision* (2004) 4, 967-992 http://journalofvision.org/4/12/1/ 967

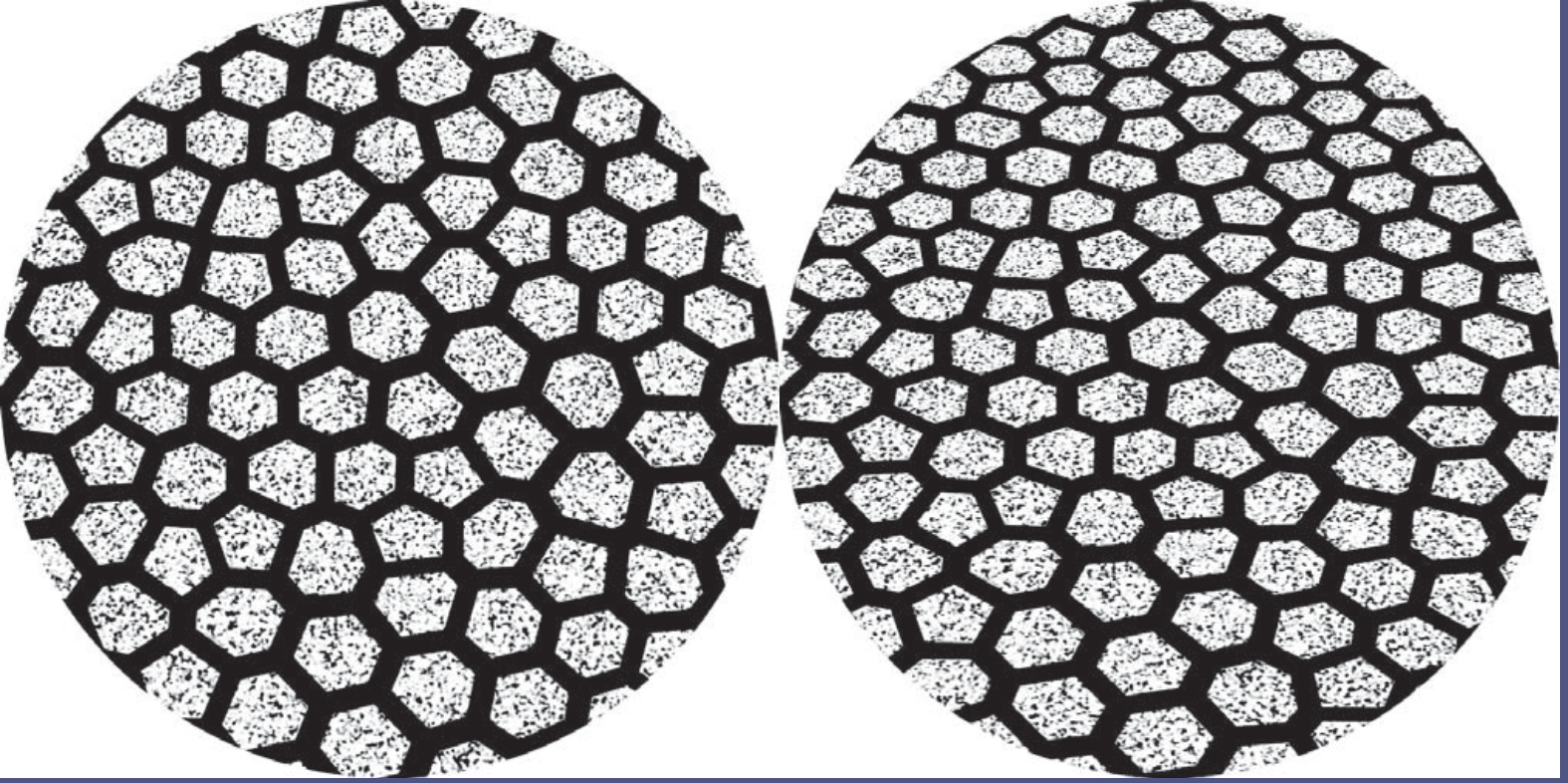
# Slant from texture and disparity cues: Optimal cue combination

**James M. Hillis** Department of Psychology, University of Pennsylvania, Philadelphia, PA, USA

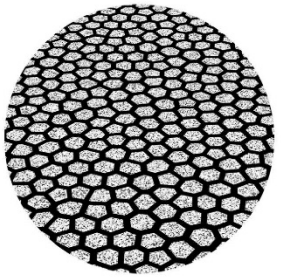
**Simon J. Watt** Department of Psychology, University of Wales, Bangor, Wales, UK

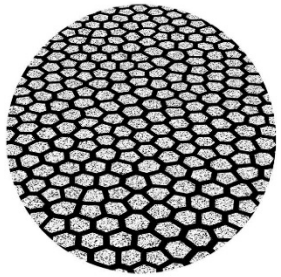
**Michael S. Landy** Department of Psychology & Center for Neural Science, New York University, New York, NY, USA

**Martin S. Banks** Vision Science Program, Department of Psychology, & Wills Neuroscience Institute, University of California, Berkeley, CA, USA

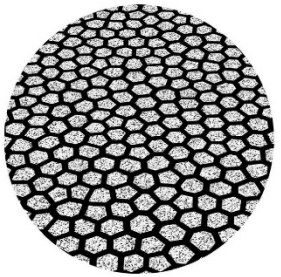


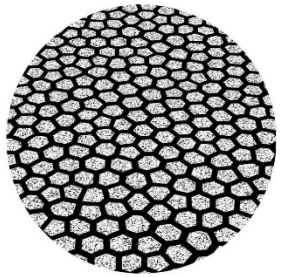
Cue conflict stimulus



Consistent cues PSE



right eye

left eye

## Benefits of super-resolution display (2/3)

**2. Improves dynamic SNR of the image**

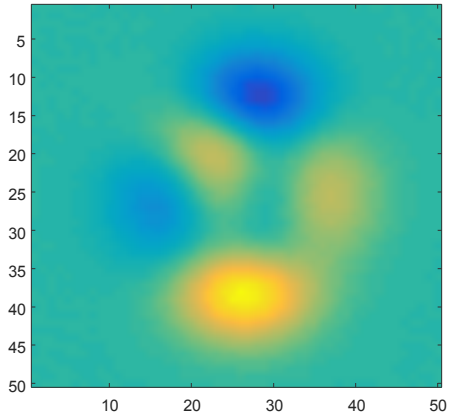
- Reduces noise:
  - edge distortions
  - temporal discontinuities
  - moiré patterns
- Preserve signal:
  - smooth trajectory in space & time

→ **Less load to the brain & deeper immersion in contents**

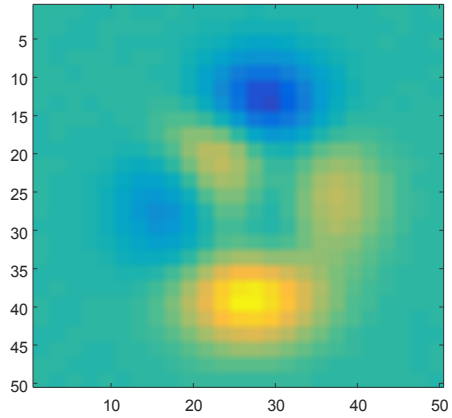
# Digitization error: continuous variable ≠ discrete values

- Aliasing: moiré patterns and low-frequency beats
- Changes in SNR
  - Signal: ‘smooth, correlated ’ variations in the image
  - Noise: ‘irregular, uncorrelated’ variations
- SNR changes due to subsampling
  - SNR in images: subsampling in space only
  - Dynamic SNR = S(x, t) / N(x, t):
    subsampling error in space, in time, & their interactions
- Temporal subsampling worsens the time-series noise, N(x, t), since the high-frequency variations are sampled randomly during the subsampling.

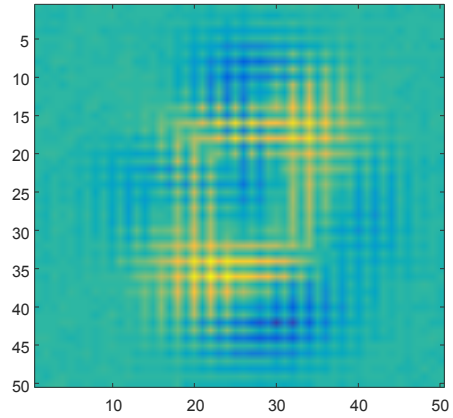
High resolution



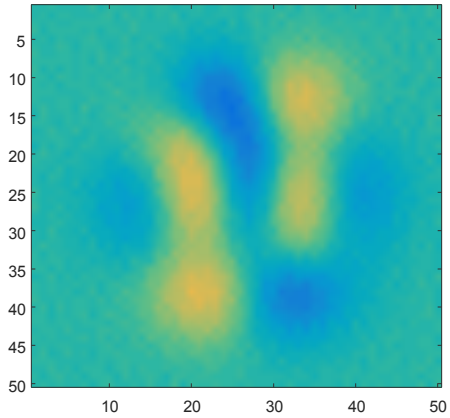

Subsampled



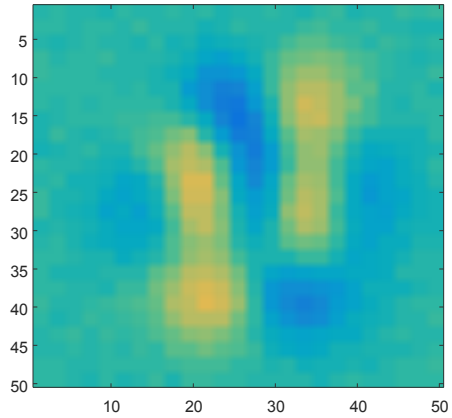

Static subsampling error



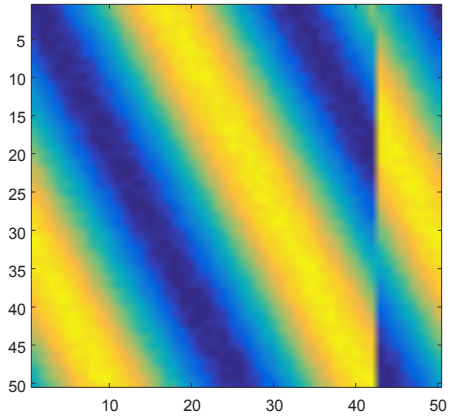

inter-frame difference:
high resolution



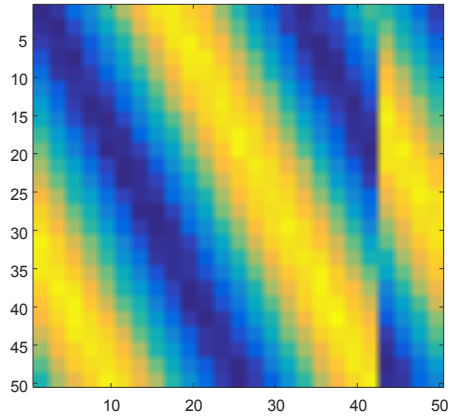

inter-frame difference:
subsampled



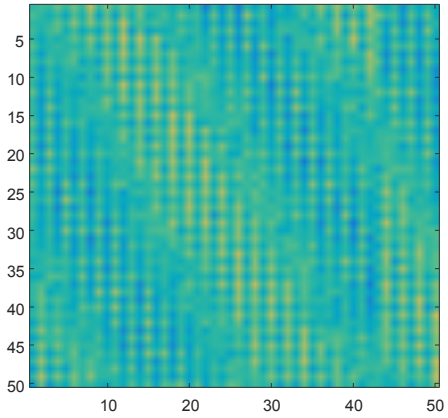
High resolution



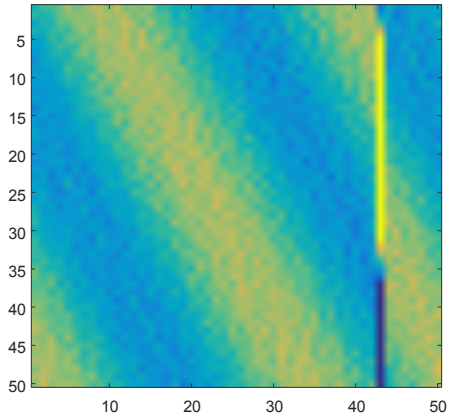

Subsampled



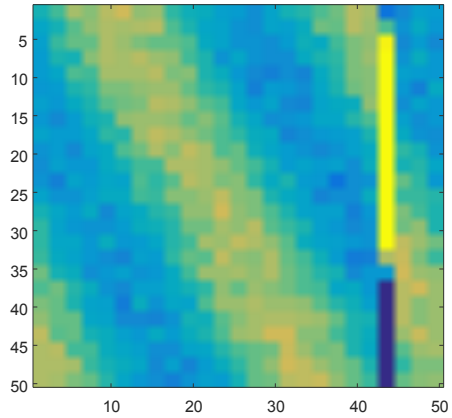

Static subsampling error

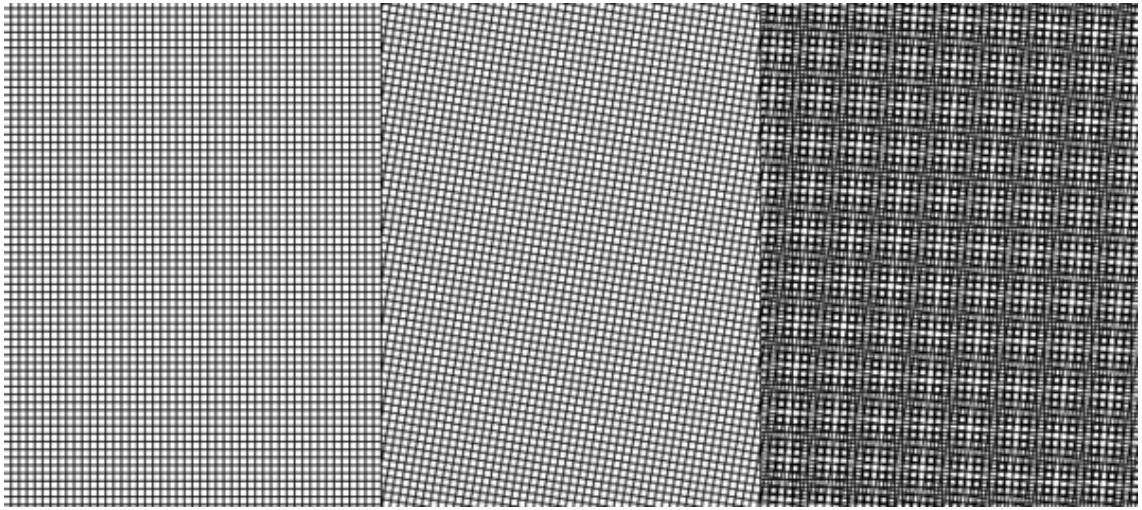


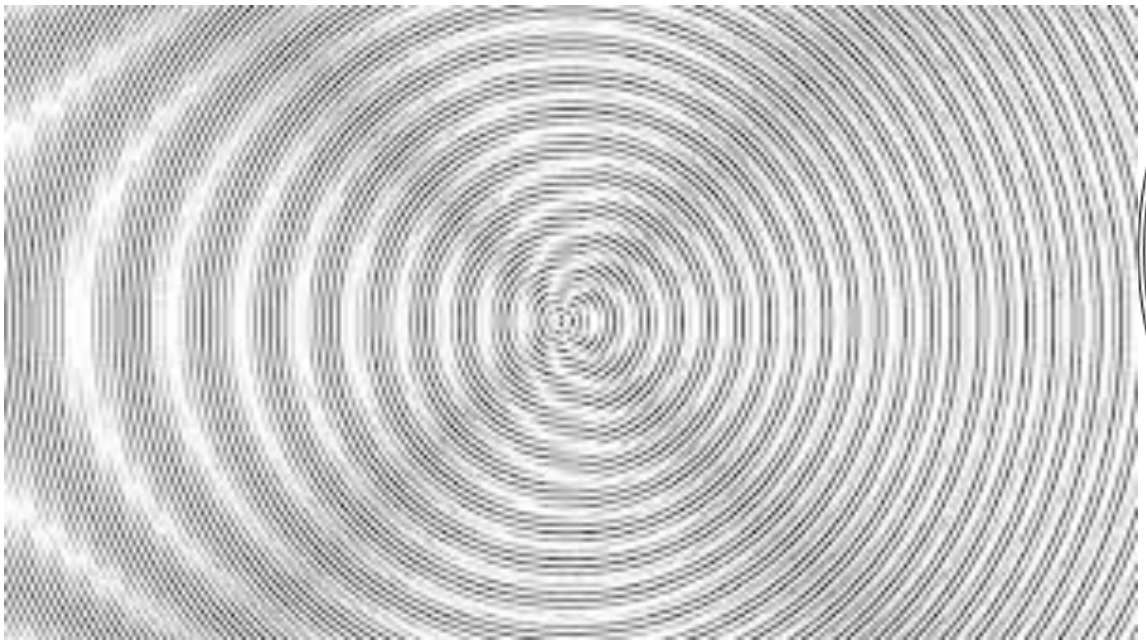

inter-frame difference:
high resolution

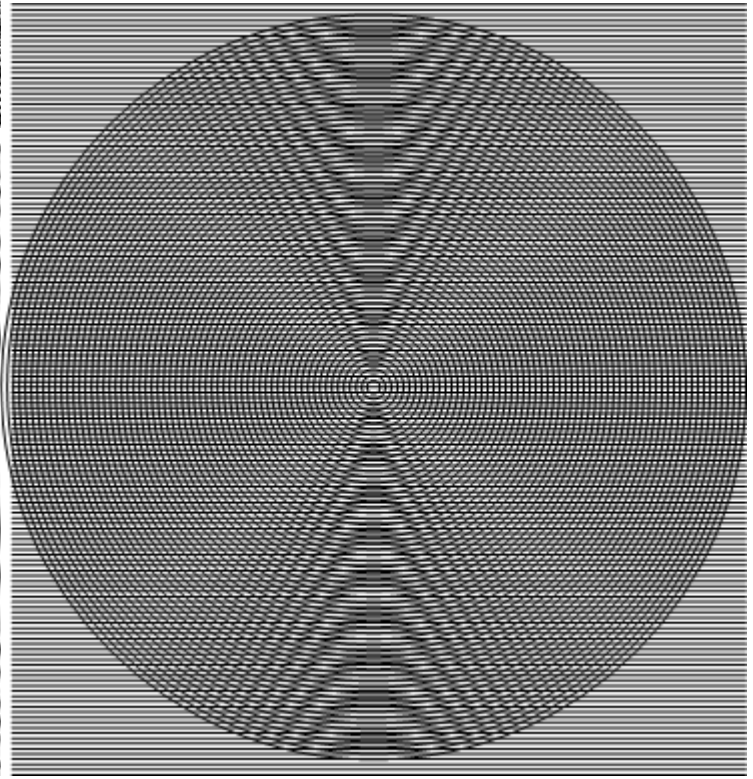



inter-frame difference:
subsampled









# 4K

# 2K

# 1K

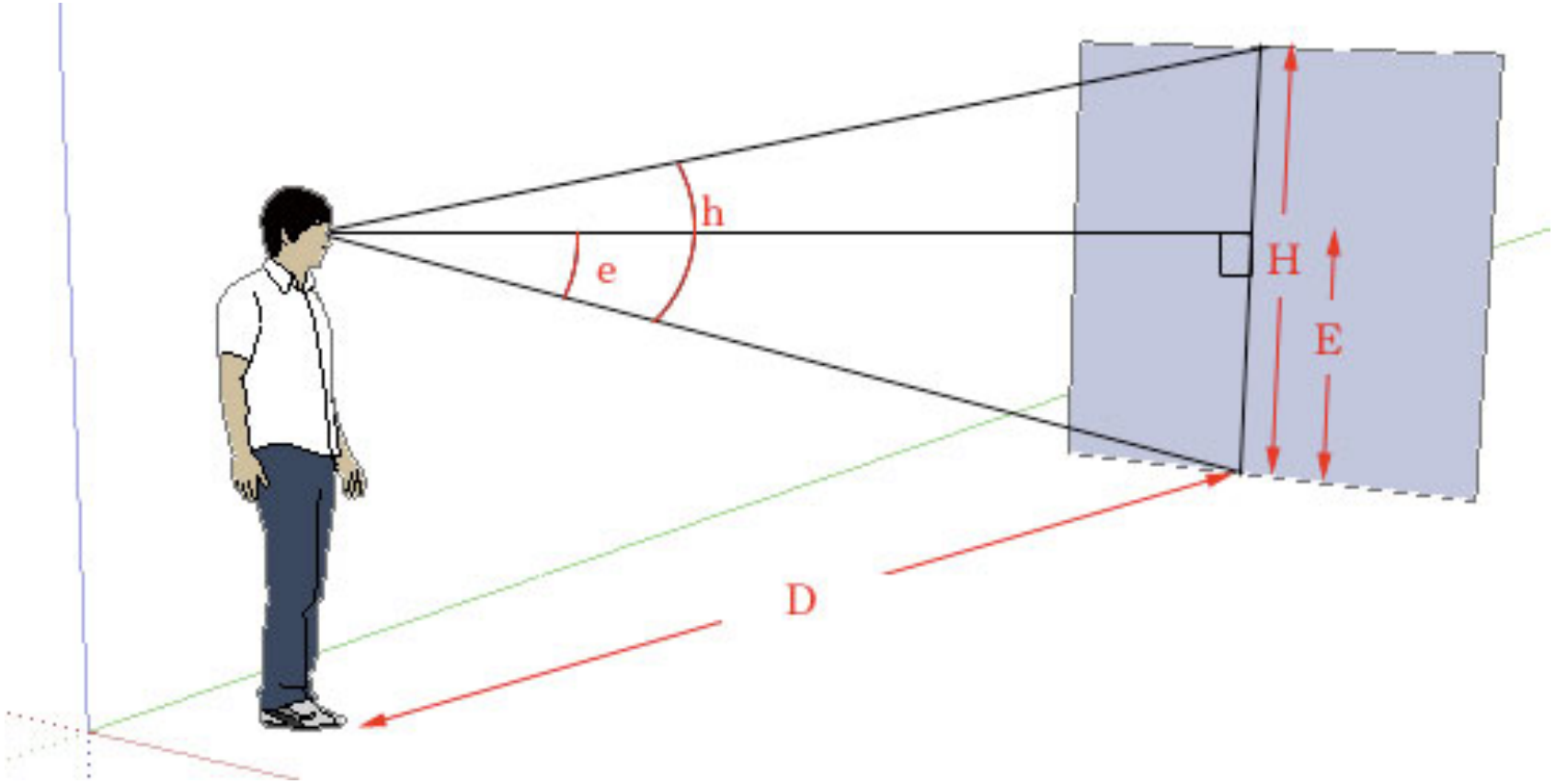
# Benefits of super-resolution display (3/3)

**3. Wider field-of-view with high image quality**

- Visual information from the peripheral fields
- Pretention and retention in perception
- Pixel grid invisible in the display

→ **More natural visual experience**

# Field of view ≈ Screen size / Distance

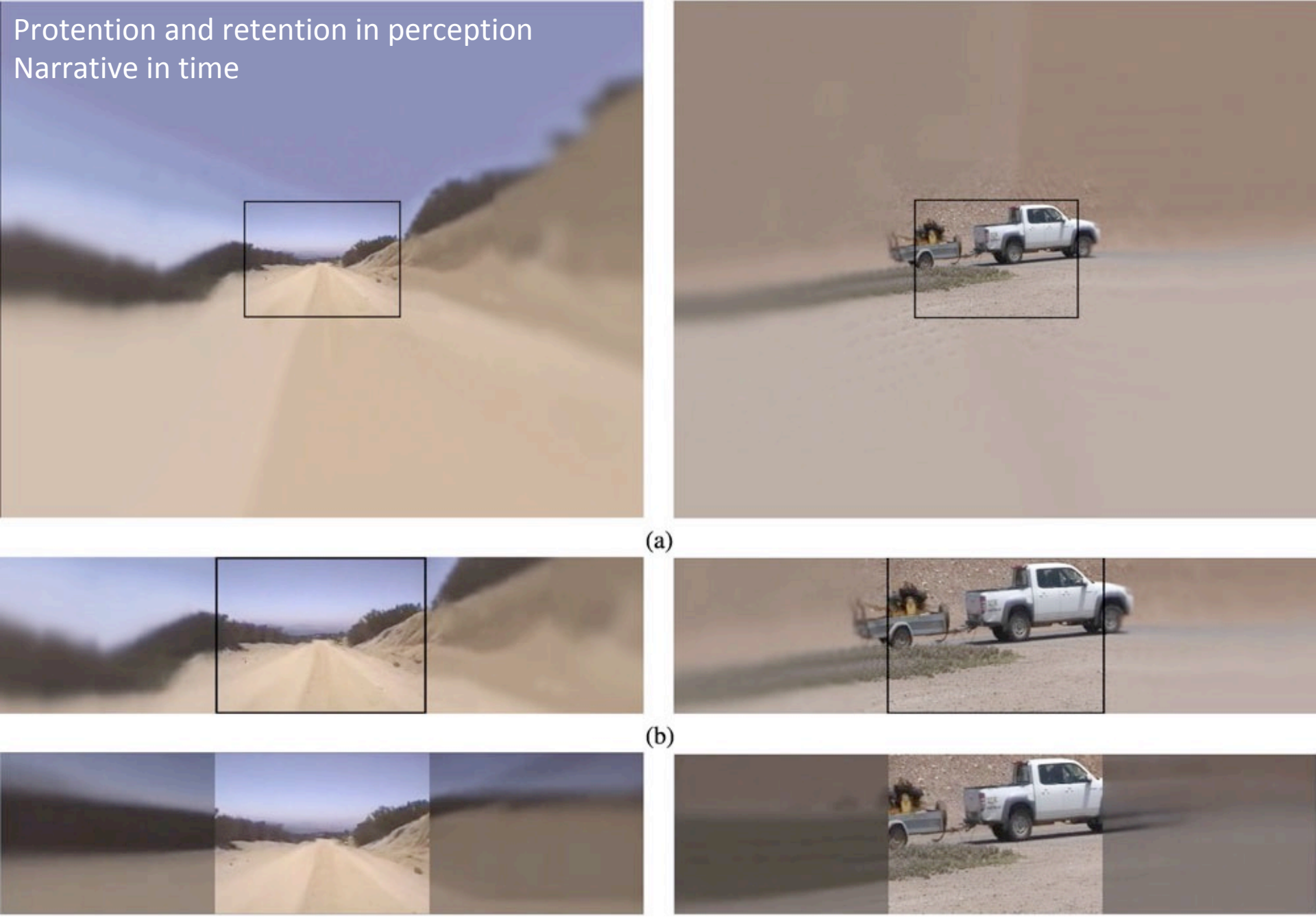


# Field of view gets larger, proportional to display resolution

- Two meanings of display resolution
  - Image resolution: DPI(dots per inch) ≈ 1 / pixel size
  - Angular resolution: dots per visual angle (º, ‘, ‘’)
- Upper and lower bounds of viewing distance
  - Lower bound: Visibility of the pixel grid
  - Upper bound: Size of the screen and objects in it
- Distance ≈ Screen size / Display resolution
  (https://stari.co/tv-monitor-viewing-distance-calculator)
  Field of view ≈ Screen size / Distance

  ∴ **Field of view ≈ Display resolution**

  **(keeping pixel size the same)**




Lin *et al*. Effects of Field of View on Presence, Enjoyment, Memory, and Simulator Sickness in a Virtual Environment *Proceedings of the IEEE Virtual Reality 2002 (VR'02)*

# Summary: Benefits of super-resolution display from the viewpoint of brain science

- Reduces information loss in pixelated displays
  - Supports hyperacuity, especially for slanted edges
  - Accurate object perception
  - Vivid depth perception

→ More realistic perception

- Improves dynamic SNR of the image
  - Reduces edge-distortion during motion
  - Removes the moiré patterns
  - Preserve spatiotemporal trajectory of the signal
  - Decrease the uncorrelated time-series noise during motion

→ Less load to the brain & deeper immersion in contents

- Widens the field-of-view with preserving image quality
  - Full use of visual information from the peripheral fields
  - Pretention and retention in perception
  - Pixel grid invisible in the display

→ More natural visual experience

Thank you.