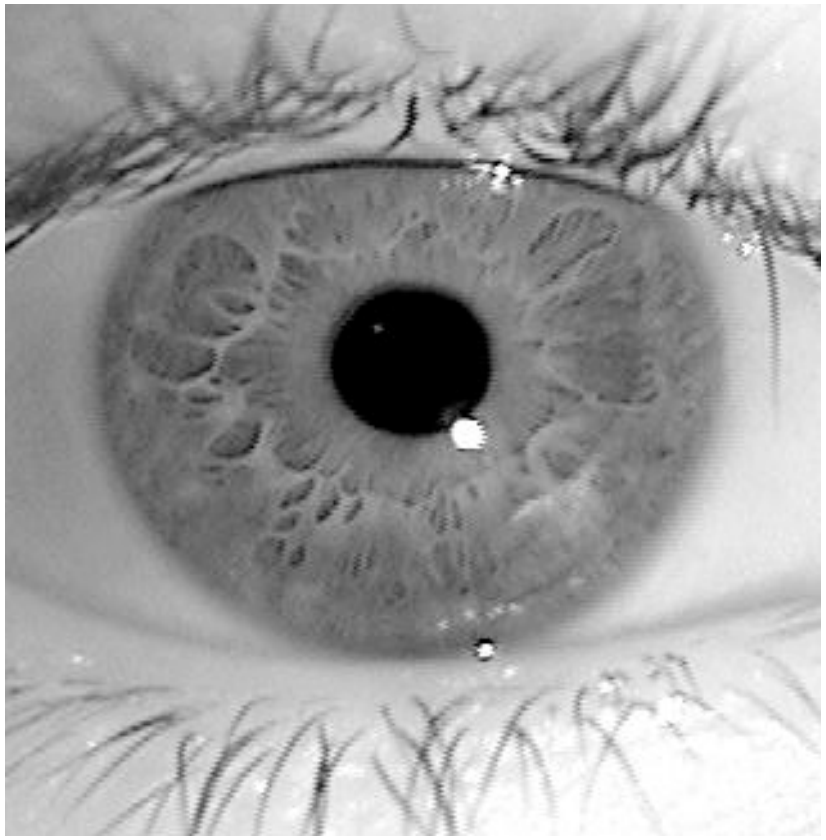

The Importance of Small Pupils: A Study of How Pupil Dilation Affects Iris Biometrics

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Outline

1) Camera optics
2) How much light enters the eye?
3) How does dilation affect iris biometrics?

Camera Stops

The effect of a stop depends on its location in the system. An aperture stop limits the light entering the system.

Source: Optics pictures from “The Human Eye” by Clyde Oyster

Camera Stops

A field stop limits the field of view.

Based on what you know about the iris, can you determine whether it is an aperture stop or a field stop?

Camera Stops

The iris lies next to the anterior surface of the lens, and operates mainly as an aperture stop.

How much light enters the eye?

- The amount of light entering the eye is proportional to the pupil area.
- Area = pi * r^2
  = pi / 4 * d^2
- Pupil diameter ranges from 2 to 8 mm, so the amount of light admitted to the eye will vary by a factor of 16.
- Magnitude of depth of field varies inversely with pupil diameter: The smaller the pupil, the larger the acceptable depth of field.

How much light enters the eye?

The difference between a dark night and direct sunlight is a factor of more than 10^9!

Illuminance	Example
10^-4 lux	No moon, overcast sky
1 lux	Full moon overhead at tropical latitude
100 lux	Very dark overcast day
300-500 lux	Office lighting
1000 lux	Overcast day
10,000 – 25,000 lux	Full daylight (not direct sun)
32,000 – 130,000 lux	Direct sunlight

Source: http://en.wikipedia.org/wiki/Lux

How much light enters the eye?

- The eye deals with change in illumination by
  - Adjusting pupil size,
  - Using different photoreceptors for dim and bright light, and
  - Internally adjusting the sensitivity of the photoreceptors and other retinal neurons.

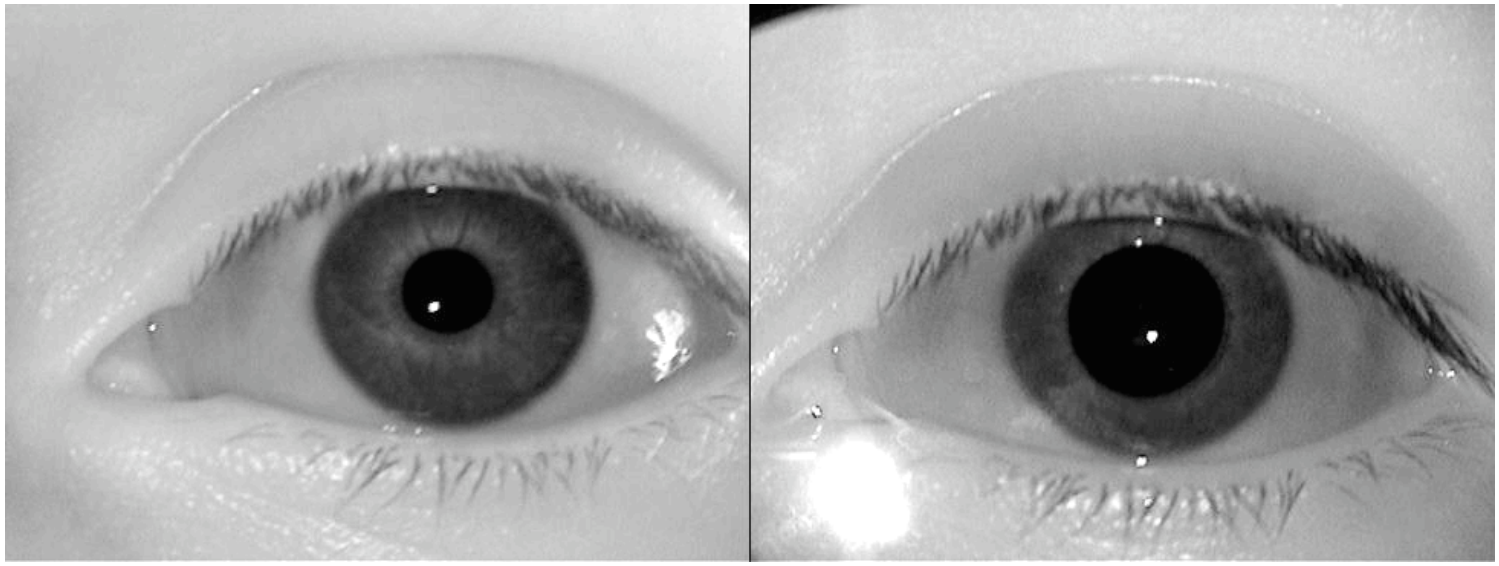
Other than lighting, what factors influence pupil size?

- Accommodation = the automatic adjustment by which the eye adapts itself to distinct vision at different distances. (Source: Dictionary.com)
  - Pupil size varies with accommodation.
- Hippus = rhythmic, involuntary oscillation of the pupil.
  - The pupil dilates and constricts about two times a second over a range of 0.5 mm.
- The pupil dilates less rapidly than it constricts. (Why?)

Other than lighting, what factors influence pupil size?

- Age: Smaller pupils are predominant in the elderly population (Source: Winn et al., 1994)
- Mood
- Medication

How does pupil dilation affect iris biometrics?

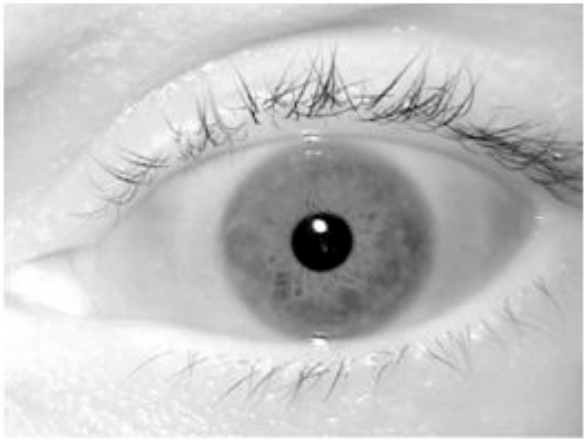


Me, without sunglasses

Me, with sunglasses

A canonical iris biometrics algorithm:

Image Acquisition



Segmentation

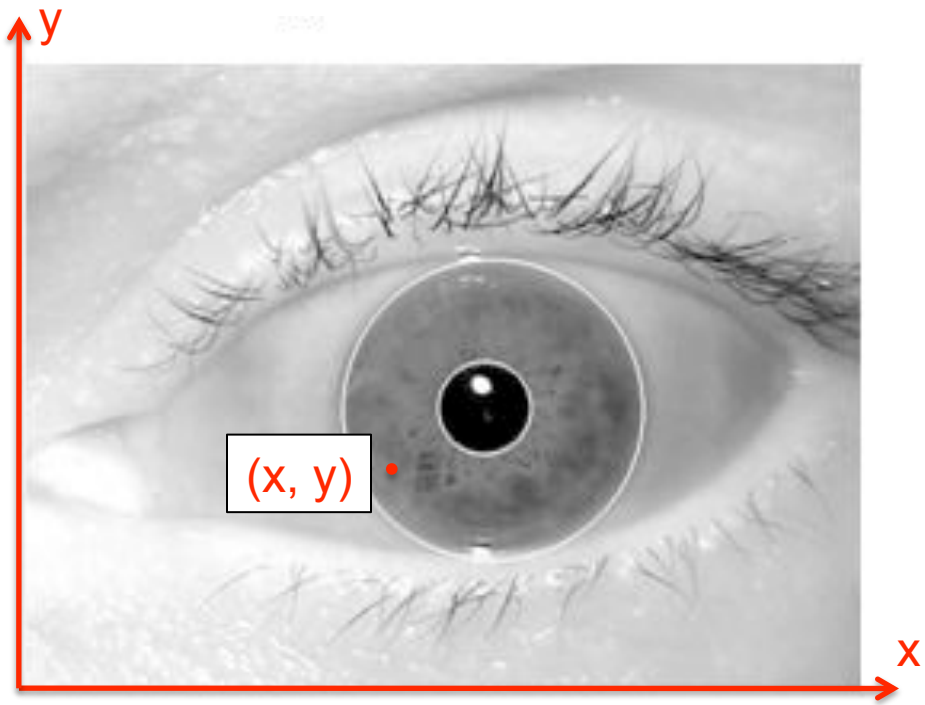
Feature Encoding

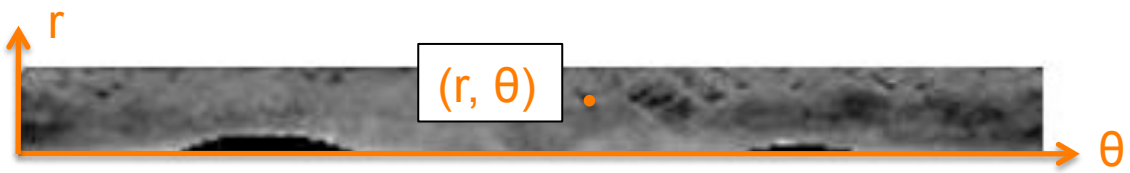
1 1 1 1 1 1 1 0 1 0 1 0 1 0 0 0 0 0 . . .

Matching

$$HD = \frac{\|(codeA \otimes codeB) \cap maskA \cap maskB\|}{\|maskA \cap maskB\|}$$

During segmentation, raw image coordinates, (x, y), are converted into normalized polar coordinates, (r, θ).





Mapping to Polar Coordinates
"Rubber-sheet" model: Pros and Cons

Pros

- Makes possible comparing images with different sizes of iris.

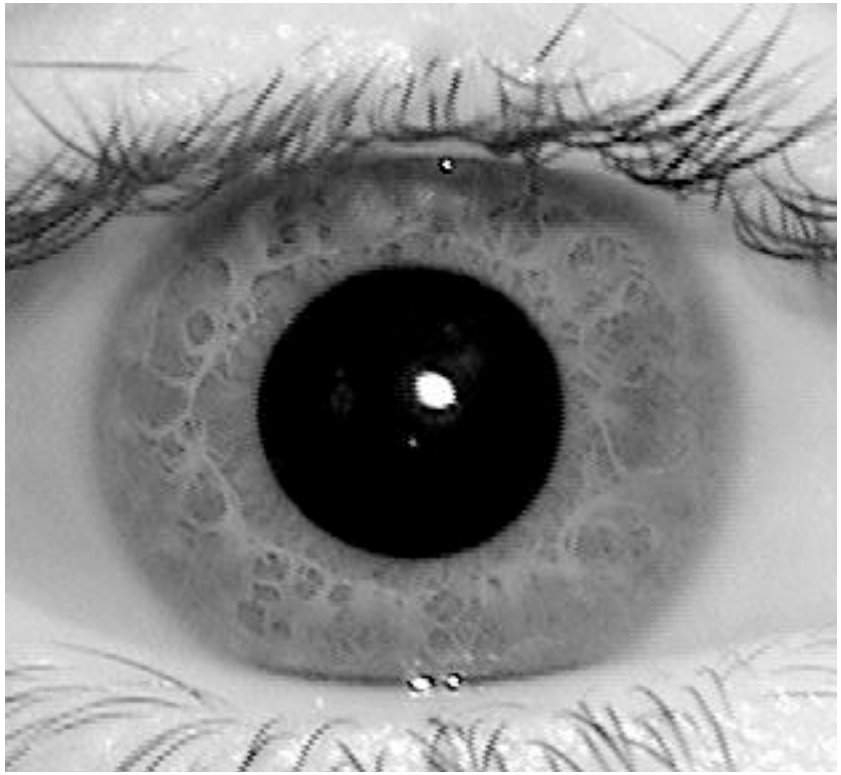
Cons

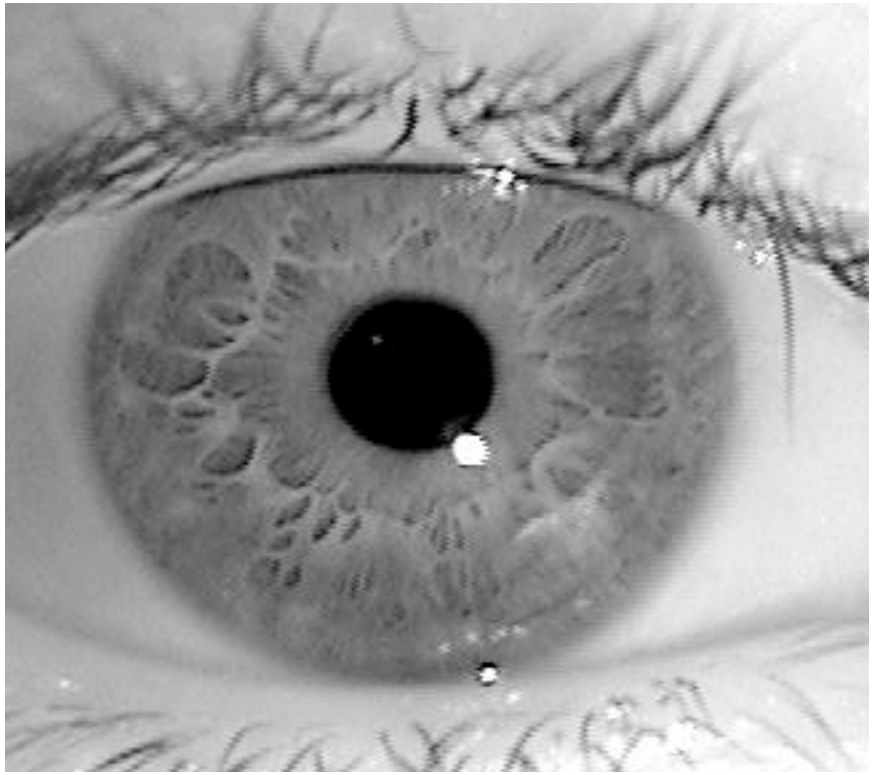
- Does not capture the complex changes in iris tissue
  - Assumes that iris tissue stretches linearly in the radial direction, an assumption which is not necessarily accurate.

Source: A 'minimum-wear-and-tear' meshwork for the iris, Harry J. Wyatt, *Vision Research*, 2000.

"The [iris] has … radial streaks [that] … straighten when the pupil is constricted and turn wavy when the pupil is dilated."

Source: Multispectral Iris Analysis: A Preliminary Study, Boyce et al., *CVPRW*



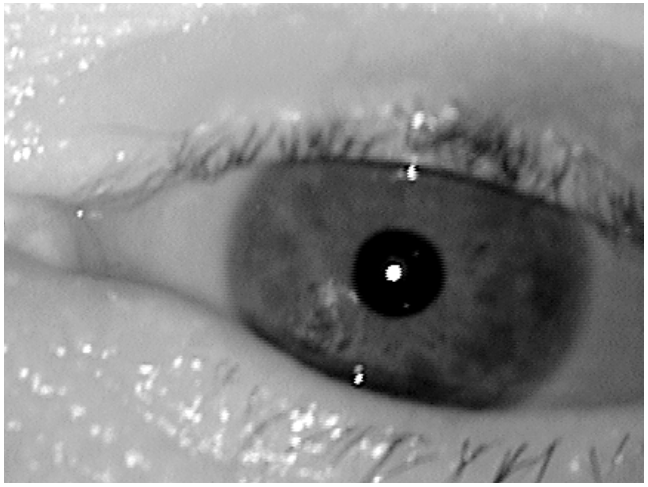


Data

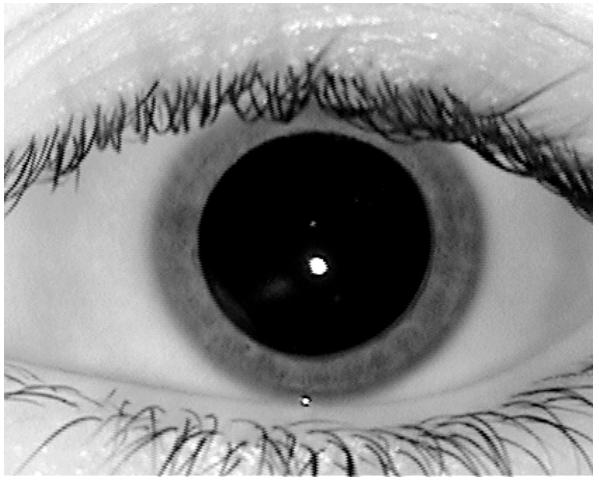
- collected data between July 2007 and September 2007
- 28% of images were taken with the room lighting turned off
- 630 left eye images and 633 right eye images
- 18 subjects

We measured the dilation ratio for each image.

$$\text{Dilation ratio} = \frac{\text{Pupil radius}}{\text{Iris radius}}$$



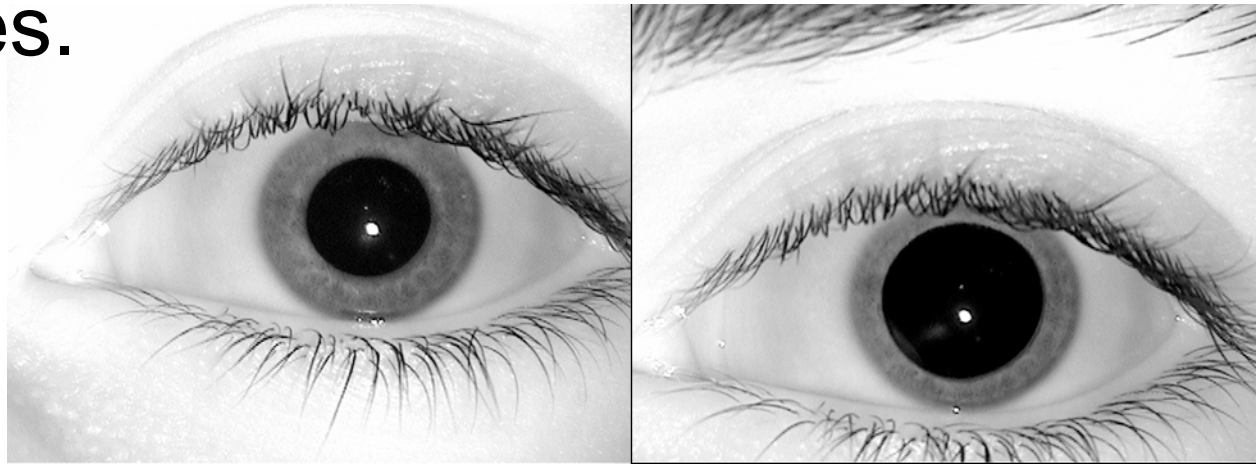
Dilation ratio = 0.2459

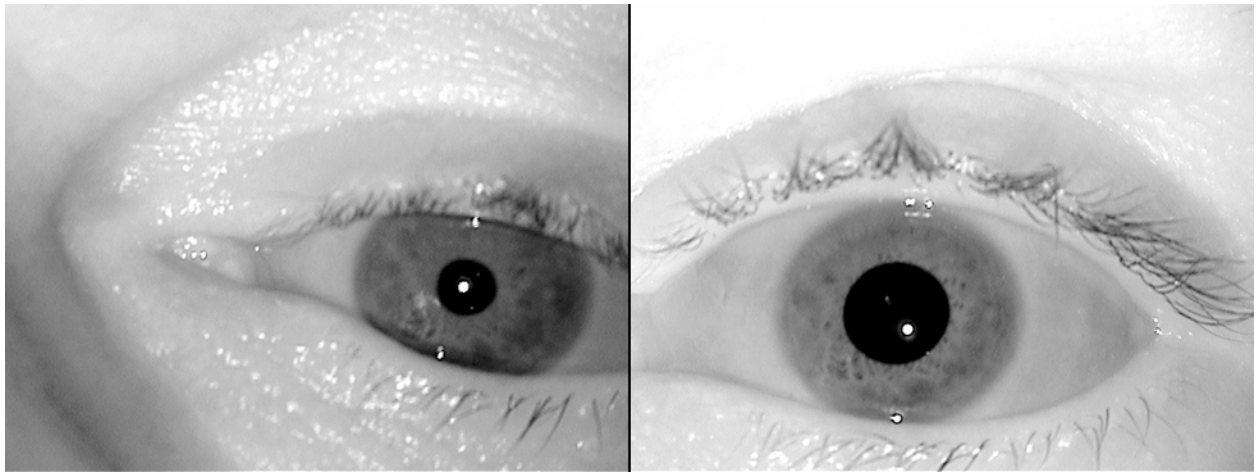


Dilation ratio = 0.7009

New segmentation algorithms use ellipses instead of circles to describe iris boundaries. Future experiments with dilation may want to take this into account.

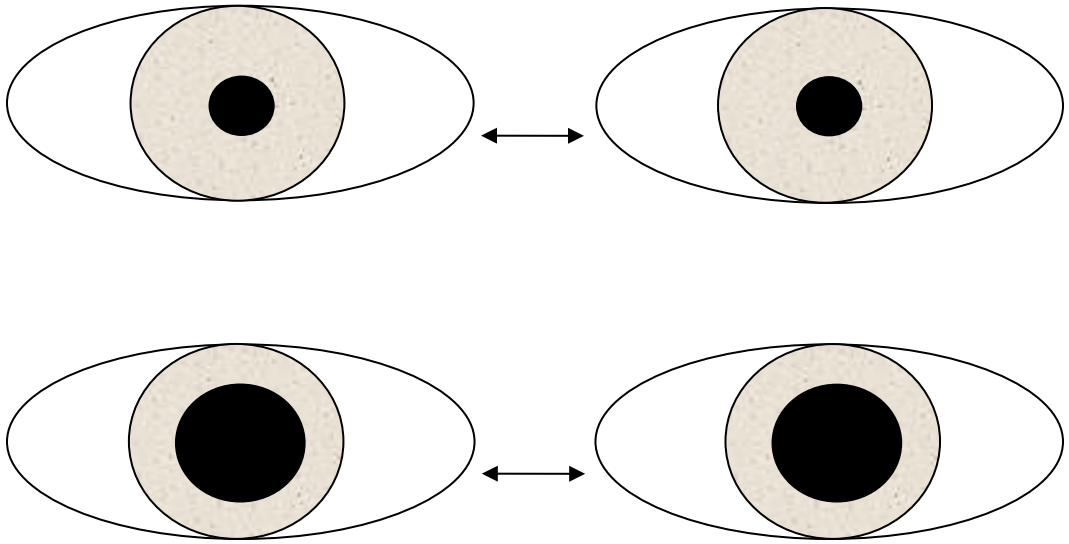
Some subjects' eyes naturally tended to have higher dilation ratios than other subjects eyes.





Experiment 1:

Our iris biometrics algorithm performs well on datasets with small pupils. Would iris biometrics work as well on a dataset with all large pupils?

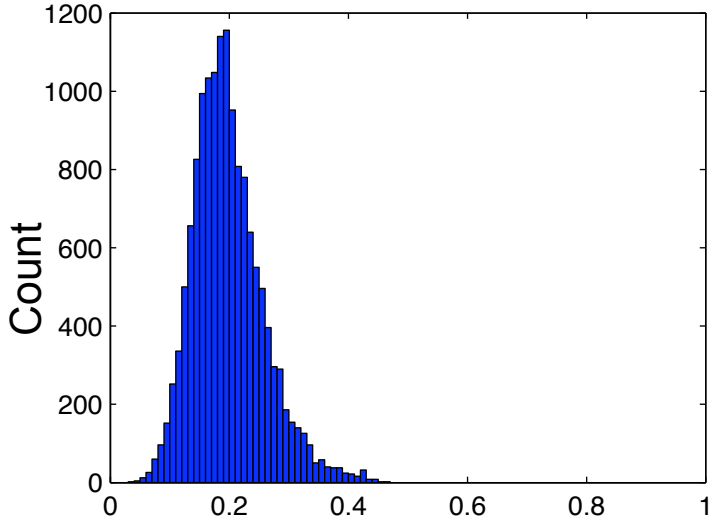


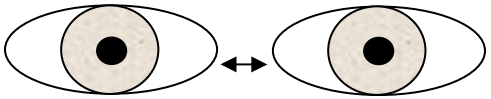
Good Performance

?

Experiment 1: Small Pupils vs Large Pupils

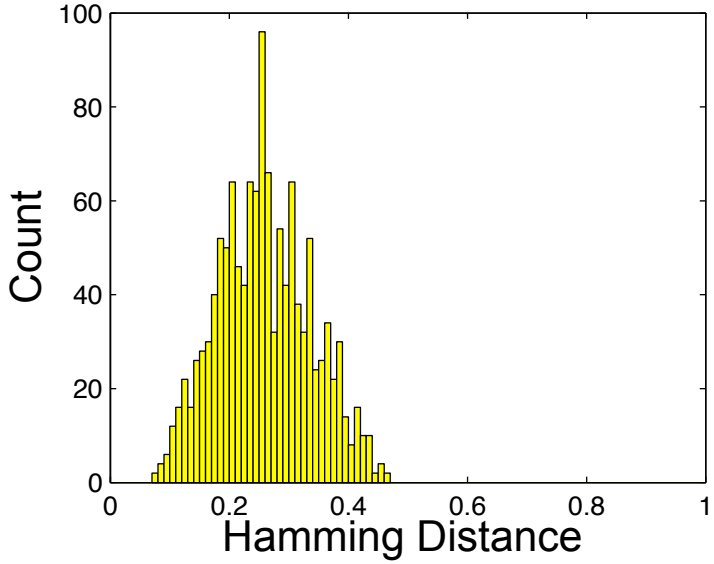
Match Distributions (Authentics)

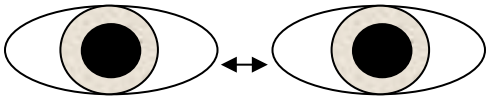




Small pupil vs. small pupil
Mean: 0.1982
Std dev: 0.0595
Number of comparisons: 14542

Good

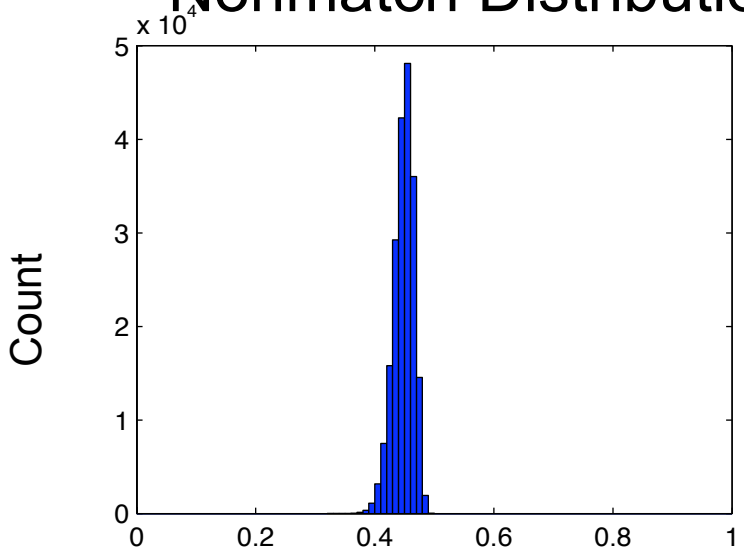


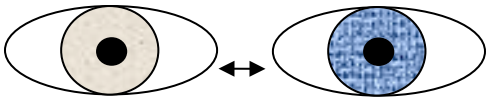


Large pupil vs. large pupil
Mean: 0.2592
Std dev: 0.0784
Number of comparisons: 1260

Not as good

Nonmatch Distributions (Imposters)





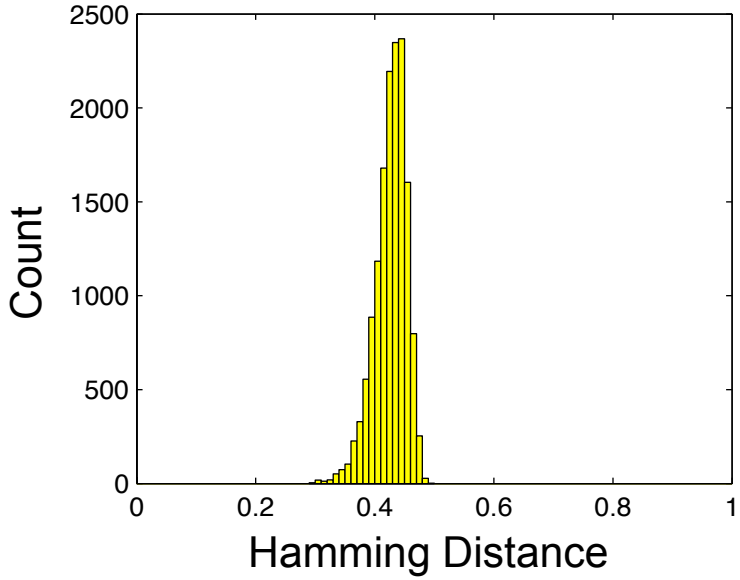
Small pupil vs. small pupil

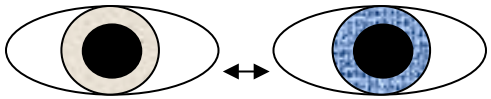
Mean: 0.4483

Std dev: 0.0170

Number of comparisons: 200290

Good





Large pupil vs. large pupil

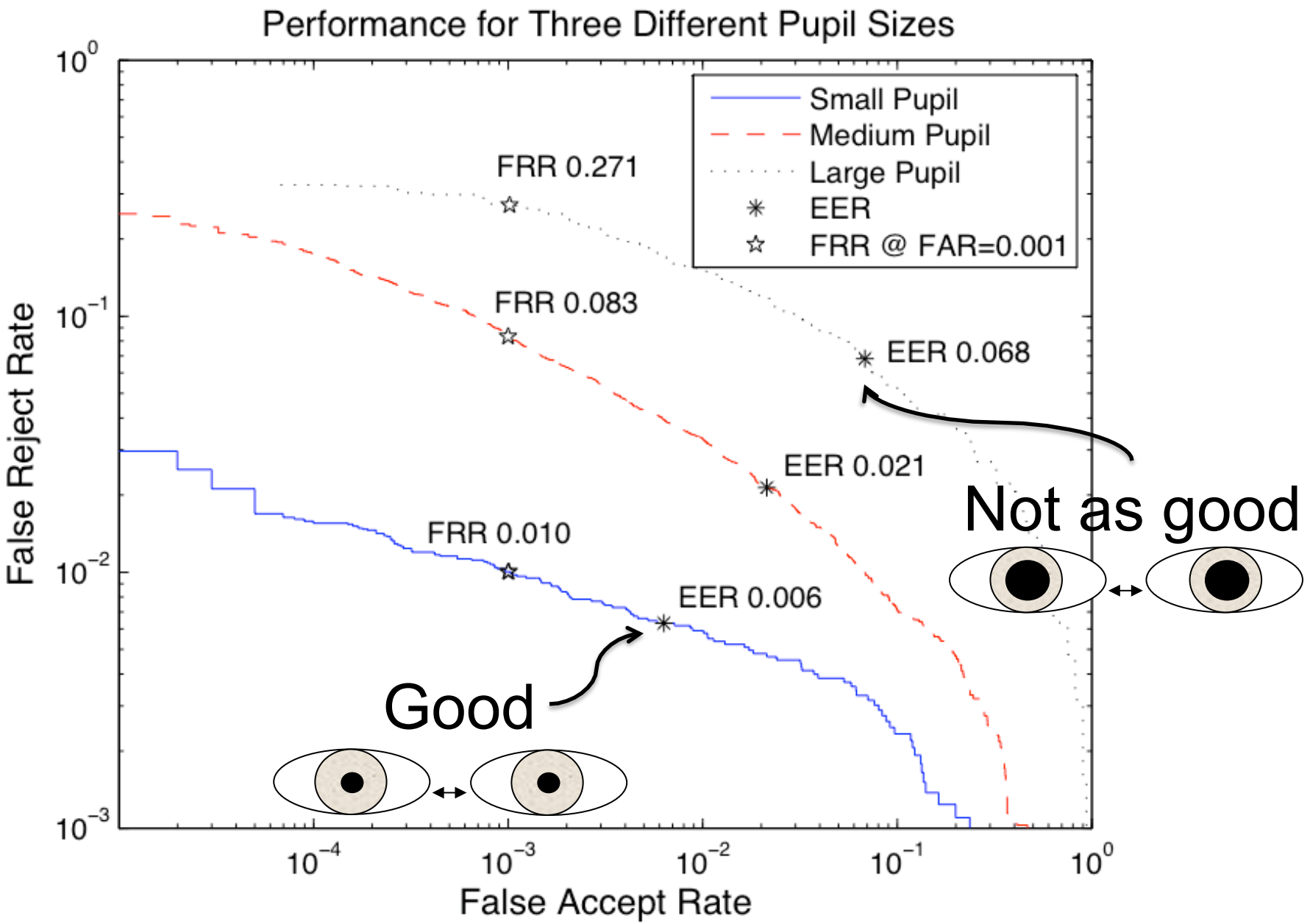
Mean: 0.4265

Std dev: 0.0267

Number of comparisons: 14742

Not as good

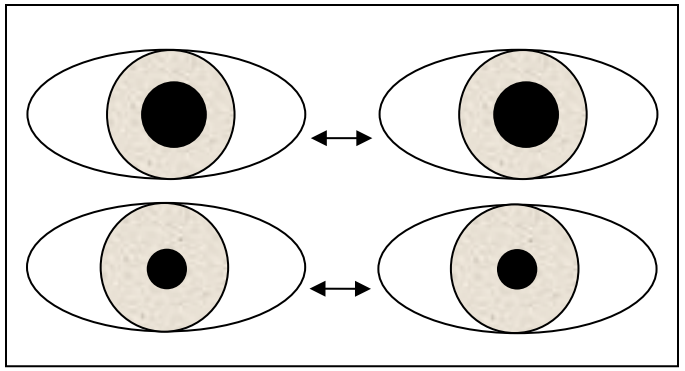
Experiment 1: Small Pupils vs Large Pupils



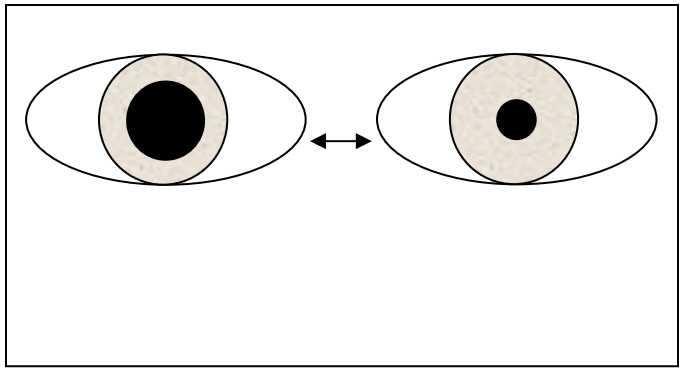
Why would images with larger pupils have worse performance?

- Less iris area (fewer pixels in iris region).
- Pupil dilation pulls more of the iris towards the eyelid, so a larger percentage of iris area is occluded.
    - This phenomenon encourages the idea of score normalization as proposed by Daugman.

Experiment 2: Do two images with the same dilation match better than two images with different dilation?



Good Performance?

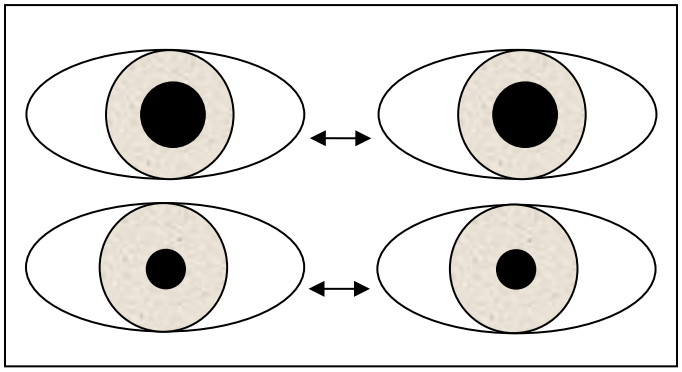


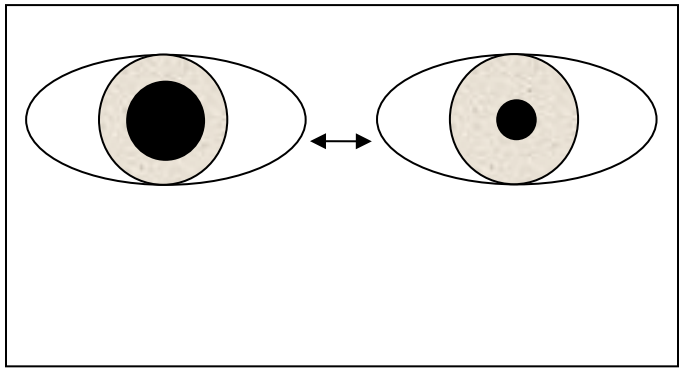
Bad Performance?

Experiment 2: Comparison between iris images with varying Degrees of Dilation

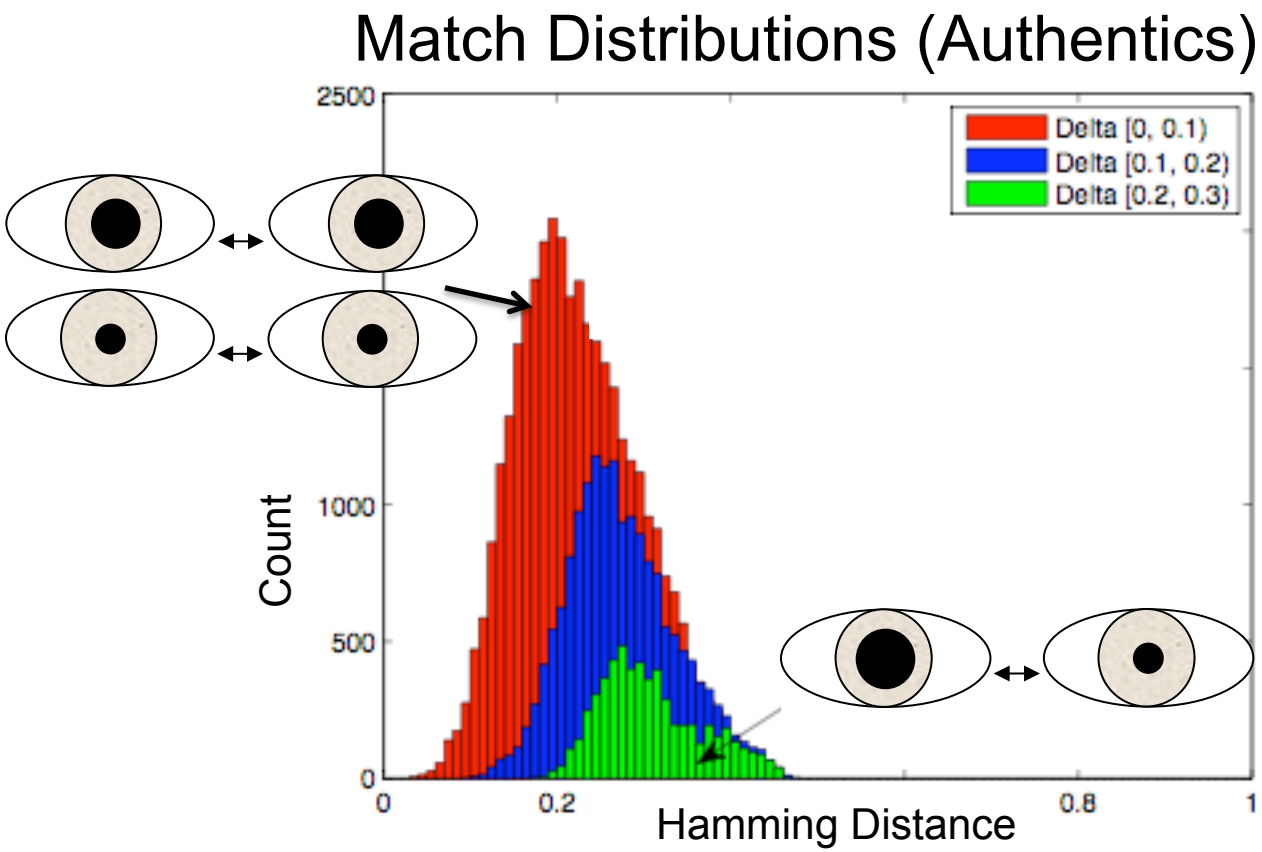
For this experiment, we defined a metric to measure the different degrees of dilation between two images in a comparison.

$$delta = \frac{pupil\ radius_1}{iris\ radius_1} - \frac{pupil\ radius_2}{iris\ radius_2}$$





Experiment 2: Comparison between iris images with varying Degrees of Dilation



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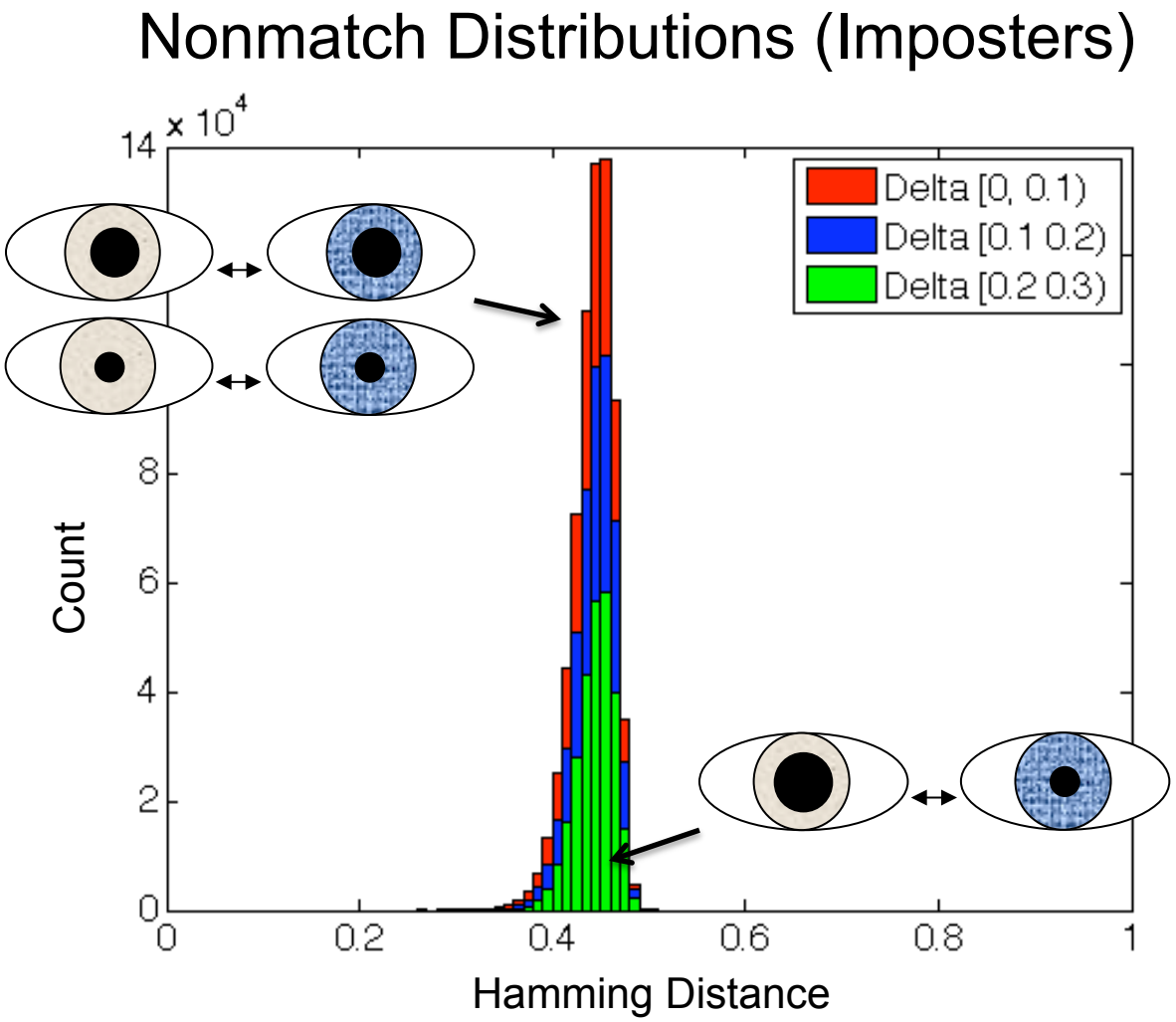

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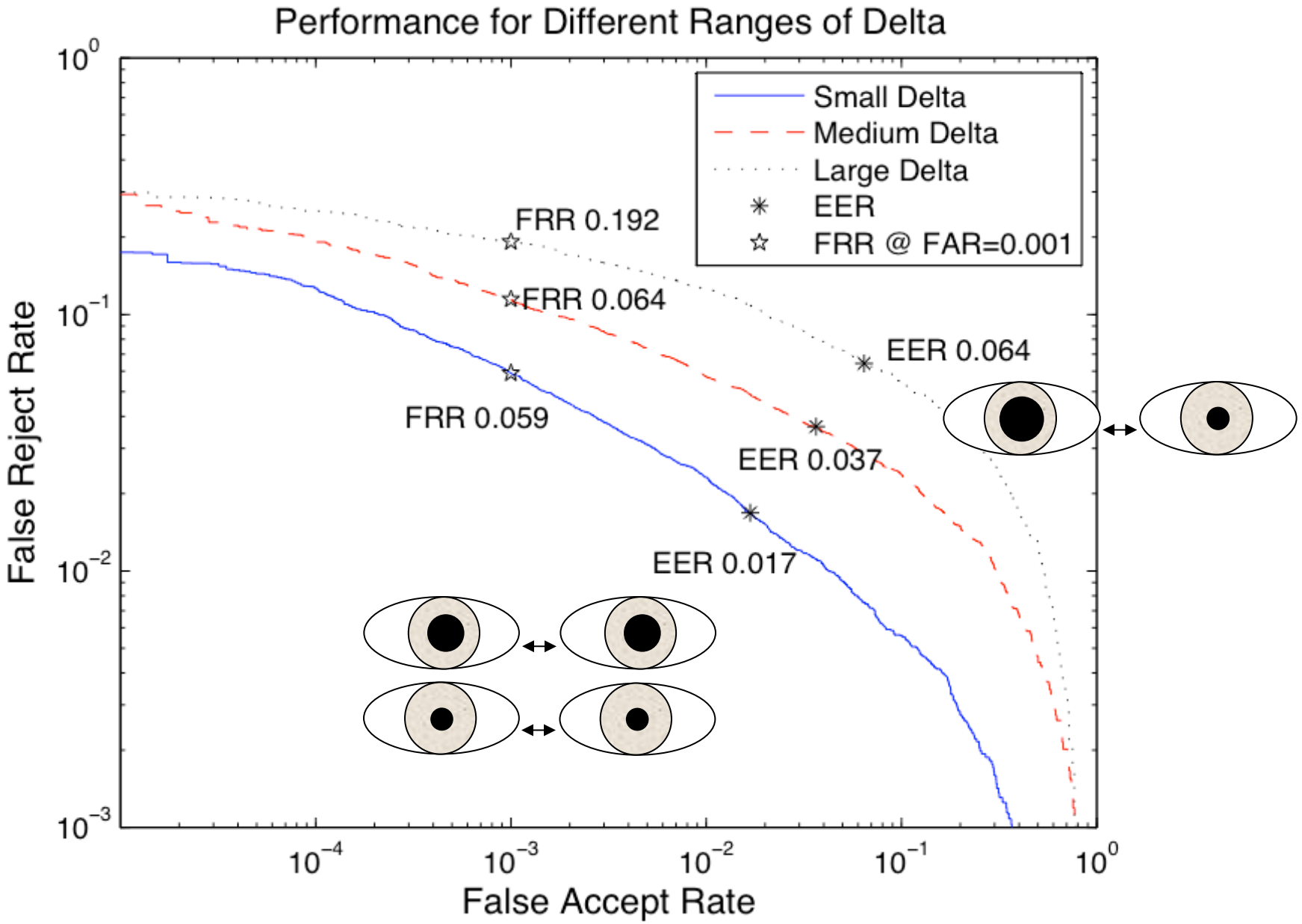
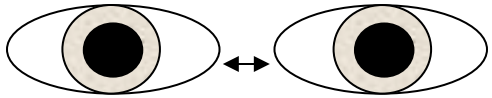


Conclusions

1) Match comparisons between dilated eyes yield larger Hamming distances.
   - The mean fractional Hamming distance is 0.06 higher for dilated eyes.
   - This shift leads to *increased false reject rate*.



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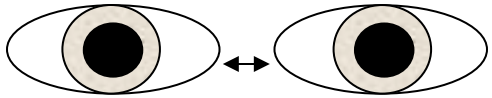
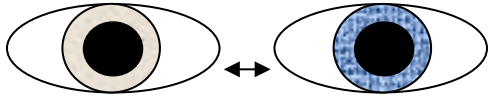
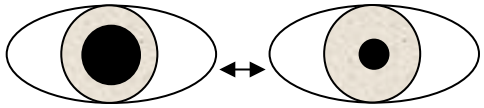


2) The nonmatch distribution is also affected.
   - Lower HD scores lead to *increased false accept rate*.



Conclusions

3) Match comparisons between images with widely different degrees of dilation yield larger Hamming distances.
   - The mean is about 0.08 higher.



Recommendations

- Degree of pupil dilation should be incorporated into quality score.
- Use score normalization to prevent false accepts.
- Purposely enroll multiple images of a subject with varying degrees of dilation.
- Investigate other ways to account for dilation (see for example work by Thornton et al. and Wei et al.).

Thank you.