INSTRUCTORS' GUIDE FOR WAVEFRONT ABERROMETRY

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By now, you know quite a bit about the human eye and how it functions, as well as some information about vision defects such as nearsightedness and farsightedness. During this activity, we will explore some ways in which we can diagnose vision defects. However, let's begin with a quick review of the human eye and the features of our model.

The Model of the Eye

? In front of you is the same equipment that we used in previously to model the human eye. What features of the model do you recognize?

The features that students recognize are in large part dependent on their familiarity with the human eye and vision. Some features which are present on the model are: cornea (thin clear film on the outside), iris (blue part), pupil (the hole), a stand to place corrective lenses, retina (screen at rear of model), and the adjustable lens of the eye.

? How does one account for nearsightedness and farsightedness in this model?

The thumbscrew at the top of the model allows us to adjust how round the eyeball is on this model.

? What about the accommodating lens? How does it work in this model?

In this model, the accommodating lens is attached to a system of syringes. By adding more water to the lens or by taking some away, we can adjust the thickness of the lens.

It should be noted that this is not the way in which our eye really accommodates – the eye uses muscles to change the thickness of a fixed-volume lens.

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As you may remember from last time, the model we are using includes an adjustable lens, and a screen that represents the retina of the eye.

In order to model nearsightedness and farsightedness, we can simply adjust the distance between the lens and the retina: a nearsighted eye has a retina that is farther than average from the lens, while a farsighted eye is modeled by a retina that is closer to the lens.

Accommodation is the ability of the eye's lens to change in order to focus on objects at a range of distances away – this can be achieved using the syringe on our lens in order to change the radius of curvature of the lens.

Vision Diagnosis

As you already know, most of us have or will have some vision problems. It is important to understand not only what these problems are, but the ways in which they can be diagnosed.

? Here is a picture of a typical eye chart that is used at a doctor's office. How does an eye doctor use a vision chart like this one to diagnoses vision defects?

It is possible to get a wide range of answers for this question. In general, students will likely say that the patient is asked to read the chart, and the doctor determines the quality of their vision based on how far down the chart (or how small of letters) you are able to read.

? What are the advantages of a system like this one?

The advantages that students most likely bring up are: quick, cheap, easy, everyone knows letters, accurate, standard because all doctors use it the same way all the time. Others may arise as well

? What are the disadvantages of a system like this one?

The disadvantages that students likely bring up are that people who are illiterate (or the very young) can't use it, and that the steps are not small enough and so it is not accurate, and that you can guess some letters.

Ideally, we would want them to realize that it is subjective because of the notion of relying on the patient.

? Have you ever tried to squint to see one of the letters (or anything else) better? What does squinting do to help us? Why does it help?

Most of the students will recognize that squinting does help them seem better. Most students initially attribute this to the reduction of light that enters the eye – such as would occur if you were squinting on a very sunny day.

Depending on the prior knowledge of the students, some may realize that squinting also changes the way the muscles of your *eye are working, perhaps helping to focus that accommodating lens better.*

As you probably know from experience, the eye chart is frequently used to diagnose vision defects. By placing the chart a certain distance away and asking the patient to carefully read the letters, an eye doctor (and ophthalmologist or optometrist) can begin to determine what vision defects you have and begin to determine the level of severity.

However, this diagnosis method depends on the patient's ability to read the chart, and to do so as directed by the doctor. If the patient squints or guesses letters they can't quite see, they may not get a perfect diagnosis – for that reason, the eye chart can be considered a *subjective* diagnostic too – the results depend to some extent on the person being tested.

Modeling the Aberrometers

Now let's look at a new instrument that's being used for vision diagnosis: it is called an aberrometer – it measures the aberrations (or differences from the normal) in our eyes. Aberrations are like defects, and they can occur in any part of our vision system.

♦ We will make a model of an aberrometer by using the eye model we've been using. In the real aberrometer, a light source comes into your eye, reflects off the retina, and comes back out through the front of the eye. This would be rather hard to imitate, so we'll make it simpler: take the small flashlight and clip it to the "retina" so that it points out through the front of the eye. Next, we need a screen so that we can see the light – put up the grid paper screen so that it's just in front of the eye. Lastly, there is an array of small lenses that is the essence of the aberrometer.

? You have a lens array sitting right in front of you – one of the lenses is loose – take it out and look at it. What kind of lens is it? How do you know?

The lenses in the array are convex/converging lenses. They are thicker in the middle – if they try, they will also see that they can create a real image (for example, of the lights overhead).

? What does that type of lens do with the light?

These lenses converge the light to a single point.

The lens you have is a convex lens, also called a converging lens because it converges the light to a point.

♦? Now place the array in the slot in front of the eye – what do you see on the screen?

When all of the lenses in the array are placed in front of the eye, the students should see a grid pattern made of points of light. Each of these points corresponds with a lens in the array – there are an equal number of lenses and points of light.

? Why do you see it?

The light from the retina is shining through the front of the eye, and exiting the pupil. Then, it hits the array – those converging lenses create a spot of light onto our screen. If the screen is located at the focal point of the lens, the dots will be small and focused.

The grid pattern that you described above is caused by light from the eye lens projected onto the array of lenses – each of those lenses in turn creates a point of light on the screen. This grid pattern is where we will focus our attention for the rest of this activity.

Nearsightedness and Farsightedness

♦? Right now, the eyeball is set up in such a way that there are no aberrations (defects) in the eye or its components. What do you think would happen if, instead of a perfectly shaped eye, we had an eye that was either longer or shorter than normal? What would happen to our grid pattern, and **why**? (Hint – what is happening to the light?)

This section begins the difficulty for most students. In fact, we have found that they are very tentative in their predictions. In particular, they avoid answering the question of WHY the proposed phenomenon happens.

For this question, students most frequently predict that the grid pattern will change size and focus. These predictions are very logical, particularly for those students who used the eye simulation and observed the changing size and focus of the image in that situation

♦? Go ahead and try it out. Change the shape of the eye (while keeping the flashlight aimed at the lens), and see what happens to the grid pattern. What changes are happening? Why? (If the results do not agree with what you predicted above, discuss it with your instructor.)

Again, this proves difficult for many students. Frequently, they attempt to answer this question with a minimalistic "yes we were correct" and not attempt to explain any further.

When they actually try this, they will indeed see that the dots of the grid pattern change size and focus. This is due to the fact that we are changing the object distance – since the focal point of the lens is not changing, the location of the image must change. If we slide the paper screen either front or back, we can find that new image distance.

As you saw, when the eye is either nearsighted or farsighted, the spacing of the grid pattern changed. This is because the retina (the location of the light source) is either closer or farther from the lens, which changes the way the light enters the lens and in turn changes the location of the focal points of light.

Aberrations in the Lens

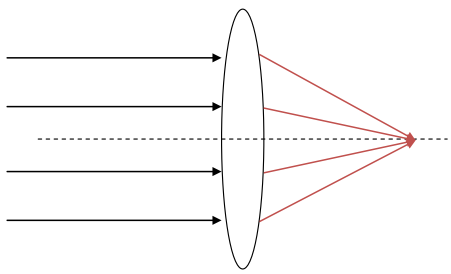
♦? Now make sure the eye is back to a normal shape. This time, please predict what you think would happen if the lens of the eye had an aberration – if it was not as well shaped like it is right now. What do you think would happen to the grid pattern, and **why**?

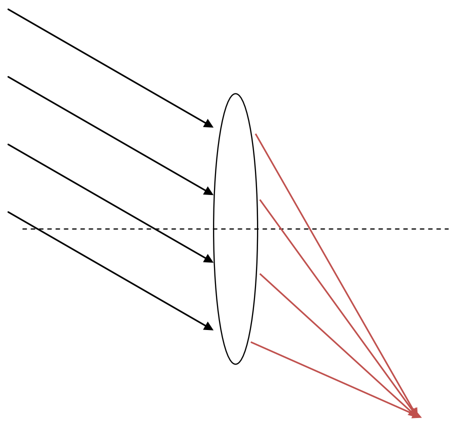
Again, this question – and in particular the explanation – proves difficult for many students. Most of them predict that the grid pattern will change focus, and some even say that it will be distorted.

♦? Try it – the lens is flexible, so just reach in and push on it lightly. What do you see happening? Why? Does it correspond to what you predicted above?

The grid pattern does indeed distort. Some students will notice that the location of the distortion of the grid pattern correlates to where they push on the lens. This occurs because when they are deforming the lens, they are changing the direction at which light exits the eye lens. This in turns changes the direction at which the light hits the array lenses, thereby changing the location of the image. This relation is what we are trying to trigger in the following questions:

? Below are two lenses (both are identical), with light rays entering as shown. Please draw the light rays on the other side, after they passed through the lens. If they make a focal point, mark it with a dot.





As you saw above, an aberration in the lens of the eye causes the shape of the grid pattern to be deformed. In this situation, only part of the lens has a defect, and therefore only part of the light is projected differently.

In the ray-diagram activity above, you should have realized that in the first case, the converging lens focuses the light to a single point at a location on the optical axis. In the second case, however, all the light rays are falling on the lens at an angle. Because it is a converging lens it will still form a single point of light, but that point will be shifted – in this case, it will be below the axis (if all the light rays were directed upward and hitting the lens, the point would be shifted above the axis). It is this shift of position of the focal point that causes the grid pattern image to be distorted by aberrations.

♦? Now let's look at a computer simulation that shows you a little bit more about the aberrometer. It's called the "Shack" program – load it up, and switch to English. The white diamonds allow you to change the eye. Move both of them – one allows you to change the length of the eye, and the other allows you to deform the front of the eye. Does this simulation correspond to what you saw with the model? How are the model and the simulation similar?

The computer simulation has the same functionality as the model. In fact, many students prefer the simulation because it is "less messy", and the results of their changes are very evident.

The simulation is again useful in that it shows the path of the light rays. It also has a fixed bottom-half that can be used for comparison when the top-half is being altered.

One difference is that in the simulation, the size of the dots never changes, and nor does their focus. The students will often notice this difference.

? How do you think that a doctor could use a system like this aberrometer to diagnose vision defects, both near/farsightedness and aberrations?

Many times, students will indicate that in order for this to be useful for vision diagnosis, they need to compare an individual's eye to a known standard, or a perfect eye. This is a reasonable consideration, and is in fact very true based on how the real aberrometer works.

It is the grid pattern that is the key focus in diagnosis – the most important thing is the location of the grid pattern dots for each individual eye.

? What do you think are some advantages of using a system like this one?

Ideally, the students will realize that this system has a great advantage in that it is totally objective – all subjectivity based on human error has been removed because we are studying only the properties of light.

Other advantages students often bring up are that it has a high level of accuracy, and that it can work for both near- and farsighted people.

? What about any disadvantages of using a system like this one?

Students will often bring up the following disadvantages: expensive, too technological, might not diagnose all aberrations (which is not true), might be uncomfortable for the patient, and that perhaps the doctor will make mistakes in interpreting the results.

Some students are also uncomfortable with the idea of a laser shining in their eye, and may bring up that that is dangerous the patient.

Conclusion

The model that we have created actually functions quite like a real aberrometer. The "screen" of the aberrometer is actually a highly sensitive detector that can measure the properties of the grid pattern – it measures position, intensity, size, etc of the dots of light – the very things you saw changing with the defects. That information is then recorded and, through the use of mathematical algorithms, a computer program transforms that data into what looks like a map of the defects of your eye. One example of the aberrometer output can be seen in Figure .

A doctor can use this system to very accurately and precisely identify the defects in your eye, and as such it is frequently used in conjunction with laser eye surgery techniques. This system allows for the identification of not only nearsightedness and farsightedness, but also aberrations, astigmatisms, and combinations of defects. The aberrometer has the added advantage of being an *objective* diagnosis method because the patient can in no way affect the results of this test. For all these reasons, the aberrometer is quickly gaining popularity and becoming a widely-used diagnostic instrument.

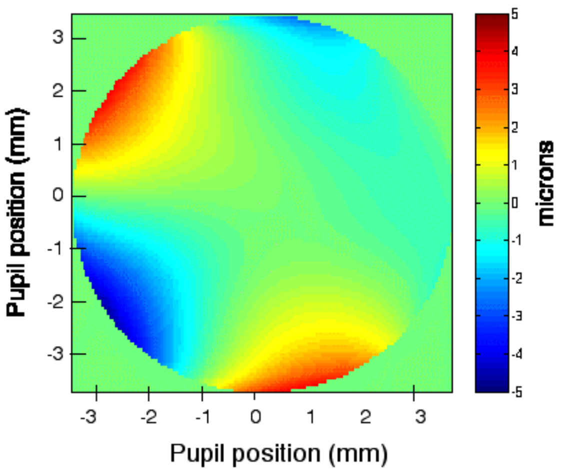


Figure 1 - Sample output of wavefront aberrometer
From http://research.opt.indiana.edu/Library/VSIA/VSIA-2000_taskforce/TOPS4_3.html