# Effects of ocular aberrations on contrast detection in noise

***Bo Liang[1,2], Rong Liu[3], Yun Dai[1,2], Haoxin Zhao[1,2], Jiawei Zhou[3], Yifeng Zhou[3], Yudong Zhang[1,2]***

[1]Institute of optics and Electronics, Chinese Academy of Sciences, Chengdu, 610209, China

[2]The Key Laboratory on Adaptive Optics, Chinese Academy of Sciences, Chengdu, 610209, China

[3]Vision Research Lab, School of Life Science, USTC, Hefei, China

*bojob.liang@gmail.com, daiyunqq@163.com*

**Purpose**

To investigate the effect of ocular aberrations on contrast detection in noise and to assess how much the observer's ocular aberrations and internal noises respectively contribute to the loss of contrast detectability.

**Methods**

*Equipment and Model*: A customized adaptive optics (AO) visual simulator [1] was used, in which a video converter [2] was integrated to produce 14 bits gray levels. Psychophysically, we used the classical equivalent input noise method and noisy perceptual template observer model (PTM) [3] to characterize the contributions of optical and neural factors in limiting visual contrast detection at different signal spatial frequencies.

*Observer*: Two observers participated in the experiments (JCZ, age 20, and JZD, age 21). All had normal (JZD) or optically corrected to normal (JCZ) vision by trial lens. All observers were well trained with the task and naïve to the purpose of the experiments.

*Stimuli and Procedure*: The stimuli in the task were sinusoidal gratings (signals) and pixel patch noises (noises) whose gray level of each patch was sampled from a Gaussian distribution with mean 0 and the standard deviations were 0, 0.02, 0.04, 0.08, 0.16, 0.28, 0.52, and 1.00. Three spatial frequencies i.e. 4c/deg, 8c/deg and 16c/deg were respectively used in task. And we applied a temporal two-interval forced choice (2IFC) detection task in experiments. A three-down one-up staircase procedure was used to obtain psychometric functions.

**Results**

Fig.1 plots (double logarithmic coordinate) the threshold signal contrast versus external noise contrast (TvC), in which mean data of two observers is used. At spatial frequency 4c/deg, AO and unAO TvC curves intersect with external noise contrast increasing. Before the intersection, AO threshold values are systematically lower than that of unAO. Conversely, AO thresholds are higher after the intersection. Both signal contrast and external noise contrast are degraded by ocular aberrations, so if the contrast enhancement is higher for signal than that for noises, AO correction will reduce threshold contrast. On the contrary, the threshold rising will occur. Furthermore, the spatial frequency increasing produces a lateral shift of the intersection toward to high external noise contrast. As we can see from the single TvC curves, signal spatial frequency increment gives rise to a leftward shift of the curve elbow, which reflects the equivalent internal noise [3]. The results demonstrate a positive correlation between the intersections and equivalent internal noises.

In order to assess how much ocular aberrations and internal noises respectively contribute to the loss of contrast detectability, we specify the condition that internal noises (including multiplicative noise and additive noise, details about noisy observer models see [3]) are set to zero as the performance of the ideal observer. It should be mentioned that the ideal observer is added to a nonideal template and a nonlinear transfer function, as Levi and Klein [4] called near-ideal observer. So we have the near-ideal threshold signal contrast. When external noises are smaller than internal noises, internal noises dominate the performance. Thus we could know the respective contributions of ocular aberrations and internal noises to the loss of contrast detectability. In Fig.1 (b), we mark the area bounded by red and black curves as limitations by ocular aberrations and the area bounded by the red curve and blue line as limitations by internal noises. We find that the contributions of ocular aberrations are comparable with that of internal noises only at 8c/deg.

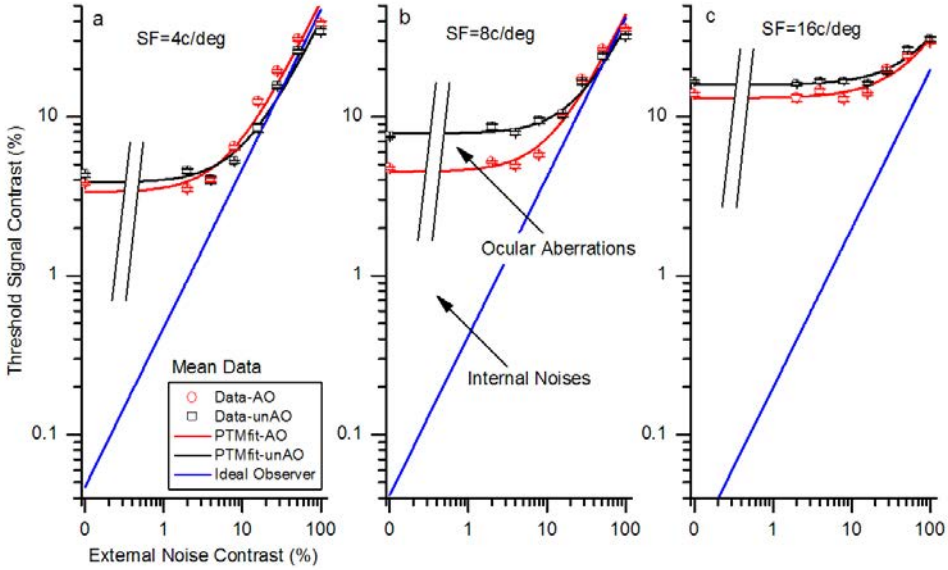


Fig.1 plots the threshold signal contrast versus external noise contrast at three signal spatial frequencies (i.e. 4c/deg, 8c/deg and 16c/deg). Blue line shows the contrast threshold for near-ideal observer as described in text. Red circles and black boxes are the contrast threshold for human observers with and without ocular aberrations corrected. Error bar indicates the ±1 standard error. Respectively, red and black lines are the PTM prediction to the data. Text arrows show the limiting factors of threshold contrast. Area bounded by the black and red curves reflects the limitations of ocular aberrations while area bounded by the blue and red curves demonstrates the limitations of internal noise. Simply, we only mark at 8c/deg.

## Conclusions

We present a separable analysis of ocular optical aberrations and neural intrinsic noises for a contrast detection task in noise at different signal spatial frequencies. Our results suggest that the threshold reduction by AO correction occurs when signal contrast degradation dominates. The range of this reduction is predominately expected from a concomitant increased equivalent internal noise. Adaptive optics together with the equivalent input noise method reveals a great potential on investigating the neural intrinsic responses.

## References


1. Li, S., Y. Xiong, et al., “Effects of Monochromatic Aberration on Visual Acuity Using Adaptive Optics,” Optometry and Vision Science 86(7): 1-7(2009).

2. Li, X., Lu, Z.-L., Xu, P., Jin, J., & Zhou, Y., “Generating high gray level resolution monochrome displays with conventional computer graphics cards and color monitors,” Journal of Neuroscience Methods, 130(1), 9-18(2003).

3. Lu, Z. L., & Dosher, B. A., “Characterizing observers using external noise and observer models: Assessing internal representations with external noise,” Psychological Review, 115, 44-82(2008).

4. S. A. Klein, D. M. Levi, “Stochastic model for detection of signals in noise,” J. Opt. Soc. Am. A 26, B110-B126 (2009).