The Resolving Power Of The Eye

Objective

By using the resolving power of the eye find the separation between two cones on the retina.

Introduction

The resolving power of the eye is the angle created when the separation of two objects is the least distance where the two objects can still be seen.

To find the theoretical resolving power of the eye the formula:

$$\theta = \frac{1.22\lambda}{D}$$

Is used where θ = The resolving power of the eye

λ = The wavelength of the light used

D = The diameter of the pupil

And 1.22 is a constant

This formula gives the theoretical value of θ because the receiving of the light is not a continuous process. The retina has numerous individual receptors and for two objects to be resolved then two cones must be stimulated either side of ad un-stimulated cone.

To resolve two objects the central maxima of the first object must be no closer than the first minima of the second object as above.

Plan

Prime Factors

To calculate the resolving power of the eye one must first consider the factors that have bearing upon the experiment. The greatest factor is the eyesight being tested, as everyone is different and has different eyesight it is inconsistent to use multiple people for this experiment therefore to reduce error it would be ideal for one person to be used throughout.

Another important factor is the intensity of both the light being viewed and the background light. Changing light intensity will cause the diameter of the pupil to change and errors to occur, also if background light is brighter than that being viewed it makes it more difficult to see the object or image. For these reasons the experiment must be carried out in a constant darkness with unchanging intensity of the light being viewed. The darker the better as this will give a larger pupil and better resolving power.

For greatest accuracy in the measurements of distance it is ideal to have two apertures a relatively large distance apart so the distance from the eye to the apertures is greater and any error is small. However this is unworkable in some conditions as such a large distance cannot be accommodated for in the lab.

The Measurement of Variables and Constants

During the experiment a number of variables and constants will be measured. These are the object separation, the distance between eye and apertures and the diameter of the pupil. Along with these a number of aspects will be controlled and kept constant. These are background and aperture light intensity, the wavelength of the light used and the equipment used to take the measurements.

To measure each variable specific equipment will be used and each will be measured to a suitable level of accuracy. The separation of the two apertures is measured from the centre of one aperture to the centre of the other using a travelling microscope, which measures to 0.01mm accuracy giving an error of ±0.005mm. The diameter of the pupil will be measured using a clear mm ruler immediately after prolonged darkness and will be accurate to 1mm with an error of ±0.5mm. The distance from the eye to the apertures will be measured using a tape measure with millimetre markings. It is accurate to 1mm but the point one measures from may be inaccurate due to the head movement of the tested person therefore a total error of up to ±100mm can be expected.

The other aspects to be controlled are done so by keeping constant certain key values or factors. The background light intensity will not change, as conditions will be kept constant by not opening doors, windows or uncovering sources of light. The light intensity of the apertures is kept constant by not altering the voltage on which it is on i.e. using a resistor. The LED used has a set wavelength, which is constant, so does not need to be controlled other than using the same LED for the duration of the experiment.

Apparatus

- Power pack
- Voltmeter
- Variable resistor
- Green LED, λ=556nm
- Travelling microscope
- Black cardboard
- Pin
- Tape measure
- Clear mm ruler

Method

To carry out the experiment first connect into a circuit a green LED, this will have a wavelength of 556nm, and variable resistor as well as a voltmeter. Set the variable resistor so that the LED receives a constant maximum voltage of 2.00volts. This will give a constant intensity of light. A set distance form the LED, a matter of millimetres, place a prepared piece of black card stood up. The card should have in it a number of pairs of holes, apertures; a minimum of six is desirable. Each pair of holes is two pinpricks in the card and distance between is measured using the travelling microscope. Each pair should be a different distance apart, these are the objects which will be focused on and resolved.

In total darkness with the LED turned on behind the card stand or kneel so that the two apertures are at eye level. From close to the card work gradually backwards until the two lights can only just be defined and appear separate. Mark this point on the floor for measuring later when in full light. Continue this process changing the holes used for the different readings on different separations. Repeat the whole experiment three times.

Safety

Safety is not enforced strongly as the experiment has few dangerous elements. However, it is common sense to stay safe by not putting electrical equipment next to or in a sink in use as is not running around in the darkened lab.

Calculations

To calculate the theoretical value; θ, of the resolving power of the eye use the wavelength of the light by the LED and the measured diameter of the pupil. This will give a reference value for the calculated resolving power; this can be used to check x, as x cannot exceed θ. X, the actual resolving power, can be calculated, in radians, by using separation of the apertures and the distance between the eye and apertures. By rearranging $s = dx$ you get $x = s/d$.

Using x and the radius of the eyeball the separation between two cones can be calculated through $S = rx$.

Assumptions

Throughout the experiment a number of assumptions were made. These are as follows, once the conditions are set and the eye has adapted adequately the diameter of the pupil is constant. Using a large distance, d, any error is reduced due to the large distance. All cones of same type are equally spaced from each other and there are no rods on the fovea where the light is being focused. The wavelength of the light emitted by the LED and its intensity is constant. The radius of the eyeball is 24mm and is constant. The light rays received by the two cones cross at the centre of the eyeball so r = 24mm. By using a large distance for d the light rays received by the eye are almost parallel and therefore are refracted very little by the lens so that the angle of separation between the two apertures and the centre of the eye is equal to the angle of separation between this point and the two stimulated cones.

Preliminary experiment

A preliminary experiment was carried out in which one set of two holes, created using a pencil in white paper, was used to test the resolving power of the eye. A white light bulb was used in full light, daylight. This proved to be unrealistic as a tool for calculating the resolving power of the eye as the pupil was small and the distance from the eye to the apertures is short as in full light it is hard to resolve two holes of white light in white paper.

For these reasons certain changes were made, firstly instead of one measurement being taken three sets of six will be taken for improved accuracy, a green LED will replace the white bulb as the LED has a known wavelength. The whole experiment will be conducted in complete darkness and pinpricks used as holes on black card, this improves the effectiveness and accuracy of the experiment.

Results

Separation of Apertures (10^{-3} m)	Reading, d, (m)			
	1	2	3	Average
0.86	3.56	3.25	3.30	3.28
0.90	3.44	3.45	3.40	3.43
1.45	5.50	5.51	5.56	5.52
1.50	5.69	5.73	5.72	5.71
1.76	6.71	6.63	6.77	6.71
1.81	6.82	7.01	6.86	6.90
1.38	Averages			5.26

Percentage error for separation = 0.725% Percentage error for reading = 1.90%

Anomalous Result

Due to human error there is a 0.100m error possible in measuring the distance, d. this equates to a 1.90% error. The total error in measuring is a possible ±2.65%. There is a 0.725% error with the travelling microscope due to an accuracy of .01mm or 10^{-5} m, the 1.90% error on distance, d, is due to the 1mm or 10^{-3} m accuracy of the tape measure used. The sum of these errors is the total percentage error of the readings to 3sf. The anomalous result in the first set of readings is discounted from the averages taken. This result was caused by a change in light intensity during the reading and the pupil not being fully adjusted to the conditions i.e. the reading being taken too early after the conditions were changed to complete darkness.

The errors incurred are constant because they are limits of accuracy in the measurements except for human error however the percentage error can be decreased. Increasing the magnitude of the measurements taken can do this. By increasing the separation between the apertures the distance from eye to apertures increases but the percentage error of both decreases.

Conclusion

Through my results and using the previously noted formulae the separation of the two cones was calculated at 3.15×10^{-6} m (±0.80m). Using the theoretical value of θ S is calculated at 2.03×10^{-6} m, the literature value being similar to the width of one cell, which is 50μm. This is in agreement with my objective as this experiment can be used to find the separation between two cones on the retina.

The calculated resolving power is less than the theoretical value as expected and by assuming the triangles inside and out of the eye are the same an accurate answer of separation can be found so the refraction is little as light passes through the lens.

Evaluation

This experiment had a number of errors which were systematic as well as those which were entirely random. Of the systematic those associated with the measurements such as the radius of the eye, the separation of the two apertures and the distance between the eye and apertures were the greatest and had most effect on the final result.

The rounding through calculations and movement of head when measuring were also constant throughout the equipment. Random errors were mainly the condition i.e. tiredness of the human being tested and the time of day as well as the darkness or light intensity outside as cloudy weather means darker conditions in the lab. The random errors were responsible for the one anomalous result found at a separation of 0.86mm, this was proved to be anomalous by the other results taken at this separation which were around 300mm away from this. The averaged out results give an almost perfect straight line.

My final result for the separation of the two cones, 3.15×10^{-6}m ± 2.65% was a factor of 10 out from the literature value of 50μm. This could be caused by an error in calculation, measurement or inaccuracy caused by the number of assumptions that I used.

The final result for the separation of two cones on the retina is dependant upon the diameter of the eye as a 10mm difference in this could double or half the answer, for the theoretical value of θ the pupil diameter is the most important factor.

The techniques I used were suitable for this experiment but could have been vastly improved, the conclusions drawn, mainly the cone separation, were very reliable as for such a small distance a factor of ten out is very accurate. A large number of errors and inaccuracies can be eliminated from the experiment. Random errors can be removed completely and systematic errors reduced. By carrying out the experiment in fully darkened conditions with no light source at all, time of day and conditions outside will have no effect. Also by performing the experiment in one afternoon after acclimatizing (sitting in the dark) the pupil diameter will be as large as possible and constant plus any tiredness should be alleviated.