VISUAL DISCRIMINATION OF SURFACE ATTITUDE FROM TEXTURE

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Introduction

Judgement of surface attitude is important for a broad range of visual tasks. The visual system employs a number of cues to make such estimates, including projective distortion in surface texture. While egocentric surface attitude is comprised of two variables (slant, tilt), previous studies have focused almost exclusively on slant. Here we estimate the full 2D discrimination function.

General methods

Stimuli

The stimulus was a real surface of greyscale discs mounted to a pan-tilt unit that was seen through a 3 deg aperture with the right eye.

We randomly sampled 36 surface attitudes on the view sphere, with a maximum slant of 60 degrees.

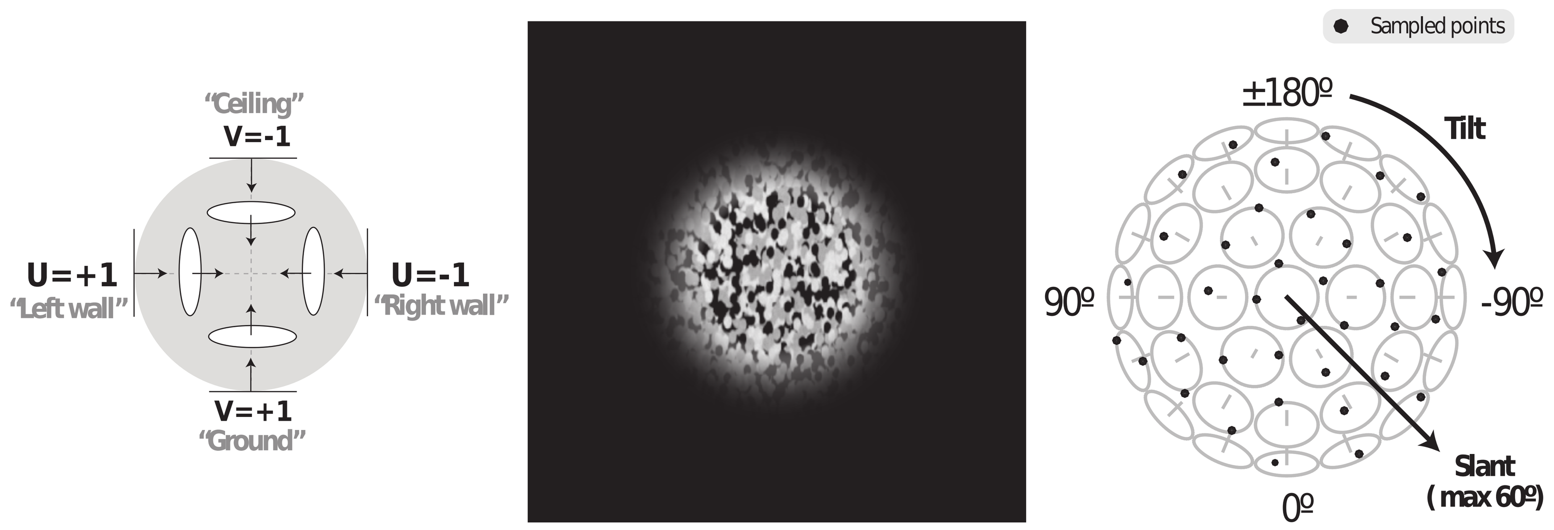


Figure 1: Interpretation of UV coordinates, a stimulus seen through aperture and the 36 standards.

Representation of surface normals

3D coordinates: The normal of a 2D surface is a 3D unit vector $[u, v, w]^T$, and can therefore be represented as a point on the unit view sphere.

UV coordinates: The space of normals is a hemisphere, the two dimensions (u, v) fully determine a surface normal.

Slant and tilt coordinates: Slant and tilt (s, t) give a polar representation of a (u, v) point, in which t is the point's angle and $\sin(s)$ its radius:

$$u = \sin(s) \cdot \sin(t), \quad v = \sin(s) \cdot \cos(t). \quad (1)$$

Modeling discrimination noise

Like [1], we assume a Bayesian ideal observer, who knows and takes into account their internal noise. For a stimulus attitude represented by its normal $\mathbf{n}$, we model the measured attitude as a random variable $\mathbf{M}(\mathbf{n})$ following a von Mises-Fisher distribution of parameter κ on the unit hemisphere:

$$p(\mathbf{m}|\mathbf{n}, \kappa) = C_\kappa \cdot \exp(\kappa \langle \mathbf{m}, \mathbf{n} \rangle). \quad (2)$$

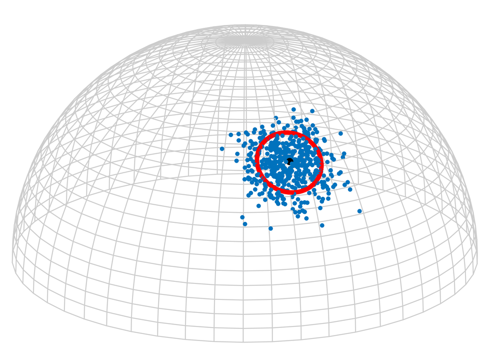


Figure 2: A set of 500 points sampled from a von Mises-Fisher ditribution on the unit hemisphere. The slant of the mean attitude (black dot) is 45. The precision is $\kappa = 100$. The red circle represents the standard angular deviation from the mean attitude.

Experiment 1: Surface attitude discrimination.

Match-to-sample task: On each 3-interval trial, observers viewed 3 surface attitudes; the first was always the standard. The observer indicated which of the 2nd and 3rd stimuli matched the standard. For each of the 36 standard attitudes separate adaptive staircases were used to find thresholds to discriminate **changes in U or V**. Six subjects participated.

Results: discrimination noise in 2D

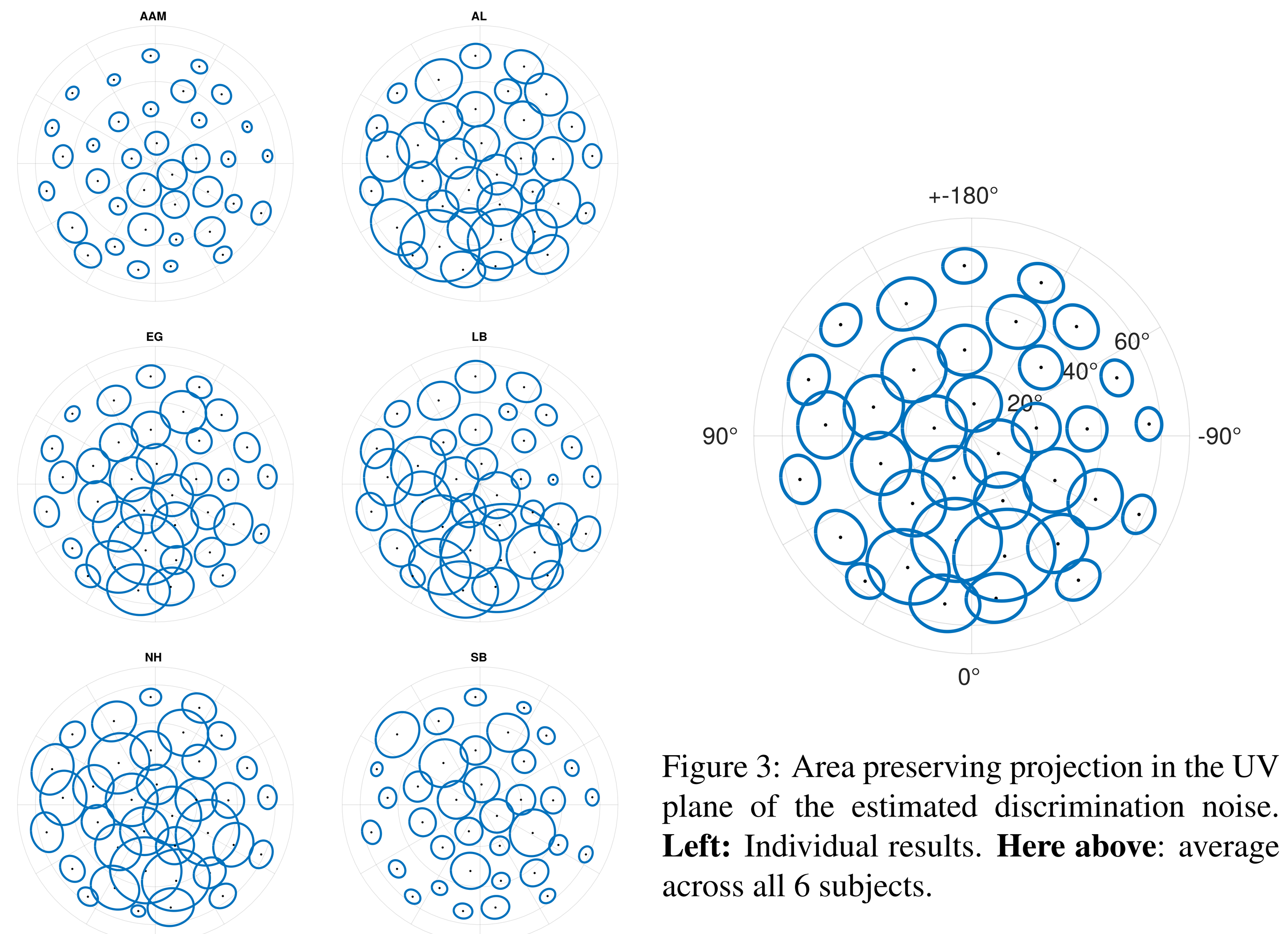


Figure 3: Area preserving projection in the UV plane of the estimated discrimination noise. **Left:** Individual results. **Here above**: average across all 6 subjects.

Discrimination noise vs. slant and tilt

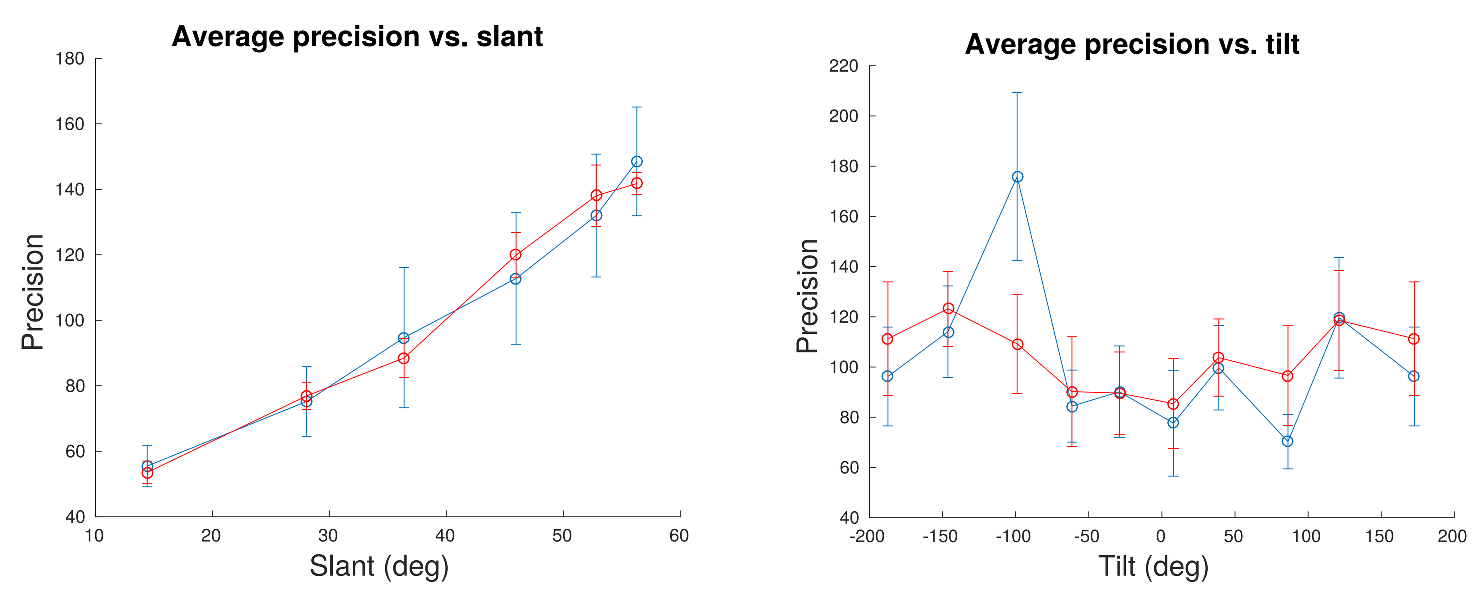


Figure 4: Precision κ as a function of slant and tilt. Observers' data are shown in blue with the best linear regression model shown in red (details below).

$f(S,T)$	R^2	$F(n, N-n-1)$	p
$a + bS$	0.10	23.4	$2.5 \cdot 10^{-6}$
$a + bT$	0.004	0.93	0.34
$a + bS + cT$	0.11	12.8	$5.6 \cdot 10^{-6}$
$a + bS + cT + dST$	0.11	8.54	$2.2 \cdot 10^{-5}$
$a + b\cos(S)$	0.10	24.0	$1.9 \cdot 10^{-6}$
$a + b\cos(S) + c\cos(T)$	0.12	14.0	$2.0 \cdot 10^{-6}$
$a + b\cos(S) + c\cos(T) + d\cos(S)\cos(T)$	0.12	9.3	$8.1 \cdot 10^{-6}$

Table 1: **Linear regression of the precision $\kappa = f(S, T)$.** We tested **7 linear models**. Comparing linear regressions. n is the number of parameters and $N = 6 \times 36 = 216$ the available number of triplets (κ_i, S_i, T_i).

A leave-one-out cross validation on the observers revealed that the last model best explains the data, with $a = 276$, $b = -228$, $c = -38.4$ and $d = 27.2$.

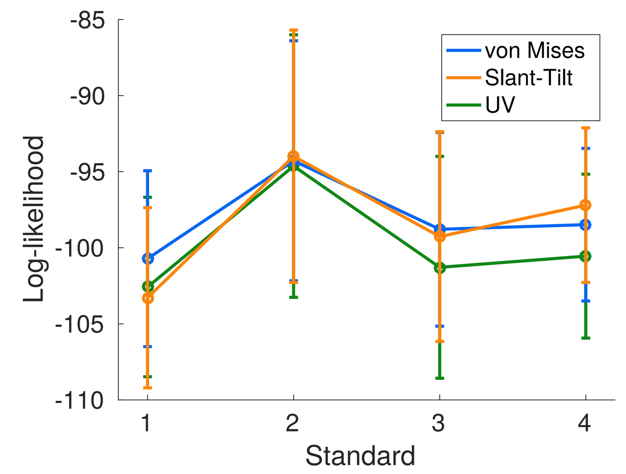
Precision increases roughly linearly with slant, and is roughly invariant with tilt.

Experiment 2: Comparison of three noise models.

- **Match-to-sample task** (like Experiment 1)
- **The test attitude could vary from the standard in any direction** on the hemisphere (whereas Experiment 1 it could vary only along U or V).
- **Only 4 of the 36 previous attitudes** were used as standards (see Figure 6), but more trials were completed for every standard.
- **5 observers** all of whom had completed Experiment 1.

No evidence for anisotropic noise

Figure 5: We compare the von Mises-Fisher (isotropic noise) model to two bivariate noise models, using data from the four standards of Experiment 2. Despite its lower complexity, the isotropic model achieves a higher likelihood than a bivariate noise model in slant-tilt and a significantly higher likelihood than a bivariate noise model in UV. Slant and tilt values for the four standards are respectively $(26°, 175°)$, $(53°, 178°)$, $(27°, 139°)$, $(54°, 130°)$ (see Figure 6).



Experiment 3: Validating the match-to-sample method.

- A two-alternative forced choice (**2AFC**) task: in every trial the subject reported the **most slanted** stimulus
- The standards were the same 4 attitudes as in Experiment 2
- The same 5 observers of Experiment 2 completed Experiment 3

Experiments compared

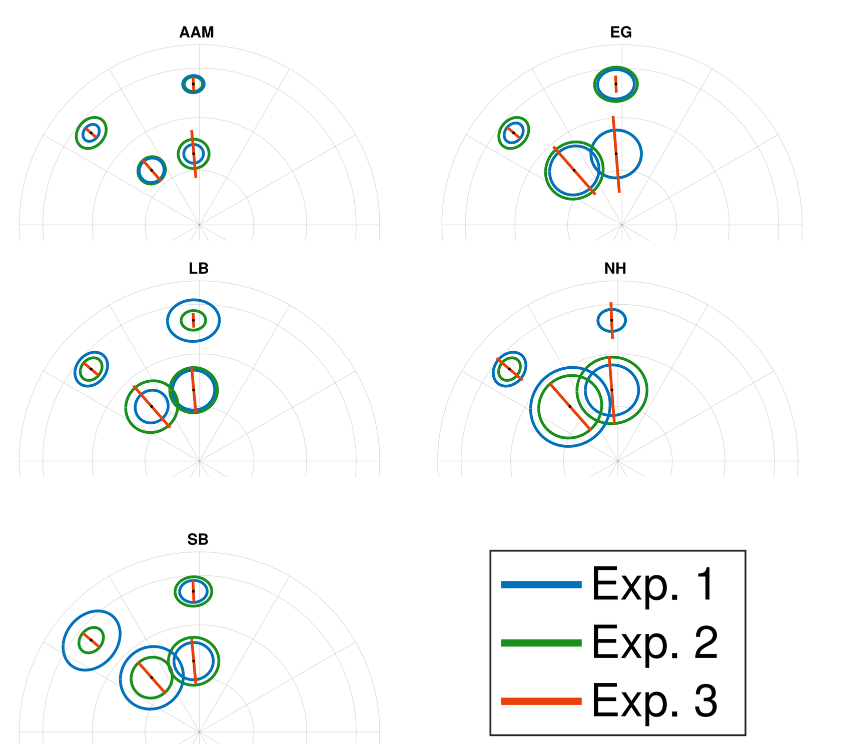


Figure 6: Estimated discrimination noise, for Experiments 1, 2 and 3. **Left:** Individual results. **Here above**: average across all 6 subjects (Area preserving projection to the UV plane). Grey numbers 1 to 4 give the indices of the standards.

Discussion

- A one parameter model accounts for 2D discrimination noise
- A clear effect of slant on discrimination noise
- Noise seems roughly invariant to tilt
- Consistent results across three different experimental paradigms.

References

[1] Ahna R Girshick, Michael S Landy, and Eero P Simoncelli. Cardinal rules: visual orientation perception reflects knowledge of environmental statistics. *Nature neuroscience*, 14(7):926–932, 2011.

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