Correcting displays for individual differences in color appearance

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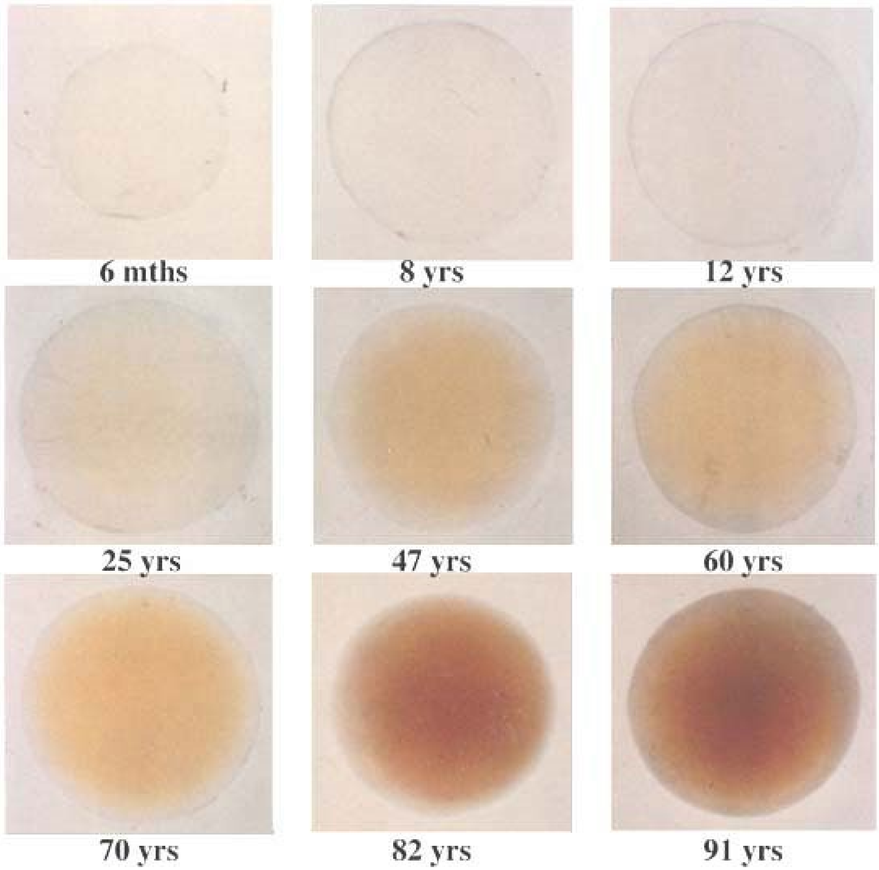
Introduction

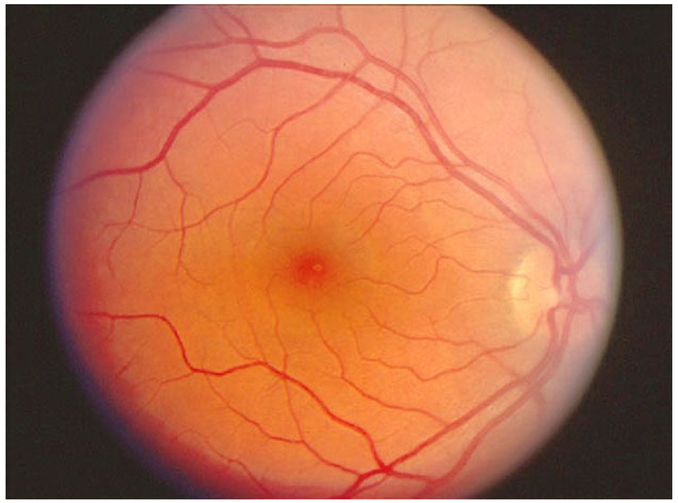
- Individuals with normal color vision vary widely in their color vision: these differences arise at all levels, from optics to cognition.
- This variability leads to differences in color perception from one observers to another, as well as within the same observer, despite processes like constancy, learning and adaptation, and factors like environment, language and age.
- The growing interest in correcting visual displays for these differences, by adding calibrations specific to the observer, has focused on correcting differences in spectral sensitivity of the cone receptors.
- However, these sensitivity differences do not predict the substantial individual differences in color perception, and thus will not equate images for appearance.

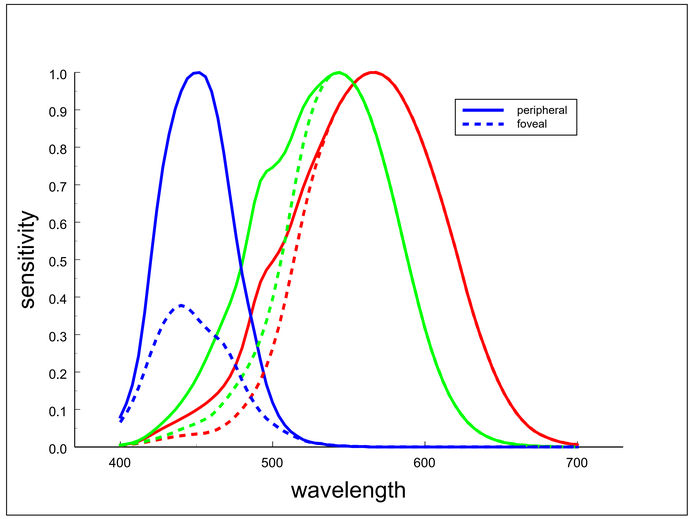
Appearance differences depend very little on spectral sensitivity differences



Lens aging has little effect on color appearance

Werner and Sheffrin 1990, 1993; Wuerger 2013

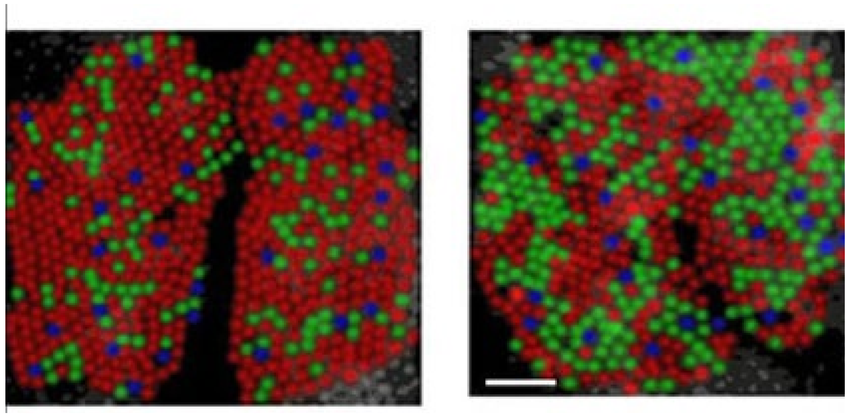




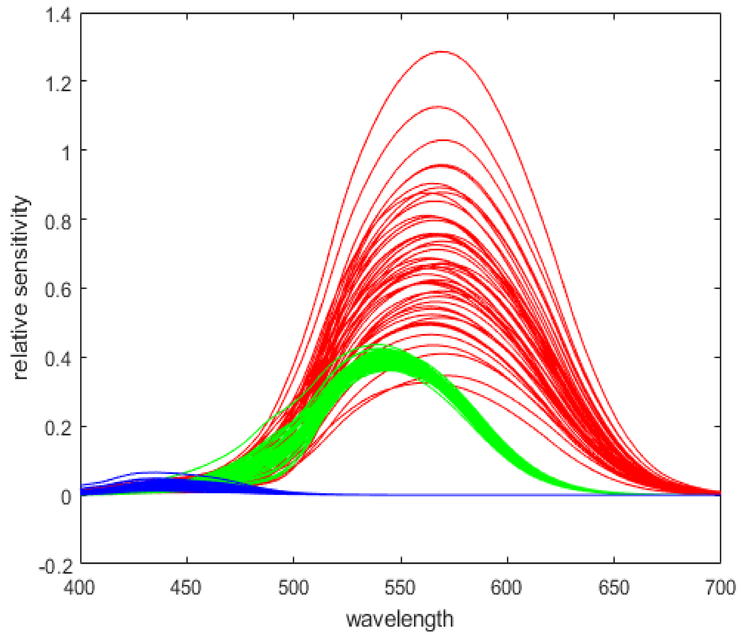
Color percepts remain similar between the fovea and near-periphery despite differences in macular pigment

Beer et al. 2005; Webster and Leonard, 2008

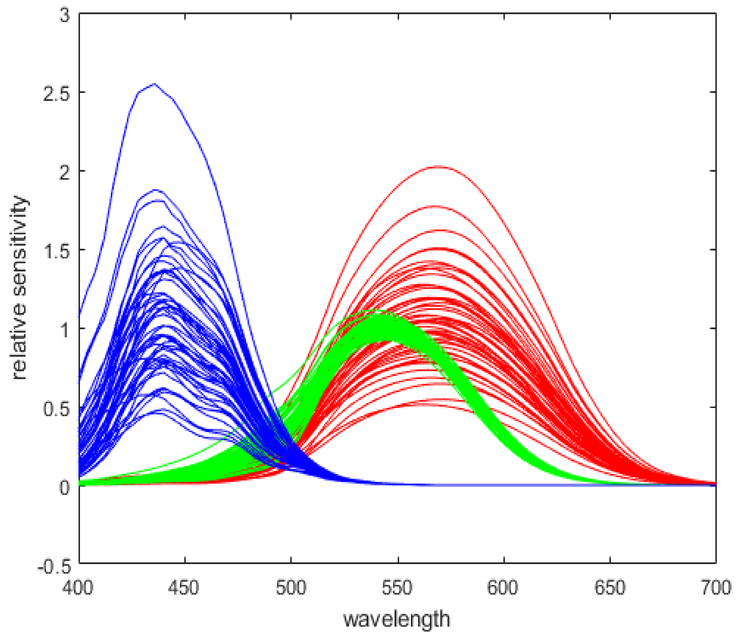
Spectral Sensitivities Variability across observers



L:M cone ratios can vary over a ~20-fold range



Observer 1



Observer 2

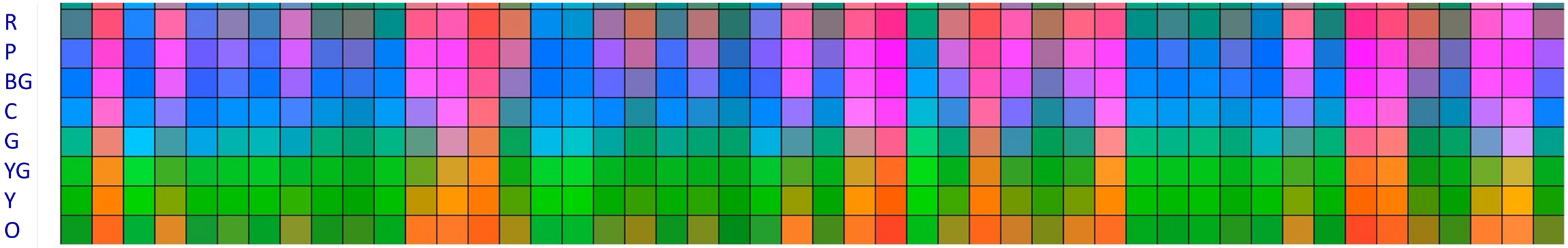
LM cones ratio (SD=2)

However, the response differences are almost completely compensated by simple renormalization (adaptation) of the cone sensitivities

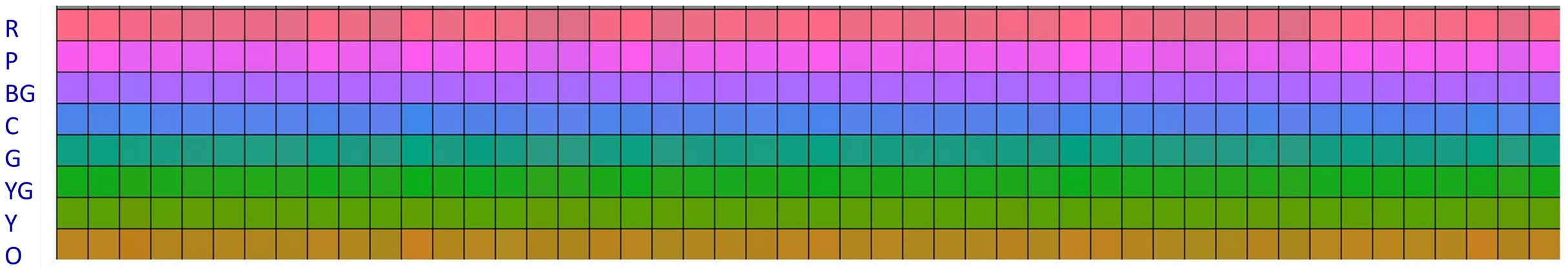
Hue perception based only on individual spectral sensitivities

50 Simulated Observers

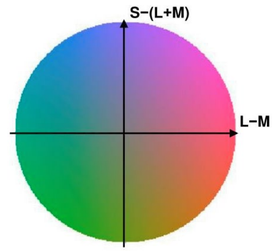
Before Adaptation



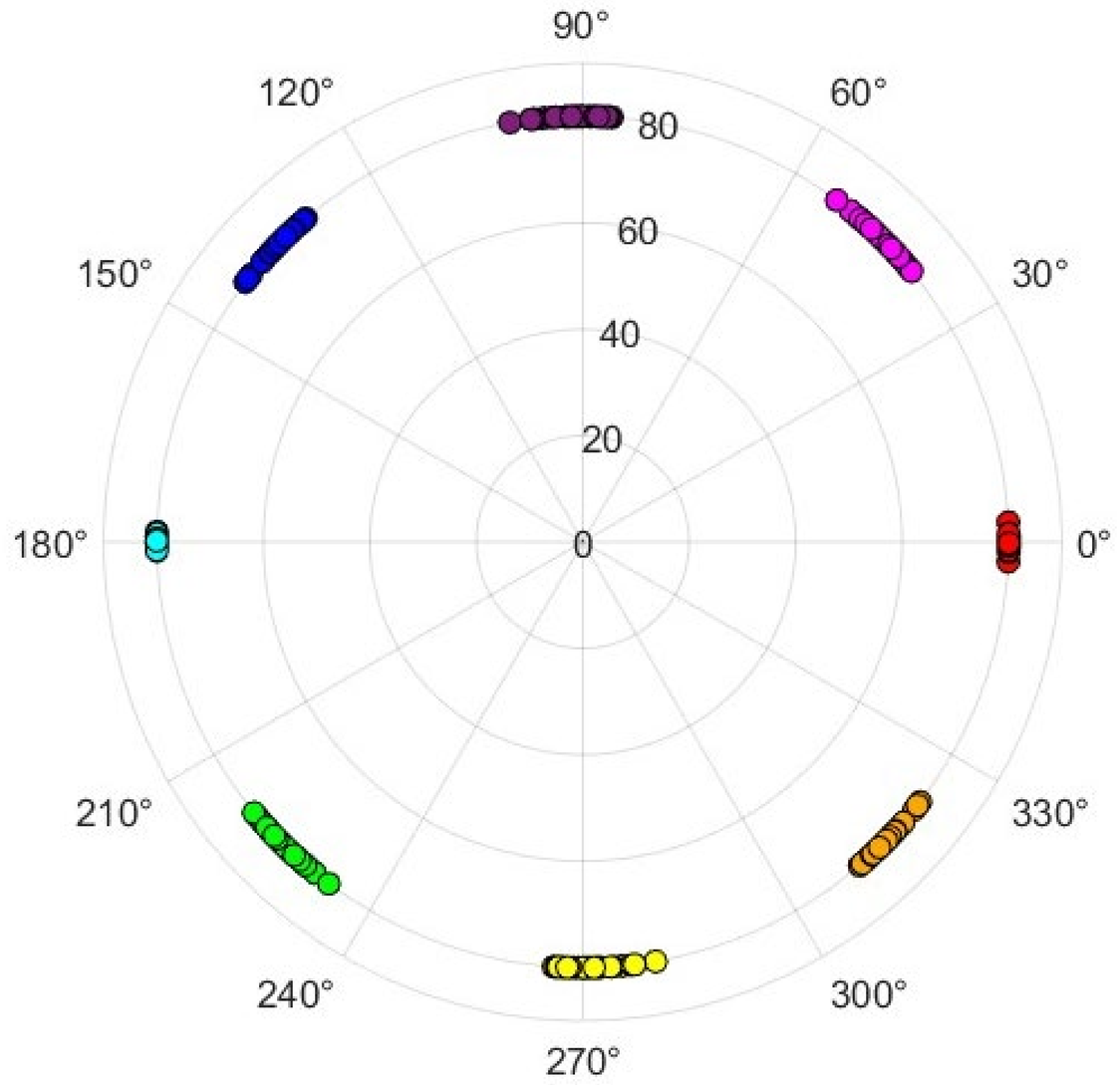
After Adaptation

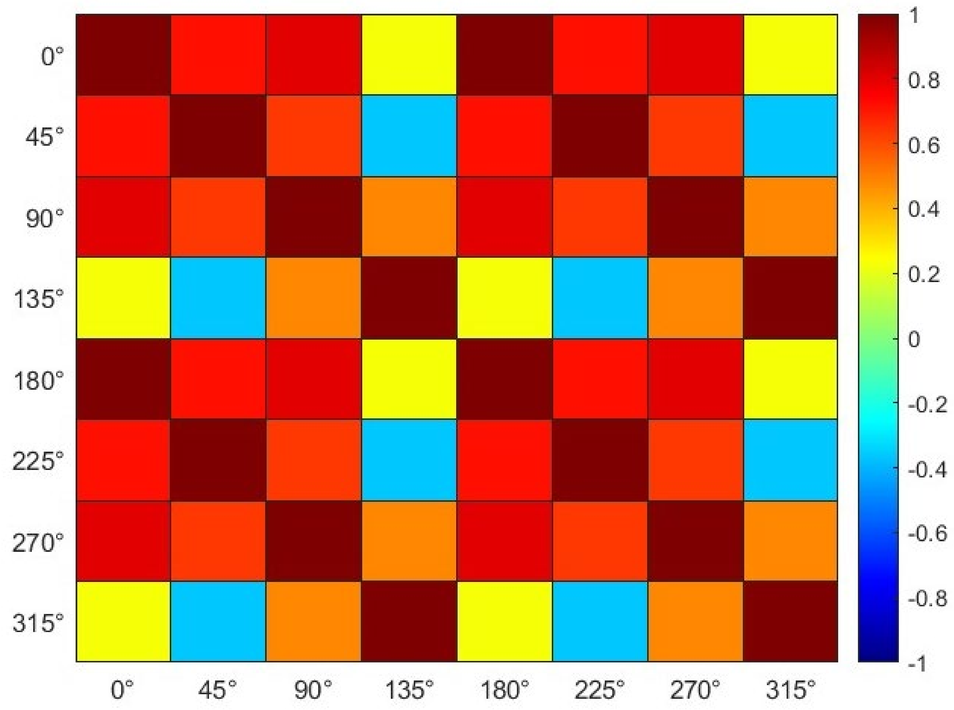


Simulated Observers
(N= 50): the sensitivity differences lead to changes in cone excitation for the same stimuli.



DKL Color Space





Hues are highly correlated

Our work

- We designed an algorithm for adjusting images to directly correct for individual differences in color appearance based on hue percepts for individual real observers (without correcting for spectral sensitivity).

- Three steps: hue percepts measurements, definition of the algorithm, application to images.

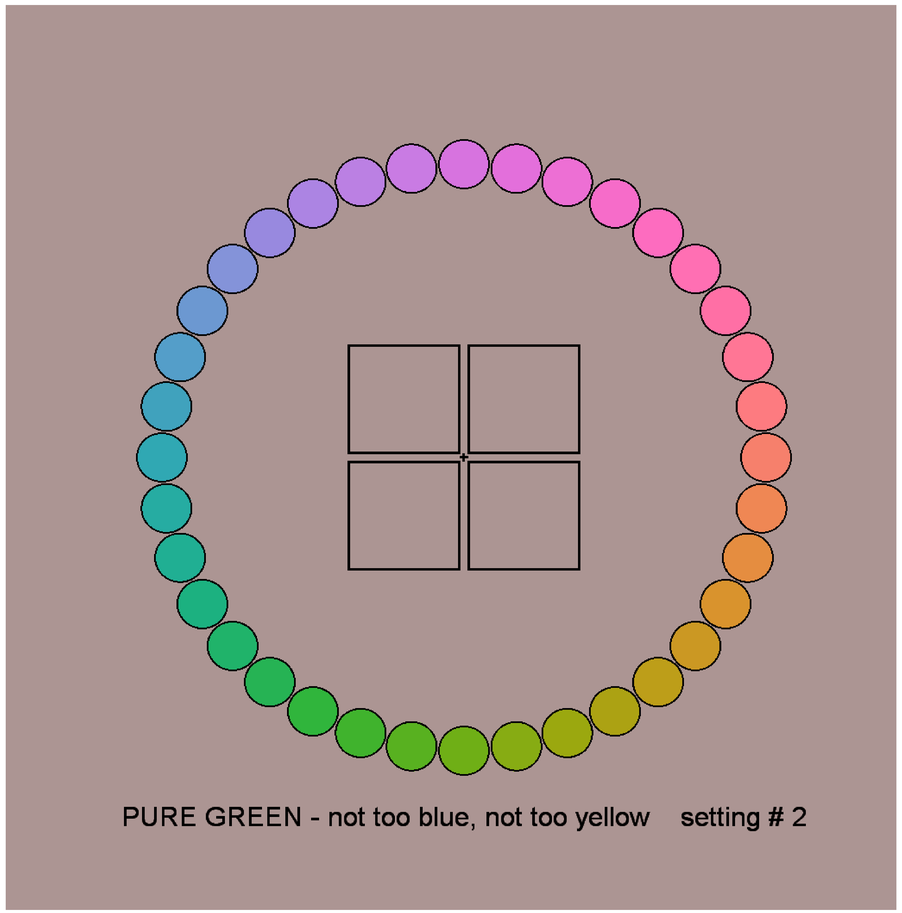
- The goal of the correction is to vary the colors in images so that two observers – each looking at images through their own correction – should show better agreement about the colors they are experiencing (different physical stimuli but same perception).

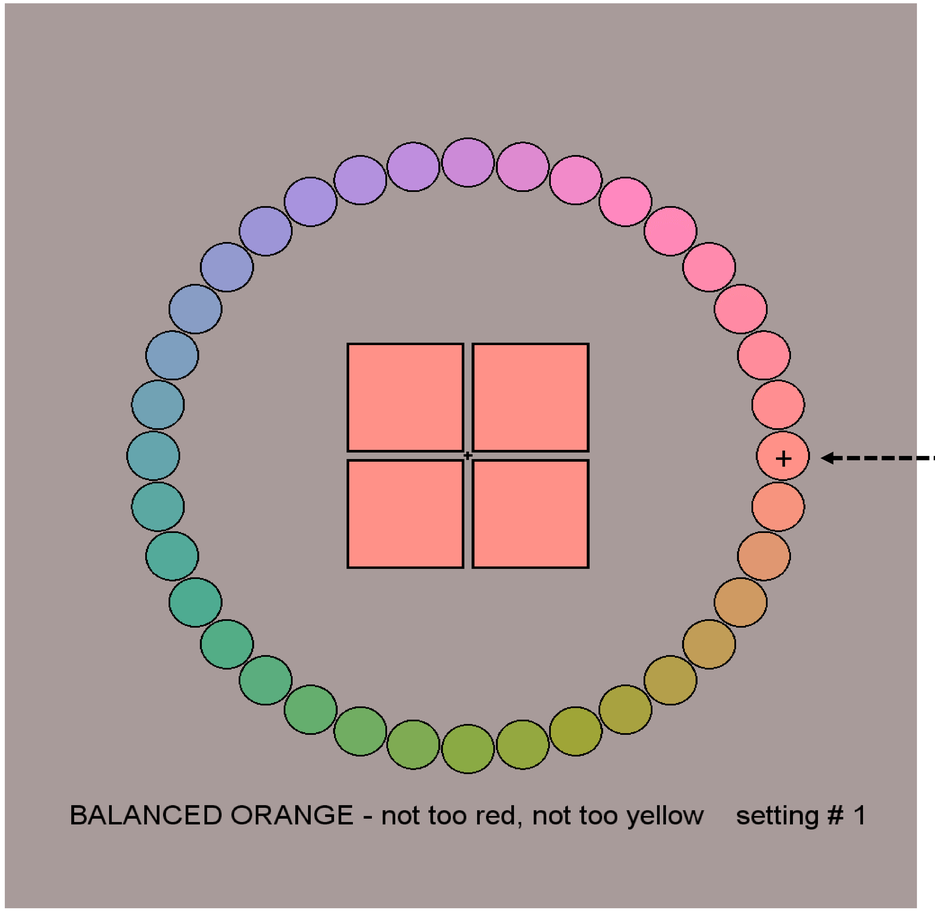
Experimental Design: hue percepts measurements

N= 21 color-normal real observers

Each hue is measured 6 times for 2 sessions → 12 total measurements

Hue foci identification task

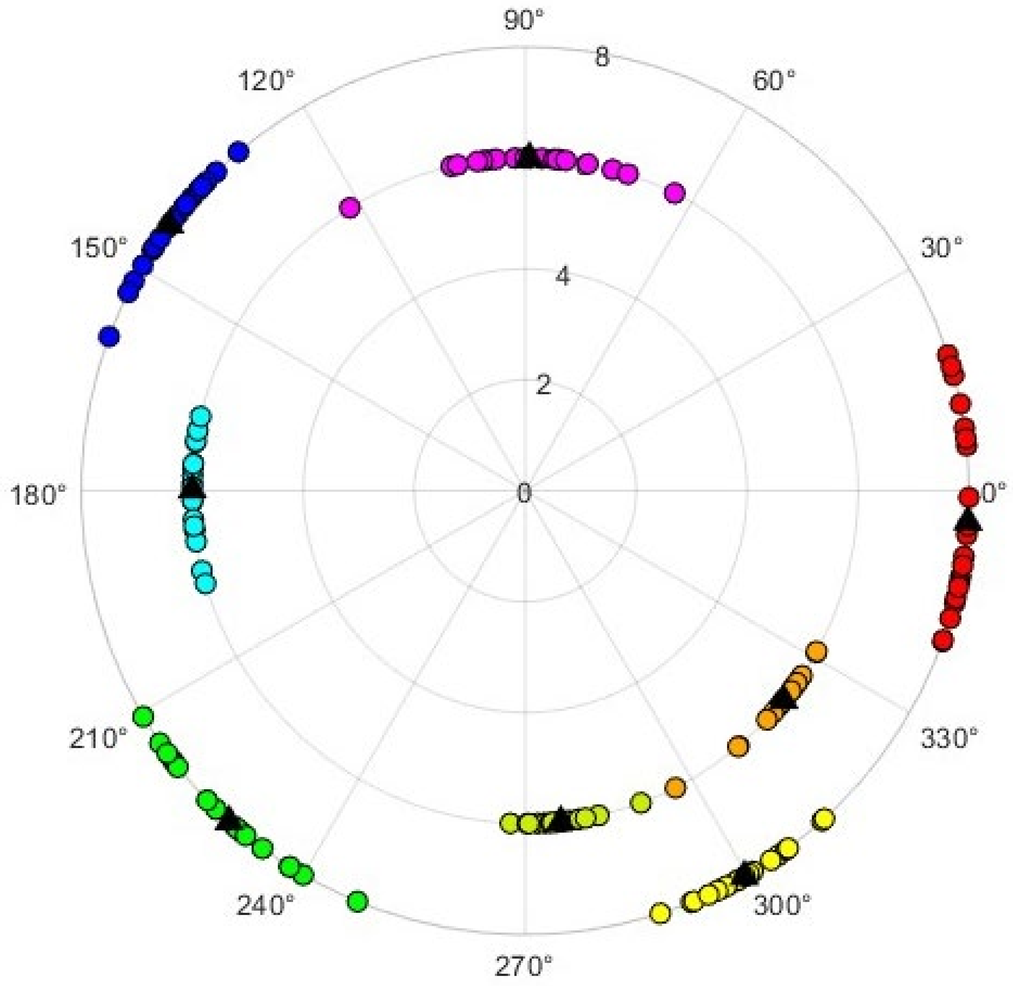


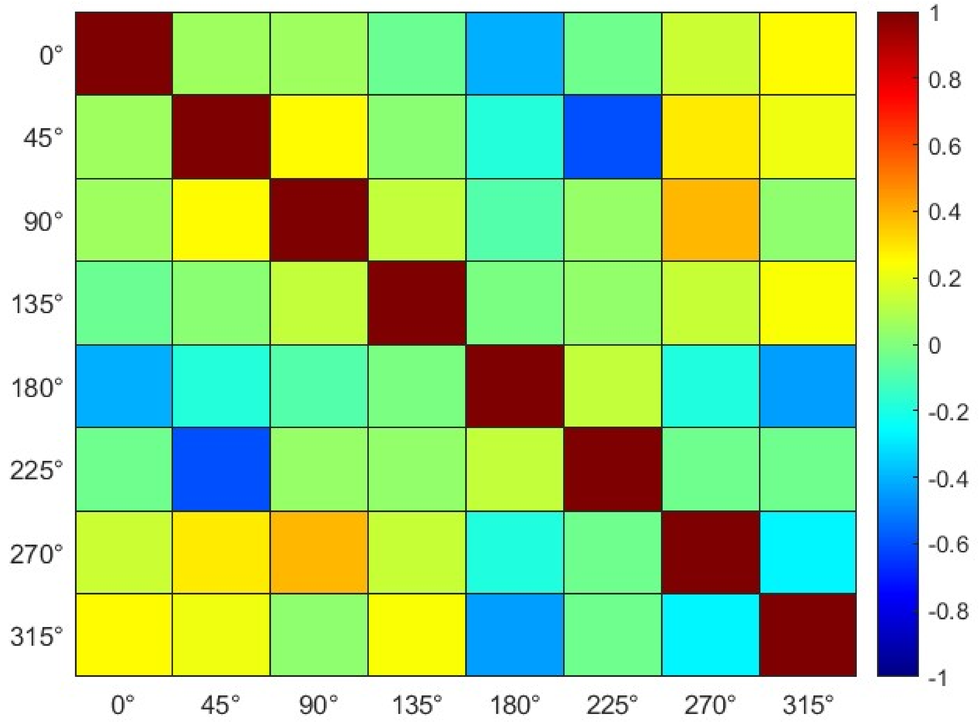


8 hues: 4 unique (e.g. blue) hues + 4 binary (e.g. orange) hues

Results

21 Real Observers' individual hues and the Standard Observer (black triangles)





Hues are not correlated

The measured differences in hue percepts are greater than the residual hue variations predicted by sensitivity differences

Results: perceptual variability across observers based on their hue percepts measurements

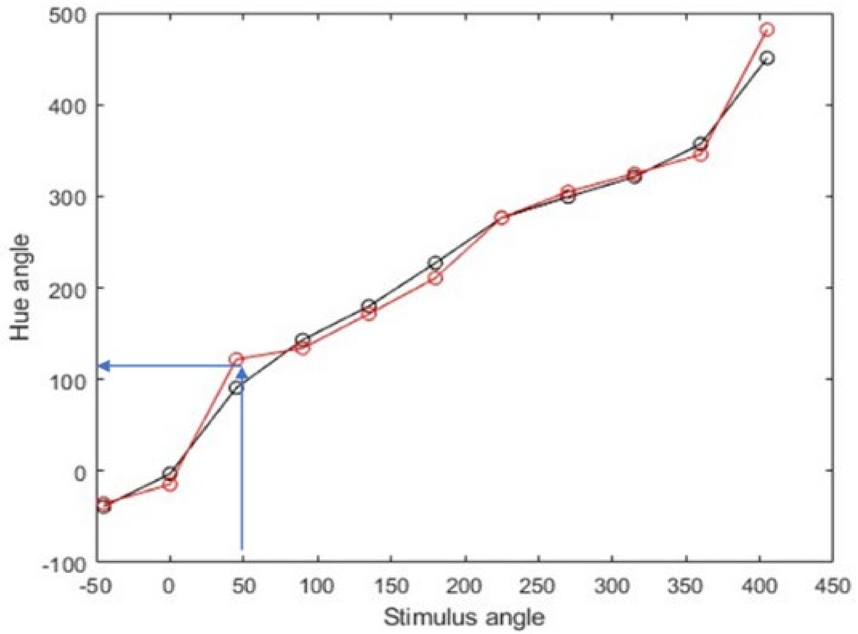
N= 21 Real Observers
The first column is the Standard Observer

Individual observers' Hue foci are the avarage of all measurements (12) for each observer.

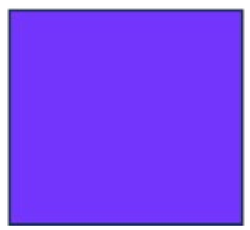
Standard Observer's hue foci are the avarage of all the measurements of all the observers together.

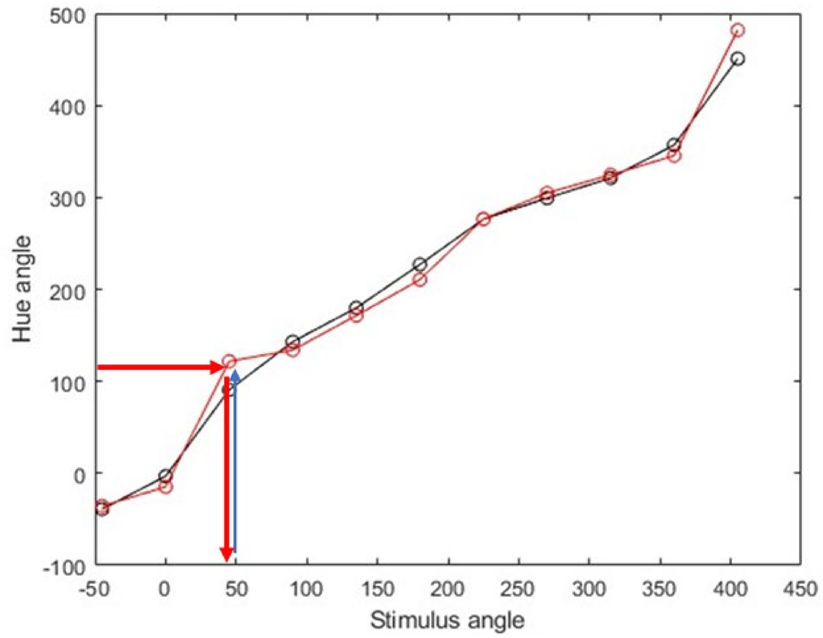
Algorithm

Adjust image colors to match hue percepts across observers

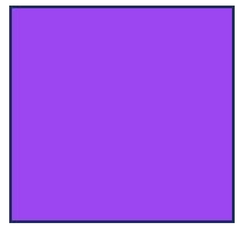


Step 1: for each pixel RGB get the hue percept for the standard observer (black line)*





Step 2: get the RGB for the same hue percept in the target observer (red line)*



* Circles represent interpolation

Application of the algorithm: correction

Some advantages

- People experience different chromatic information in similar way
- Miscommunication is limited
- The adjustment of display settings led to the achievement of a uniform desired color response that closely matches established color standards

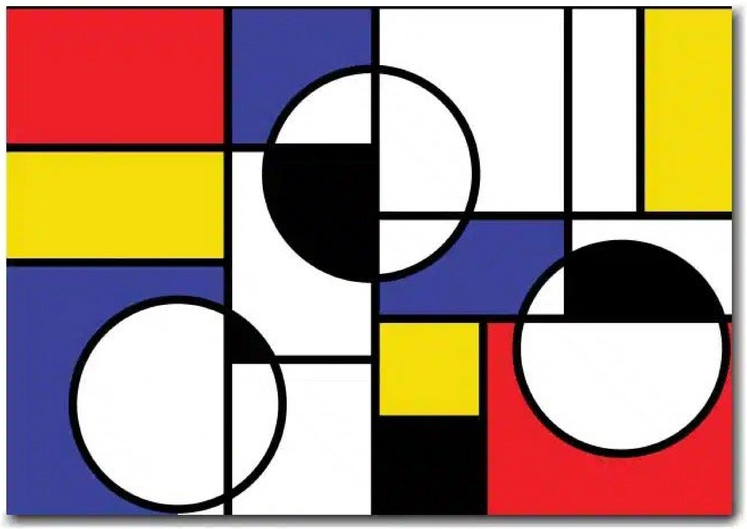
Let’s look to some examples!

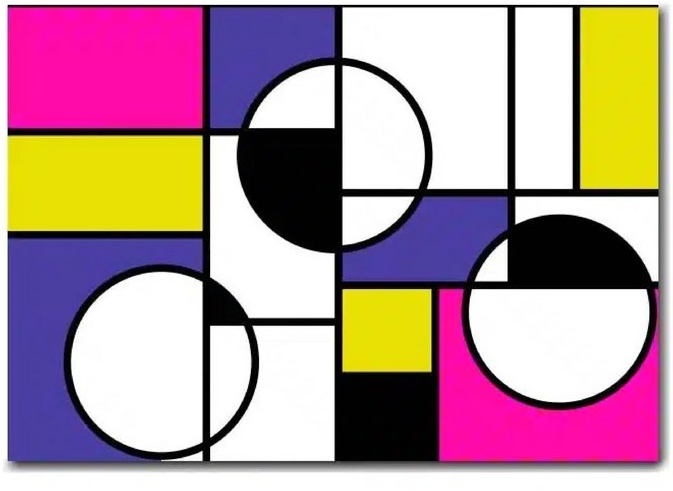
Reference Image

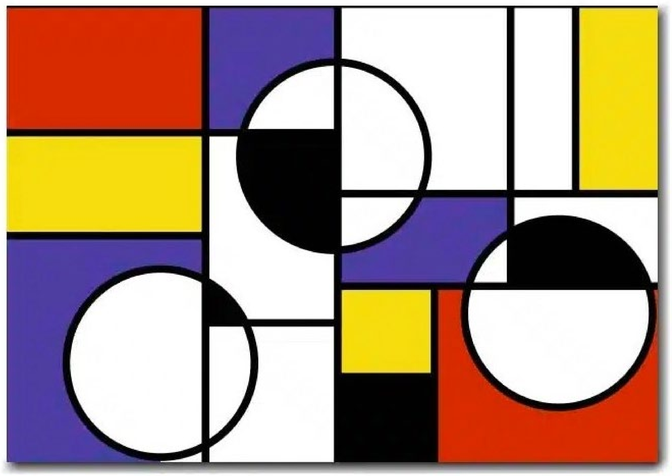
Corrected Images for 3 different observers

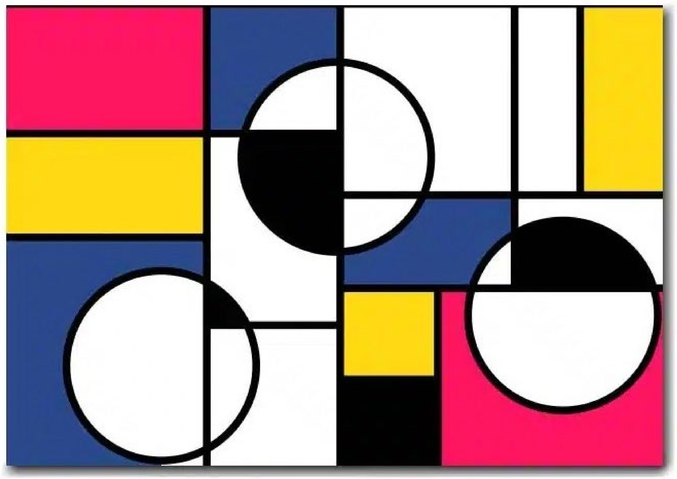
Corrected Images for 4 different observers

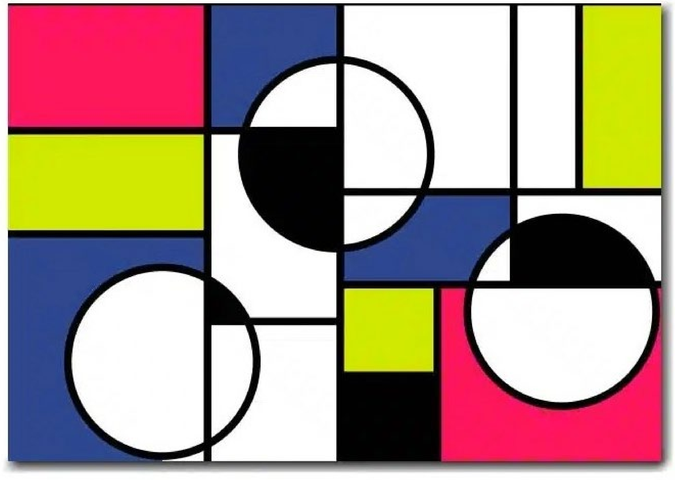
Reference Image











Reference Image

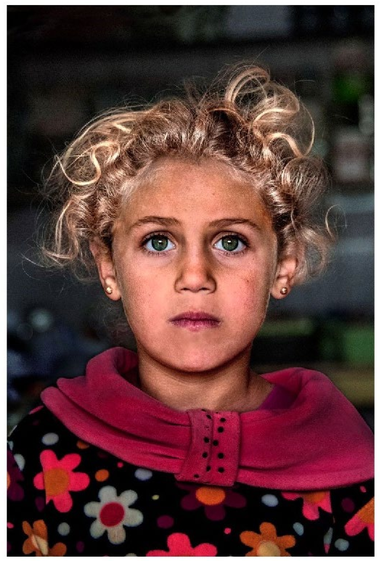
Corrected Images for 3 different observers

Some disadvantages

The correction can distort the expected colors of the image (e.g., the skin color in Steve McCurry's photograph).

Reference Image

Corrected Images for 4 different observers



Applications

- The areas of application are numerous: monitor calibration, data visualization, efficiency in communication, and research on color perception and cognition, with the main goals to:

1. Maintain color consistency and fidelity across observers and on different devices
2. Develop more inclusive tools and technologies in data visualization
3. Control for perceptual differences to study color communication and cognition
4. Visualize individual differences in color experiences.

Next Steps

1. Add other color dimensions, like saturation and brightness
2. Measure individual hue percepts in real images
3. Combine two algorithms: one to correct individual differences in spectral sensitivities and one to correct individual differences in color appearance.

Conclusions

- Individuals greatly vary from each other in how they experience the same chromatic stimulus.
- This variability in color appearance does not depend on variability in spectral sensitivities.
- Individual differences across observers in color perception can be corrected through an algorithm without correcting for variations in their individual spectral sensitivities: we can, thus, obtain images that elicit the same color perception response in any observer.
- The correction limits misperception and miscommunication

Thank you for your attention!

Questions and suggestions are welcome

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Supported by National Eye Institute EY-010834