Using Rayleigh Matching to Identify Individual Differences in Cone Parameters

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Introduction

- Within the normal range of color vision, individual differences affect how people perceive colored stimuli.
- Asano et. al.[1] developed an **observer model** with eight parameters to account for individual differences in cone photoreceptors.
  - The three classes of cone photoreceptors (L, M, and S) vary in terms of peak spectral sensitivity (lambda max) and optical pigment density. We focus on these differences here.

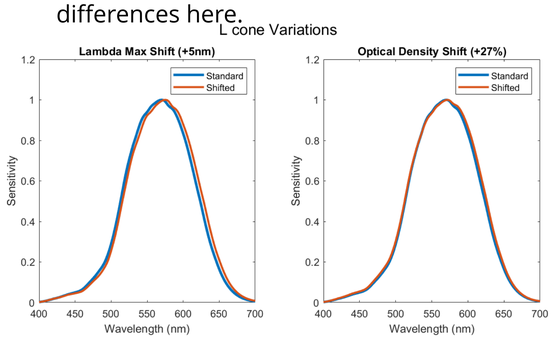

Figure 1

- **Rayleigh matching** is an experimental approach used to characterize red-green color vision.
  - Subjects view two lights: primary mixture (560 nm + 670 nm) and test light (590 nm)
  - Subjects adjust the primary ratio and test intensity until lights appear identical.

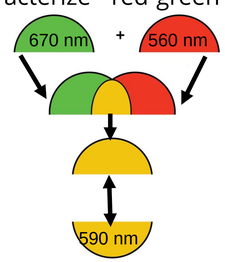

Figure 2

- Rayleigh matches reveals information about subject cone properties.
- But prior work has shown it is not possible to simultaneously recover L and M cone lambda max and optical density parameters from—Rayleigh matches conduced with a single test wavelength.[2]

Research Question

Can enhanced Rayleigh matches with multiple test wavelengths be used to identify cone individual difference parameters?

Methods

- Performed a theoretical study due to Covid-19.
- Simulated observers based on the individual difference model.
  - L and M cone lambda max and optical density varied about their means.
- Simulated observers completed a Rayleigh matching experiment.
  - In each trial, calculated the color difference between primary mixture (560 nm + 670 nm) and test light for the simulated observer.
  - Adjusted primary ratio and test intensity to minimize the color difference.
  - Simulated Rayleigh matching with 15 evenly spaced test wavelengths ranging from 570-640 nm.
- Attempted to recover observer parameters based on their match data.

Results 1

- Parameters were recovered accurately if observer matches were not noisy.

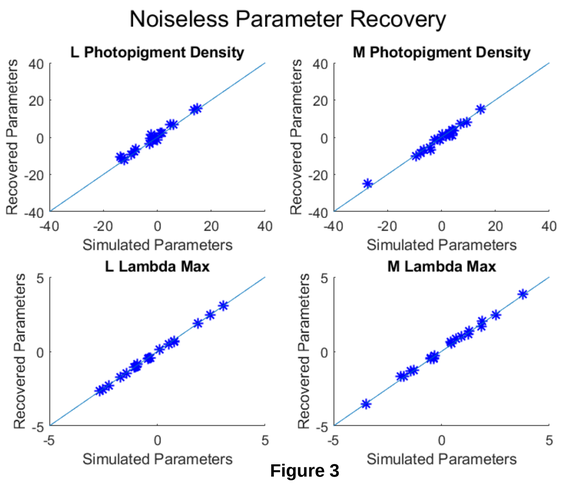

Figure 3

Results 2

- This led to accurate recovery of cone fundamentals.

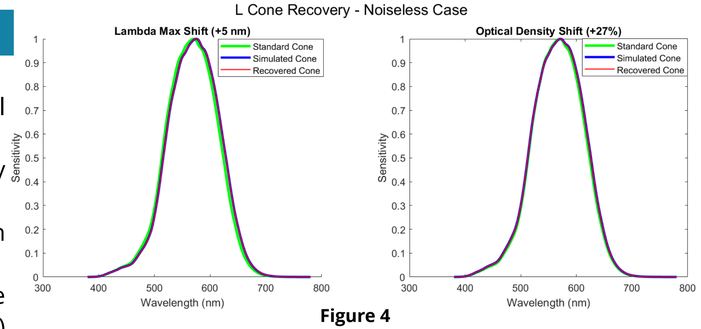

Figure 4

Results 3

- Adding noise to simulated observer judgements led to a gradual decline in the accuracy of recovered parameters and cone fundamentals.

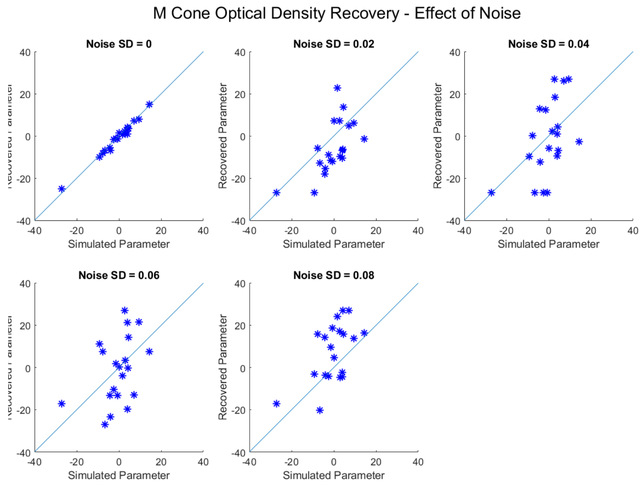

Figure 5

Results 4

- Increasing the number of matches per test light improved recovery for noisy observers (SD = 0.06).

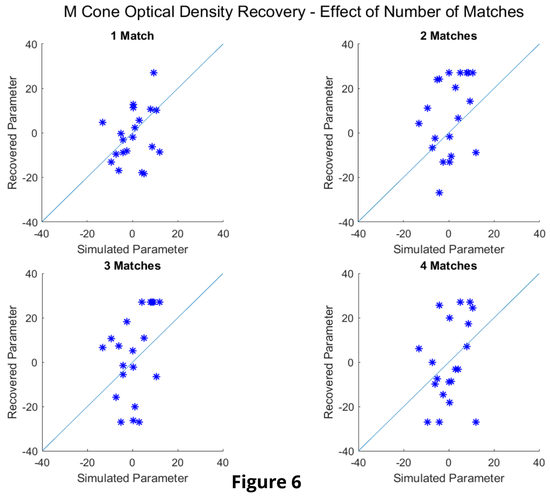

Figure 6

Conclusions

- In the noiseless case, Rayleigh matching with multiple test wavelengths provides enough information to accurately identify simulated observer parameters.
- Recovery is less accurate for noisy simulated observers. Increasing the number of matches per test light helps.
- Enhanced Rayleigh matching can be used to estimate individual human cone properties. This should allow stimuli to be tailored to individual subjects' cones.

References

1. Asano, Y., Fairchild, M. D., & Blondé, L. (2016). Individual Colorimetric Observer Model. *Plos One, 11(2)*. doi: 10.1371/journal.pone.0145671
2. Thomas, P., & Mollon, J. (2004). Modelling the Rayleigh match. *Visual Neuroscience*, *21*(3), 477–482. doi: 10.1017/s095252380421344x