THE EFFECT OF AGE AND GENDER ON THE PHOTORECEPTOR CELLS IN THE HUMAN RETINA

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ABSTRACT

This experiment evaluates the effect of age and gender on the two photoreceptors in the human retina: rod cells which are responsible for peripheral vision and the detection of shapes and motion and three different types of cone cells responsible for the perception of colour. The research questions are: **Does the efficiency of the Rods and Cones decrease with Age? What is the efficiency of the L-cone versus the M-cone versus the S-cone? To what extent are the Rod cells more efficient than the three Cone cells? Does the efficiency of Rods and Cones differ between genders?**

In the experiment I used a vision disk which is a device to measure the angle of peripheral perception on the horizontal plane of the visual field. I conducted the experiment on a total of 75 people, divided into five different age groups, 32 of which were males and 43 were females. By using three different pointers with each one having a red/green/blue coloured dot on them, I was able to obtain values for colour sensitivity of the three different cones, as well as periphery values. By deriving average values for each age group, I was able to compare average rod and cone efficiency at different stages in life. Moreover, by subcategorizing the age groups into males vs. females, I could determine trends of photoreceptor efficiency according to gender.

I concluded that the efficiency of both photoreceptors decreases with age. In addition to that, the 'efficiency hierarchy' for cone cells is increasing from L-cone to S-cone to M-cone. The experiment showed that human rod cells are more efficient than cone cells. Lastly, the results indicated slightly that female photoreceptor efficiency is better than male photoreceptor efficiency. However, for this aspect no definite conclusions could be drawn due to insufficient data.

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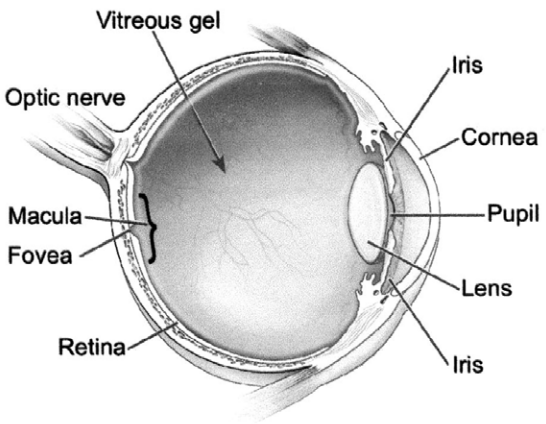
INTRODUCTION

Image 1



[10]

This investigation examines peripheral vision and colour sensitivity of the photoreceptors in the human eye in correlation with age and gender.

Visual perception is obtained through millions of tiny cells in a small part of the human eye. The eye has the second best response out of the five sense organs after the ear with having the capability to notice a stimuli at a minimum energy of 6.10^-17 Watt. [1] The cells in the eye are called photoreceptors and they are aligned on the retina in the vertebrate eye.

Photoreceptors enable us to perceive shapes and colour. The photoreceptor cells are a special type of neurons that change shape when they absorb photons in order to pass on signals to other neurons by creating an action potential. There are two photoreceptors in the vertebrate eye, rod cells and cone cells. [2]

The retina is inverted, which means that before the light reaches the photoreceptor it has to travel through layers of neurones *(see appendix A)*.
Rod cells are responsible for perceiving shapes and motion detection. Cone cells are responsible for the perception of colours. Due to a convergence of nerve fibres from many rod cells, the impulses may be transmitted on the same nerve fibre which leads to a lower visual acuity.[4] There are approximately 120 million rods, whereas there are only about 6-7 million cones in the human retina.[3] The fovea centralis in the macula lutea is the area of sharpest vision. This is where the cones are concentrated. The rod distribution is greater further away from the macula lutea *(see appendix B)*. [2] Convergence among the rod photoreceptor cells increases further away from the central portion of the retina and thus the field of vision in the periphery tends to be more blurred than on the central portion *(see appendix C)*.[5]
When light is perceived by the photoreceptors, a photo-sensitive pigment is broken down.

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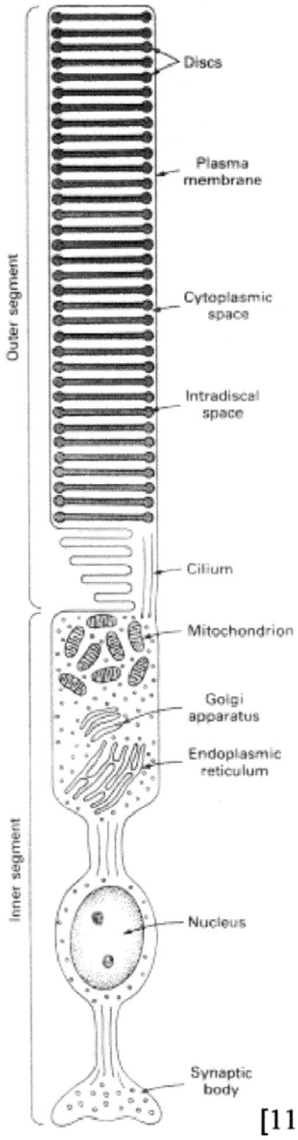
Photosensitive Pigments
Or
The Biochemistry of the Perception of Light

Image 2

Schematic Diagram Of Retinal Rod cell



[11]

RODS contain disc-like lamellae in their outer segment. These lamellae contain a photopigment called rhodopsin. [2]

CONES are structured like rod cells, but they are known to have less sensitive pigments to light intensity than rods. These pigments are called opsins. There are three different types of cone cells. It is often believed that each of the three cones has its own pigment. This theory is called the **trichromatic theory**. [3]

- The L-cone

It is responsible for perceiving red, thus photons of long wavelengths. The peak absorbance is at a wavelength of 564 nm. [4]

- The S-cone

It is responsible for perceiving blue, thus photons of short wavelengths.[4] The peak absorbance is at a wavelength of 437 nm.[4]

- The M-cone

It is responsible for perceiving green, thus photons of medium wavelengths. The peak absorbance is at a wavelength of 533 nm.[4] *(see Appendix D)*

Therefore peripheral vision is obtained through the rod cells and colours are absorbed by three different types of cone cells each coding for one of the main colours red, blue and green.[5]

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1.1) Effect of Age on Rods & Cones

Another more accurate term for ageing in this concept is *organismal senescence* which means ageing of organisms. An important feature of ageing is the loss of neurons along with decreased functioning of the organs. [6] However, it is still investigated whether ageing affects the photoreceptors. An experiment conducted at the University of Erlangen-Nuremberg in the Department of Ophthalmology and the Eye hospital concluded that the density of photoreceptors decreases with increasing age which means a decrease in the vision field. Moreover, it states that rods are more affected than cones in the case of the decline in photoreceptors. [7]

Studies have shown that two other sensory receptors show decreasing efficiency with age. The human's smell decreases with age which subsequently affects the taste.[8]

1.2) The Three Cone Types

Out of the 6-7000 cones in our retina, 64 % are L-cones, 32 % M-cones and 4 % S-cones. The S-cone however, is believed to have the highest sensitivity out of the three cones. [9] [5]

As indicated in the diagram below, the opsin in the S-cone is very different to rhodopsin in the rod cells and the opsin in the M-cone is very different to the opsin in the S-cone. However, the opsin in the L-cone is very similar to the M-cone in structure. Therefore it is likely, that functionally the S-cone and the M-cone are similar as well.

Image 3 ***Diagram showing molecular structure of the opsins in comparison:***

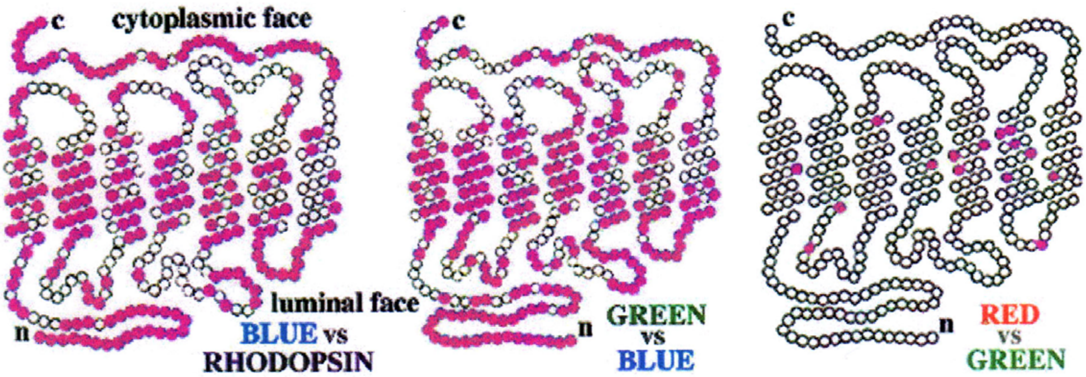

Fig. 12. The closely related molecular structure of the cone opsins. The blue-cone opsin compared with rhodopsin. The blue cone opsin compared with the green opsin and the minimal difference between the red and green cone opsins. The pink filled circles represent amino acid substitutions between these molecules. The open circles indicate identical amino acids. Adapted from Nathans et al., 1986. [12]

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1.3) Rod & Cone Efficiency

There is a much greater number of rod cells in the retina than cone cells and the rod distribution is not only centered at one part of the retina (the macula latea) but more spread out resulting in a wider visual spectrum. Also, the rods are much more light-sensitive than the cones. For example, humans can only see shapes and motion and not colour in dim light and this perception is due to the rod cells.

2.1.) Effect of Genders on Rods & Cones

*"It is generally admitted that with **woman** the powers of intuition, of rapid **perception** and perhaps of imitation, are more strongly marked than in **man**: but some, at least, of these faculties are characteristic of the lower races, and therefore of a pas"*

Charles Darwin

Women are known to have a better nose and than mean because *"females have a more acute sense of smell than men."* [1] This explains why women are preferably hired as odour testers for companies which produce perfumes. Moreover, women have greater taste sensitivity to men[15].

Vision is an ability that is often taken for granted. Why can't we perceive colours when it is dark? Is there a cell (photoreceptor) for each single colour that exists? Why didn't my grandmother see me approaching her from the side? Can we train our vision? Are women more capable than men (… considering vision)? All these questions led me to build a particular interest in sight. This interest gave me the idea to dedicate my Extended Essay to it.

Finding out whether the efficiency of the photoreceptors, is related to age group or gender, would underline the difference of the male vs. female vision and the decay of the photoreceptors over time.

[1] Tim Jacob, *"Olfaction – A tutorial on the sense of smell"* (Cardiff University, UK, 2006)

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RESEARCH QUESTIONS

PART A

1.1.) Does the efficiency of the Rods and Cones decrease with age?

1.2.) What is the efficiency of the L-cone versus the M-cone versus the S-cone ?

1.3.) To what extent are the Rod cells more efficient than the three Cone cells?

PART B

2.1.) Does the efficiency of Rods and Cones differ between genders?

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PREDICTIONS/HYPOTHESES

PART A

1.1.) Effect of Age on Rods & Cones

I predict the peripheral vision and colour sensitivity to decrease with age due to decreasing density of photoreceptors thus due to organismal senescence.

1.2.) The three Cone Types

The L-cones (coding for red) have the highest density in distribution, followed by the M-cones and after that the S-cones (coding for blue).
Therefore I predict that humans see red easiest, followed by green and then blue.

Since the distribution values for red and green are rather close together and the molecular structure is close to identical, both colours are however likely to be perceived to a similar extent *(see Image 3)*.
Even though the value for the S-cone distribution is low, the human eye can perceive blue still to a relatively high extent since the S-cone sensitivity is believed to be the best.
Therefore I predict the values for the efficiency of the 3 cones not to be very far apart.

1.3.) Rod & Cone efficiency

I predict the efficiency of the rods to be greater than that of the cones due to a big difference in number.

PART B

2.1.) Effect of Gender on Rods & Cones

I predict women to have more efficient rods and cones than men.

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APPARATUS

- vision disk (Brand: **HAP**; patent applied for HUBBARD)
- 3 pointers each with a
  - green dot
  - blue dot
  - red dot

NB: see photo 3 for measurements/sizes
Keep size of dot relatively constant!

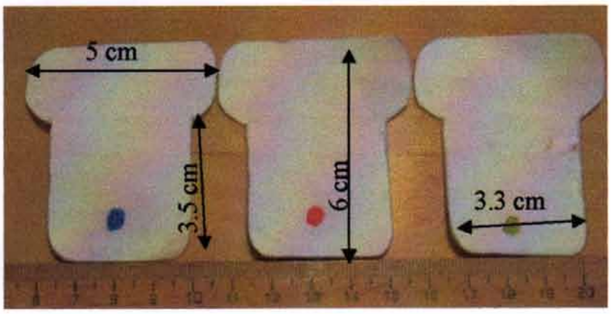
- 2 small torches (+ batteries)
- Alice band
- Sellotape

- Questionnaire sheets

Photo 1

Photo 2

Photo 3



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METHOD

This method is used to find out rod and cone efficiency on a horizontal field of vision. For the cone efficiency, only the three colours for the three cones (red, green and blue) are investigated on.

Preliminary:
Make a questionnaire that requires a subject to record:

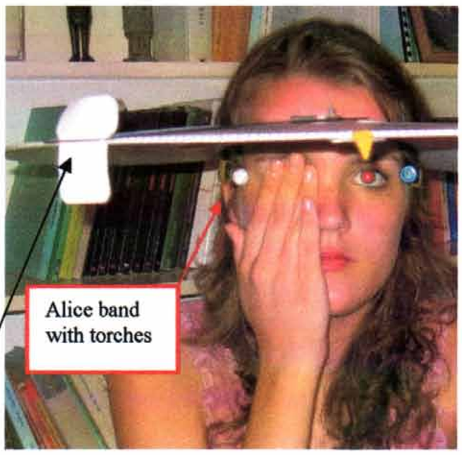
- Age
- Gender

And make a table for the measurements. For this use one table for the right eye and another for the left eye. One column of each table is called "right side" and another called "left side". Divide each column into 4 sections:

- peripheral angle
- red angle
- green angle
- blue angle

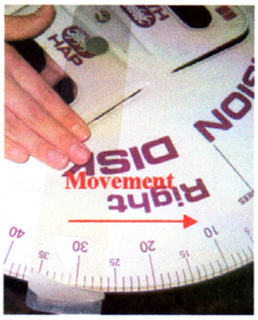
Attach the two torches on each side of the Alice band with sellotape *(see photo 2)*.

Photo 4



1. Use the vision disk on an individual. The age of the test persons is between the age of 9 years to 80 years old *(see Appendix E)*. Make sure that while conducting the experiment the individual always covers one eye with a free hand. Moreover, the person will have to wear the Alice band with the torches, so that they are on eye level *(see photo 4)*. Make sure that the person **always** looks straight ahead, in this case at the yellow slip (at 0°).

- Insert one pointer into the slit on the vision disk.
- Move the card slowly from side (starting at roughly 110°) towards the middle of the vision disk (0°).
- Tell the person to inform you when card appears vaguely (in the periphery) and note the angle of periphery.
- Note the angle when the subject can recognize each of the three main colours red, green, blue (thus use the three different cards in a random order).



- Let the card come from the right side and note the angle of periphery and colour sensitivity for red, green and blue again.

2. Follow Step 2 twice, one time having the left eye covered (thus noting down the measurements for the right eye) and the other time with the right eye closed.

3. Make sure to categorize the questionnaire. For this use different criteria:
   Part A) Age Groups
   Use 5 different categories:
   - 9-13 years (pre-puberty)
   - 14-20 years (puberty & growing phase)
   - 21-40 years
   - 41-60 years
   - 61-80 years

   Part B) Gender + Age Groups
   Use 5 different categories:
   - 9-13 years (pre-puberty)
   - 14-20 years (puberty & growing phase)
   - 21-40 years
   - 41-60 years
   - 61-80 years

4. Part A) Add value for when the card comes from the right and left side to obtain a range value.

   Part B) Add value for when the card comes from the right and left side to obtain a range value.

5. Part A) Add up the data from each person within one age group and find an average value for Rods, L-cones, M-cones and S-cones.

   Part B) Add up the data from each female person within one age group and find an average value for Rods, L-cones, M-cones and S-cones. Do the same for males. Also include the average obtained from Part A) in a column next to the female and male columns.

6. Add the value for one category (eg. Periphery) of the left eye to the right eye and divide it by two. Thus you get an average value for both eyes. Do this for every category.

RESULTS

(see Appendix for all results)

Part A)

Table 1 *Table showing average data of all age groups*

Group				I	II	III	IV	V
Age group				(9 to 13)	(14 to 20)	(21 to 40)	(41 to 60)	(61 to 80)
Left eye	Range	Peripheral	(in °)	138	139	141	128	112
		L-cone	(in °)	77	71	58	53	44
		M-cone	(in °)	71	67	44	41	30
		S-cone	(in °)	75	70	61	54	38
Right eye	Range	Peripheral	(in °)	143	142	138	129	108
		L-cone	(in °)	100	75	58	52	40
		M-cone	(in °)	69	72	46	39	32
		S-cone	(in °)	77	70	53	49	38
average	Range	Peripheral	(in °)	140.5	140.5	139.5	128.5	110
		L-cone	(in °)	88.5	73	58	52.5	42
		M-cone	(in °)	70	69.5	45	40	31
		S-cone	(in °)	76	70	57	51.5	38

a) Rod efficiency

Average peripheral range data used to portray the changes in periphery with age.

Graph 1

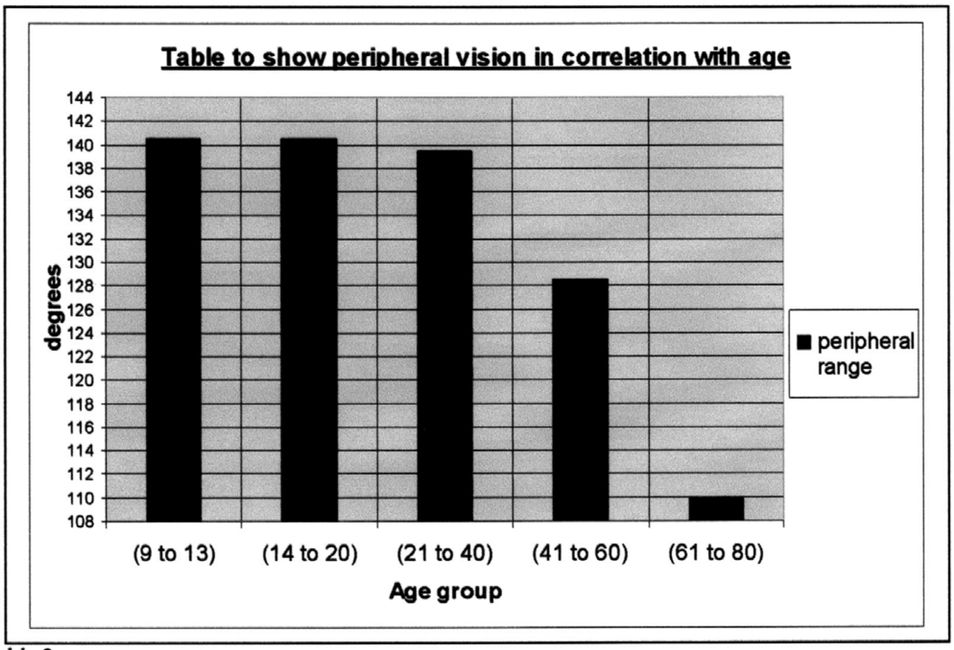


Table 2

Average peripheral vision range (in percentage)

- highest periphery value: 140.5 degrees (Group I & II) = 100%
- formula to determine change in peripheral vision in percentage:
  (x degrees / 140.5 degrees * 100%) = percentage change of peripheral vision

Group		Change in peripheral vision (when assuming that 140.5 degrees = 100% periphery)
I	(Age 9-13)	100 % periphery
II	(Age 14-20)	100 % periphery
III	(Age 21-40)	99 % periphery
IV	(Age 41-60)	92 % periphery
V	(Age 61-80)	78 % periphery

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b) Cone efficiency

Diagram showing the average range of colour perception in correlation with age.

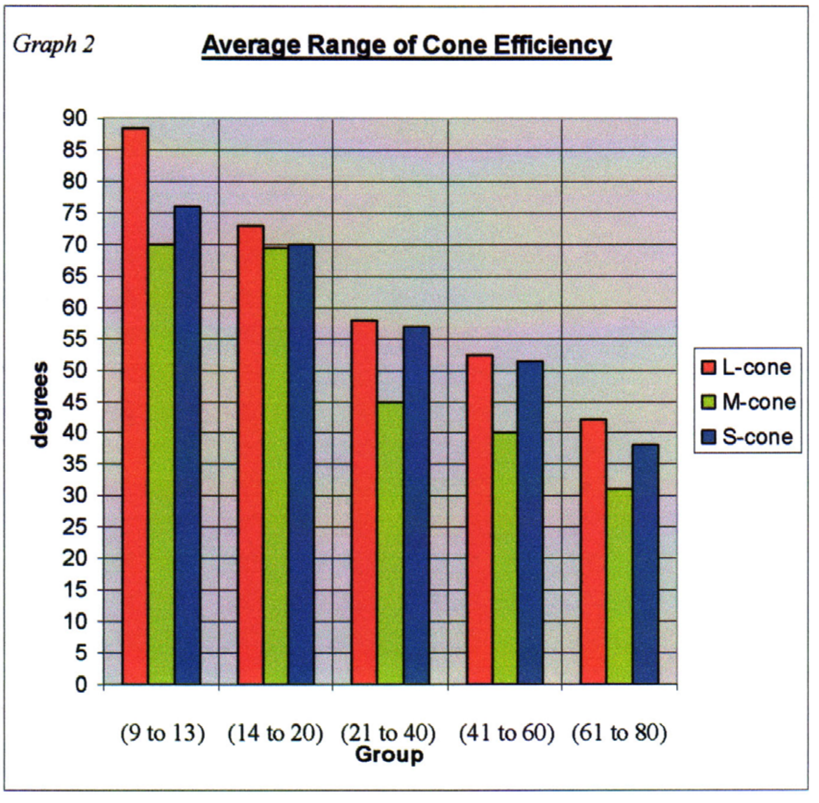

Table 3 **Average efficiency of cones (in percentage)**				
- highest colour value: 88.5 degrees for RED (Group I) = 100% - formula to determine change in colour sensitivity in percentage: **(x degrees / 88.5 degrees * 100%) = percentage change of peripheral vision**				
Group		**Cone efficiency** (when assuming that 88.5 degrees = 100% colour sensitivity)		
		Red (L-cone)	**Green (M-cone)**	**Blue (S-cone)**
I	(Age 9-13)	100 %	79 %	86 %
II	(Age 14-20)	83 %	79 %	79 %
III	(Age 21-40)	66 %	51 %	64 %
IV	(Age 41-60)	59 %	45 %	58 %
V	(Age 61-80)	48 %	35 %	43 %

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Part B)
Does the efficiency of the rods and cones differ between genders?

Table 4

Table showing efficiency of rods and cones for both genders separately

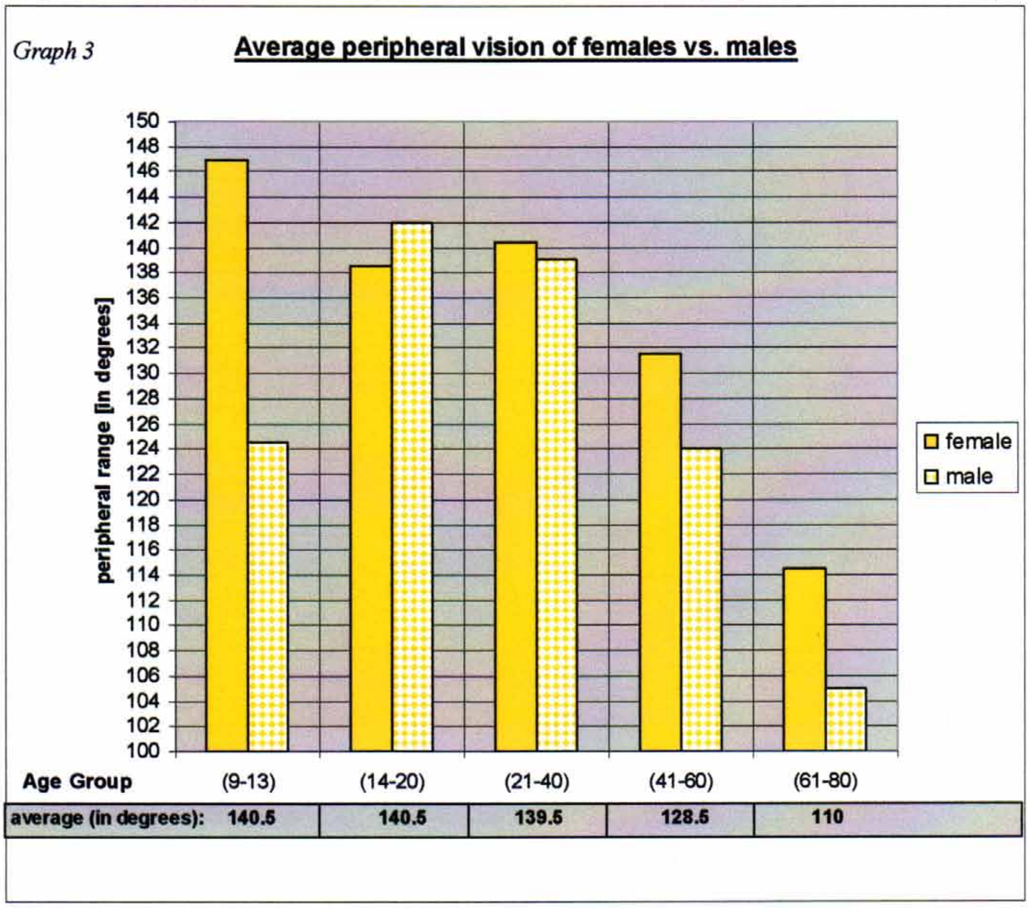
			Group I (9 to 13)			Group II (14 to 20)			Group III (21 to 40)		
			average	female	male	average	female	male	average	female	male
Left eye	Range	peripheral	138.0	144.0	123.0	139.0	138.0	140.0	141.0	142.0	141.0
		L-cone	77.0	78.0	75.0	71.0	69.0	73.0	58.0	65.0	54.0
		M-cone	71.0	73.0	69.0	67.0	62.0	74.0	44.0	53.0	39.0
		S-cone	75.0	77.0	72.0	70.0	68.0	73.0	61.0	70.0	56.0
Right eye	Range	peripheral	143.0	150.0	126.0	142.0	139.0	144.0	138.0	139.0	137.0
		L-cone	100.0	102.0	95.0	75.0	73.0	76.0	58.0	59.0	50.0
		M-cone	69.0	74.0	58.0	72.0	67.0	77.0	46.0	49.0	44.0
		S-cone	77.0	81.0	65.0	70.0	67.0	74.0	53.0	60.0	49.0
average	Range	peripheral	140.5	147.0	124.5	140.5	138.5	142.0	139.5	140.5	139.0
		L-cone	88.5	90.0	85.0	73.0	71.0	74.5	58.0	62.0	52.0
		M-cone	70.0	73.5	63.5	69.5	64.5	75.5	45.0	51.0	41.5
		S-cone	76.0	79.0	68.5	70.0	67.5	73.5	57.0	65.0	52.5

			Group IV (41 to 60)			Group V (61 to 80)		
			average	female	male	average	female	male
Left eye	Range	peripheral	128.0	132.0	122.0	112.0	113.0	111.0
		L-cone	53.0	53.0	52.0	44.0	50.0	38.0
		M-cone	41.0	40.0	42.0	30.0	36.0	24.0
		S-cone	54.0	55.0	54.0	38.0	43.0	34.0
Right eye	Range	peripheral	129.0	131.0	126.0	108.0	116.0	99.0
		L-cone	52.0	49.0	56.0	40.0	44.0	36.0
		M-cone	39.0	38.0	40.0	32.0	38.0	25.0
		S-cone	49.0	47.0	51.0	38.0	44.0	32.0
average	Range	peripheral	128.5	131.5	124.0	110.0	114.5	105.0
		L-cone	52.5	51.0	54.0	42.0	47.0	37.0
		M-cone	40.0	39.0	41.0	31.0	37.0	24.5
		S-cone	51.5	51.0	52.5	38.0	43.5	33.0

**Annotation: The average within each group is obtained from Part A) of the experiment*

a) Rod efficiency

Diagram showing the relationship between gender and average peripheral vision range



* *Annotation: the average periphery values were obtained in Part A)*

Table 5

Average peripheral vision of both genders in comparison to general average peripheral range(in percentage)					
- highest periphery value: x degrees (Group x) = 100% - formula to determine difference in peripheral vision between genders in percentage: **(gender group x degrees / highest periphery value for Group x * 100%) = percentage difference of peripheral vision for gender to average**					
		Change in peripheral vision (when assuming that 140.5 degrees = 100% periphery)			
		Gender			
Group		**Female**	**Male**	**Change between gender in %**	**Average value which equals 100 %**
I	(Age 9-13)	105 %	89 %	16 %	140.5 °
II	(Age 14-20)	99 %	100 %	1 %	140.5 °
III	(Age 21-40)	101 %	100 %	1 %	139.5 °
IV	(Age 41-60)	102 %	97 %	5 %	128.5 °
V	(Age 61-80)	104 %	96 %	8 %	110.0 °

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Table 6

b) Cone efficiency

Simplified table to show rod and cone efficiency for both genders

		Group	Group I		Group II		Group III		Group IV		Group V	
		Age	(9 to 13)		(14 to 20)		(21 to 40)		(41 to 60)		(61 to 80)	
		Gender	females	males	females	males	females	males	females	males	females	males
Left eye	Range	peripheral	144	123	138	140	142	141	132	122	113	111
		red	78	75	69	73	65	54	53	52	50	38
		green	73	69	62	74	53	39	40	42	36	24
		blue	77	72	68	73	70	56	55	54	43	34
Right eye		peripheral	150	126	139	144	139	137	131	126	116	99
		red	102	95	73	76	59	50	49	56	44	36
		green	74	58	67	77	49	44	38	40	38	25
		blue	81	65	67	74	60	49	47	51	44	32
average		peripheral	147	125	139	142	141	139	132	124	115	105
		red	90	85	71	75	62	52	51	54	47	37
		green	74	64	65	76	51	42	39	41	37	25
		blue	79	69	68	74	65	53	51	53	44	33

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The L-cone (red)

Diagram showing the relationship between gender and L-cone efficiency

Graph 4 **Range of L-cones (red) of females vs. males**

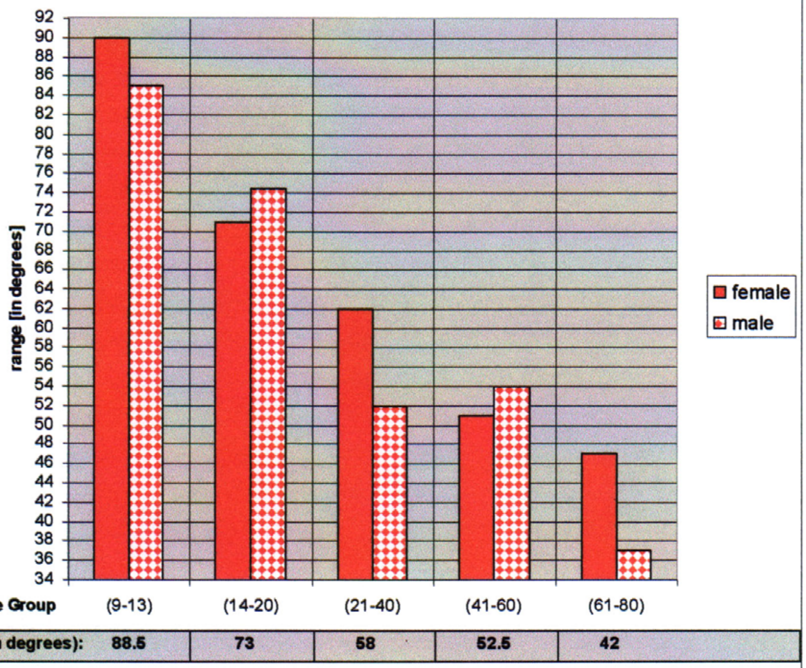

Table 7

Average L-cone efficiency of both genders in comparison to general average peripheral range(in percentage)

- highest average periphery value: x degrees (Group x) = 100%
- formula to determine difference in peripheral vision between genders in percentage: **(gender group x degrees / average periphery value for Group x * 100%) = percentage difference of peripheral vision for gender to average**

		Change in peripheral vision (when assuming that the average value of each group in degrees = 100% periphery)			
		Gender			
Group		**Female**	**Male**	**Change between gender in %**	**Average value which equals 100 %**
I	(Age 9-13)	102 %	96 %	6 %	88.5 °
II	(Age 14-20)	97 %	103 %	6 %	73.0 °
III	(Age 21-40)	107 %	90 %	17 %	58.0 °
IV	(Age 41-60)	97 %	103%	6 %	52.5 °
V	(Age 61-80)	112 %	88 %	24 %	42.0 °

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The M-Cone (green)

Diagram showing the relationship between gender and M-cone efficiency

Graph 5

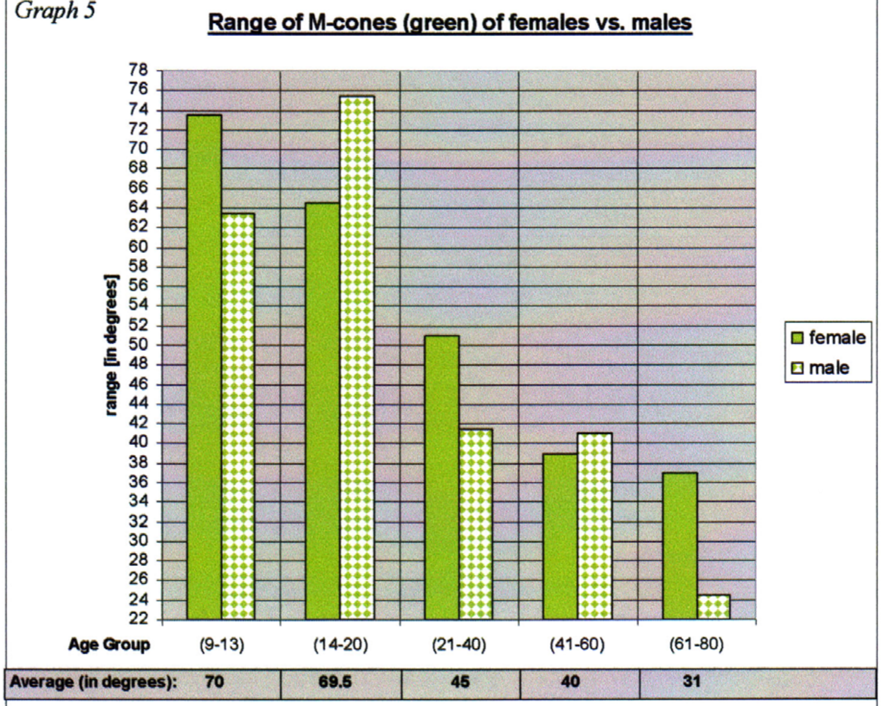

Table 8

Average M-cone efficiency of both genders in comparison to general average green perception range(in percentage)

- highest average periphery value: x degrees (Group x) = 100%
- formula to determine difference in peripheral vision between genders in percentage: **(gender group x degrees / average periphery value for Group x * 100%) = percentage difference of peripheral vision for gender to average**

		Change in efficiency of M-cones (green) (when assuming that the average value of each group in degrees = 100% efficiency)			
		Gender			
Group		**Female**	**Male**	**Change between gender in %**	**Average value which equals 100 %**
I	(Age 9-13)	106 %	91 %	15 %	70.0 °
II	(Age 14-20)	94 %	109 %	15 %	69.5 °
III	(Age 21-40)	113 %	93 %	20 %	45.0 °
IV	(Age 41-60)	98 %	103 %	5 %	40.0 °
V	(Age 61-80)	119 %	81 %	38 %	31.0 °

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The S-Cone (blue)

Diagram showing the relationship between gender and M-cone efficiency

Graph 6

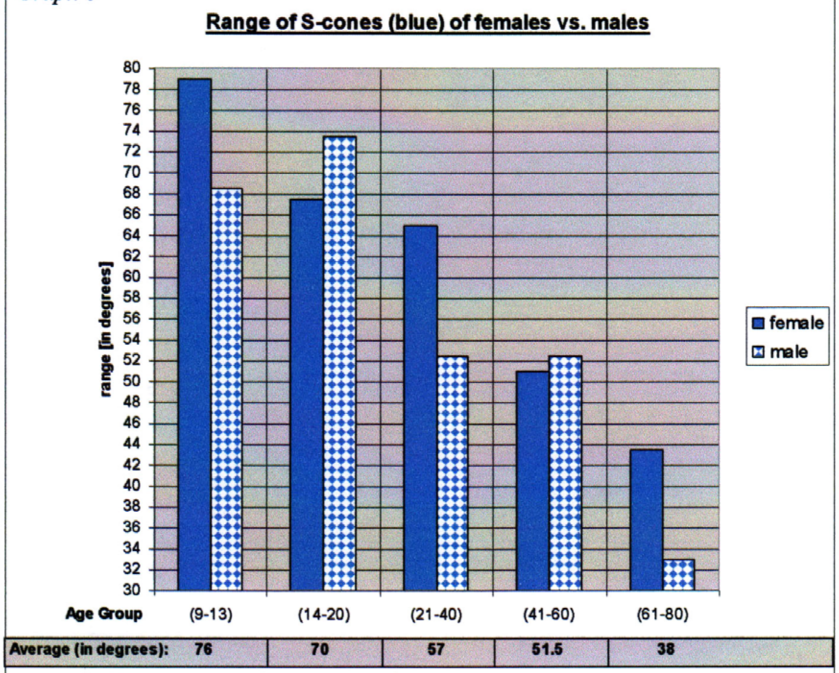

Table 9

Average S-cone efficiency of both genders in comparison to general average peripheral range(in percentage)

- highest average periphery value: x degrees (Group x) = 100%
- formula to determine difference in peripheral vision between genders in percentage: **(gender group x degrees / average periphery value for Group x * 100%) = percentage difference of peripheral vision for gender to average**

Group		Change in peripheral vision (when assuming that the average value of each group in degrees = 100% periphery) — Gender: Female	Male	Change between gender in %	Average value which equals 100 %
I	(Age 9-13)	104 %	91 %	14 %	76.0 °
II	(Age 14-20)	96 %	105 %	9 %	70.0 °
III	(Age 21-40)	114 %	92 %	22 %	57.0 °
IV	(Age 41-60)	99 %	102 %	3 %	51.5 °
V	(Age 61-80)	115 %	87 %	28 %	38.0 °

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All Three Cones

Graph 7

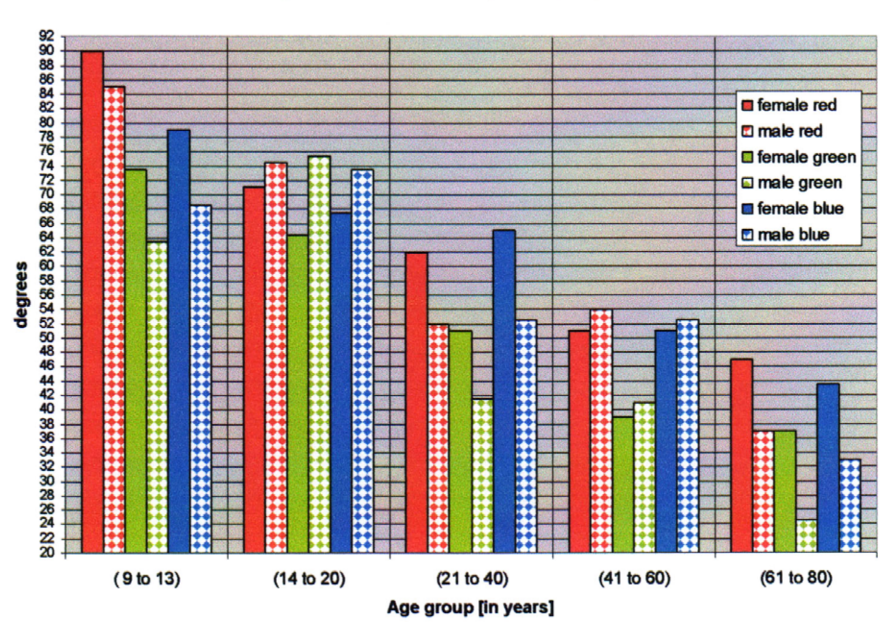

Table 10

Percentage of difference in colour sensitivity (cone efficiency) male vs. female

Calculations:

$$100 - \frac{\text{(average male (L-/M-/S-) cone value)}}{\text{(average female (L-/M-/S-) cone value)}} * 100\ \%$$ = difference of male colour (cone efficiency) sensitivity to females

	Group I	Group II	Group III	Group IV	Group V
L-cone	6 %	-5 %	16 %	-6 %	21 %
M-cone	14 %	-17 %	19 %	-5 %	34 %
S-cone	13 %	-9 %	19 %	-3 %	24 %

** positive values indicate the percentage of how much better the cones of a female are (in %)*
Negative values indicate the percentage of how much better the cones of a male are (in %)

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Summary of Results

- The efficiency of rods and cones decreases with age
  - Rod efficiency starts decreasing at the age of 40
  - Cone efficiency starts decreasing during puberty
- In colour sensitivity, the L-cone is most efficient, followed by the S-cone and lastly the M-cone.
  - The efficiencies of the cone cells do not differ greatly (the biggest difference is 21%)
  - The rate of decrease in efficiency with age for the three cone cells is the same
- Rod cells are more efficient than cone cells
  - On average rod cells are 2.4 times more efficient than cone cells
- The sight (rod and cone efficiency) **might** be better for females than for males
  - The peak in rod and cone efficiency for males is during puberty
  - The peak in rod and cone efficiency for females is during pre-puberty

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DISCUSSION

Part A

1.1) Correlation between decreasing photoreceptor efficiency and age

My prediction that the efficiency of the rods and cones decreases with age has been proven to be correct. However, my prediction, that the decrease in efficiency is higher for the rods due to a greater decline in the amount of rod cells is not what my experiment resulted in.

Rods
Graph 1 and table 2 show that the average peripheral range values stay relatively constant until 40 years. Up until 40 years the average peripheral range is around 140°. For the first two age groups (9 years until 20 years) the peripheral range values, thus rod efficiency, is the same. There is a minor decrease by 1 % from ge group II to III which is probably due to random sampling. There is a drop of rod efficiency from group III to IV of 7%. The biggest decrease is seen in group V. The rod efficiency is only 78 % compared to group I and II.

Cones
Graph 2 and table 3 show the colour sensitivity also decreases with age. The decrease for each cone is different, however follows a similar scheme. The values for colour sensitivity constantly decrease from age group to age group. However, there is an anomaly: the M-cone. There seems to be no decrease for the M-cone from group I to II, it is constant at 79%. This is probably also due to the random sampling, since all other figures show a decrease.

We lose photoreceptor efficiency with age, because the vitreous gel absorbs more light which leads to a perception of a lower level of brightness. Rod efficiency decreases starting with the age of 40, whereas cone efficiency is decreasing constantly from age group to age group. This raises the question how the decline in colour sensitivity can start earlier than the decline in peripheral vision.
Visual acuity has been examined by C.J. Owlsley and the experiments show, that it decreases from the age of 40 to 80 decreases by 83% [13] Since visual acuity is defined as the *"Assessment of the eye's ability to distinguish object details and **shape**, using the smallest identifiable object that can be seen at a specified distance."*[2] it is related to the rod cells and not the cone cells. In my experiment the decrease of rod efficiency from age 40 to 80 is only 21 %. This difference can be explained by the different methods used and considering that rod efficiency is only one of the aspects contributing to visual acuity. An investigation conducted by Kendra Jarret.[14] also concludes that peripheral vision decreases with age.

[2] Barbara Cassin, *Dictionary for Eye Terminology* (Melvin L. Rubin, 2006)

Organismal senescence in humans starts roughly around the age of 30. Since this study was conducted world wide, whereas the people I conducted the experiment on are all from countries with high standards of healthcare (Singapore and Germany), the figure should be higher. Therefore the decline in rod efficiency starting around the age of 40 is due to organismal senescence. Having established this, the only remaining question is why cone efficiency starts decreasing immediately from group I until group V? This could be an area of further study.

After all, there is a high possibility that the bipolar cells, ganglion cells or optic nerves contribute to the decreasing sight with age, since these cells/nerves connect the photoreceptors with the brain and they undergo organismal senescence as well.

1.2) L-cone vs. M-cone vs. S-cone

My prediction that the L-cone is most efficient, followed by the M-cone and lastly the S-cone is only partially proven to be correct with my experiment.
My results show that the L-cone is most efficient, followed by the S-cone and that the M-cone is least efficient. This is consistent through all my data sets *(see table 1)*. However, important is that in the experiment only the three fundamental colours red, green and blue were investigated on.

I also predicted, that the 'efficiency' values are not very far apart which can be seen in the experiment, since e.g. in Group I the L-cone is assumed to be 100 % efficient, the S-cone 86 % and the M-cone 79%.

It is remarkable to see that all three cones seem to decline in efficiency from Group I to Group V roughly 50 %.

Cone	Group I		Group V	Decline [in %]
L-cone	100 %	→	48 %	48 %
S-cone	86 %	→	43 %	50 %
M-cone	79 %	→	35 %	44 %

This shows that all three cones are affected by age to the same extent.

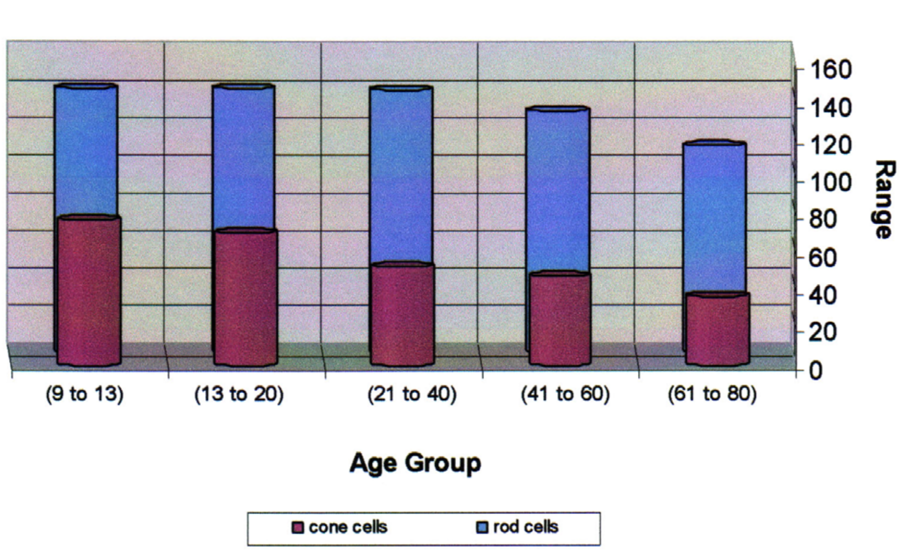
Considering that studies have shown that the percentage of S-cones out of all three cones is around 4 %, however blue is seen second best after red, the S-cone must be extremely sensitive. Even though the figure 4 % is not necessarily reliable, other sources also state that the S-cone has a very low appearance in the retina, e.g. the ratio between M- and L-cones to S-cones is 100:1 throughout the whole retina. [13]

Since the L- and M-cone are structurally almost identical, it is obvious to believe, that functionally they would be similar as well. Seeing that the range for blue in Group I for example is 76° whereas the range for green vision is 70° only, whereas the range for red vision is 88.5°, there must be a significant anomaly in the structure of the S-cone.

1.3) Rod Cells vs. Cone Cells

My prediction was that rod cells are generally speaking more efficient than cone cells. This has been proven to be correct, since my results show that the range for peripheral vision is much greater than the range of colour sensitivity. See graph and table below:

Graph 9



Average range of rod cells vs. average of all 3 cone cells					
rod	140.5	140.5	139.5	128.5	110
cone	78	71	53	48	37
Rod/cone	1.8	2.0	2.6	2.7	3.0

Figures show how much further we can perceive shape than colour

Average = (1.8 + 2.0 +2.6 + 2.7 + 3.0) / 5 = **2.4**

My experiment shows that on average, humans can perceive shapes 2.4 times better than colour, thus the rods are 2.4 times more efficient than the cone cells.

This significant difference in efficiency can be accounted to the distribution of rods. The rods are widely spread across the fovea, whereas the cones are all centered at one portion. Therefore the periphery for the rods is better than for the cones.
It is known that the light sensitivity of rod cells is known to be around 1000 times better than that of cone cells[2]. This is vastly due to convergence of the rod cells Knowing this, the number (2.4) obtained from my experiment is far off actual values. The figure is falsified, since the data that was collected in this experiment is only related to a horizontal line on eye level. The cone cells are only situated in the middle of the retina, at the area of sharpest vision which is the fovea centralis[2] *(see Appendix C)*. Therefore my values are deducted from the area of sharpest vision, where the cone cells are tightly packed which therefore strongly falsifies the formula for cone sensitivity.

<u>After all, my results show that the rod cells are more efficient than the cone cells due to a wider distribution and a bigger number of them.</u>

<u>Part B</u>

2.1) Gender Affecting the Efficiency of Rods and Cones

I predicted that the photoreceptors of women are more efficient than the rods and cones of men. The data I obtained from the experiment has proven this hypothesis to be correct.

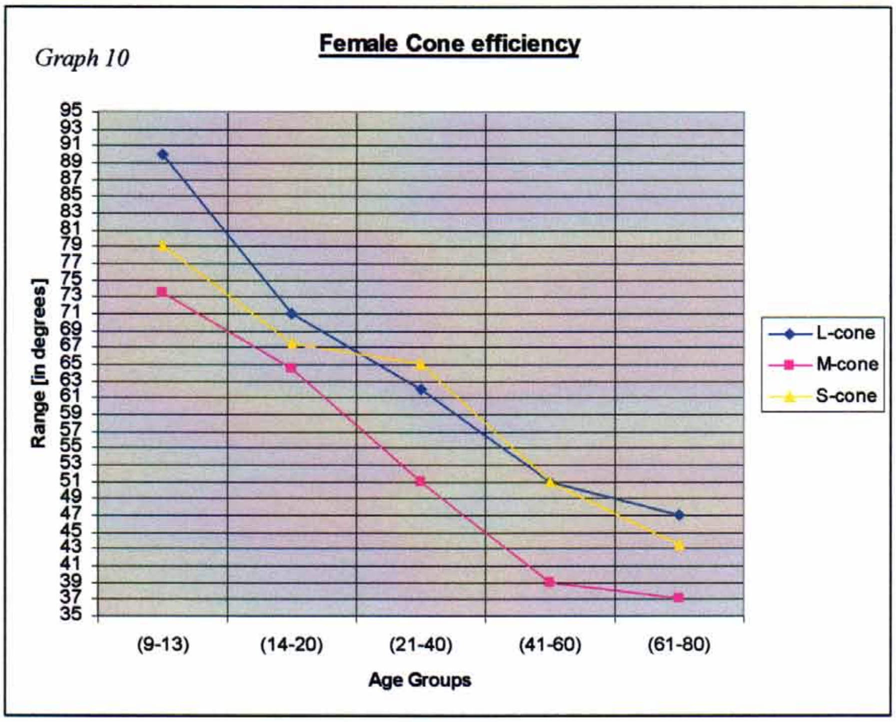
<u>As well as for the other senses such as taste and smell[15] [8], females also seem to be better in sight than males, however the data is not sufficient enough to draw final conclusions.</u>

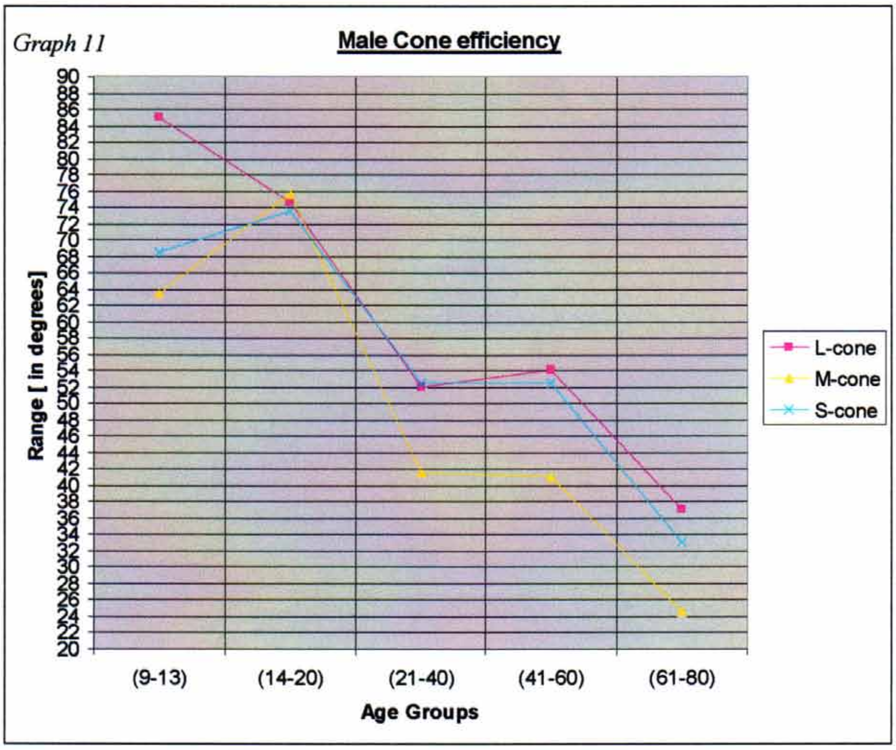
<u>Rods</u>

Graph 3 and Table 5 show that females obtained the best rod efficiency when they are young (group I), whereas the rod efficiency of males is worst when they are that age. When comparing the categorized male vs. female rod efficiency with the average rod efficiency from Part A) of the experiment, the female rod efficiency is 16 % better than that of the males. During puberty (group II) the rod efficiency for males rises, whereas it drops to an overall minimum for females. During the puberty the rod efficiency of the males seems to be 1 % better than that of females. After puberty (group III) the values are close to the same and males reach their peak in rod efficiency. Group IV and V show that female rod efficiency is again better than male rod efficiency. Female peripheral vision, thus rod efficiency is generally above average and therefore above rod efficiency for males.

Female rod efficiency decreases from Age Group I, increases from II to III and decreases from III to V, whereas male rod efficiency increases from pre-puberty to puberty. From group III to V it decreases again.

Cones





Graph 7 and table 10 (summary of graph 4, 5, 6 and table 7,8,9) show that cone efficiency in women is generally greater than cone efficiency in men. More specifically speaking, the three cones seem to follow a pattern: group I, III and V show that cone efficiency in females is better, whereas in group II and IV it is the opposite. When looking at table 10 it is obvious that the biggest differences in cone efficiency between genders are for the M-cone, then the S-cone and lastly the L-cone. In females, there is a gradual decline of cone efficiency *(see graph 10)*, whereas for males the trend for the M- and S-cone is the same, whereas the L-cone differs slightly *(see Graph 11)*. The decline for males is not smooth like in the female cone efficiency decline. An anomaly is the value for the male L-cone in group I. This might be due to limitations to the experiment, e.g. the number of males chosen in group I.

During puberty (Group II) and midlife (Group IV) there are inclines in cone efficiency in males. The peak for cone efficiency is in Group II, thus during puberty.

During pre-puberty (Group I) cone efficiency for females is at a peak. After pre-puberty there is a gradual decline in cone efficiency.

EVALUATION OF METHOD AND IMPROVEMENTS

The method used in this investigation can be viewed as successful, since my hypothesis were proven to be correct to a big extent, however there are still big flaws to this method.

Test persons

More people should have been involved in the experiment, since 75 people divided into 5 groups and for Part B) of the experiment additionally divided into females and males, leads to a very small sample number. Due to individuality the data can vary a lot from person to person, thus giving anomalies when only a few people were involved in the experiment.

The number of people for each Age Group should have been kept consistent, and the number of males vs. number of females should have been the same within each Group as well, in order to obtain fair averages.

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Method/Material

The light aspect is probably the biggest limitation to the method. Even though a hair band with attached torches was used when conducting the experiment, the light bulbs from the torches were not strong enough to be very useful. Because the experiment was always conducted under different conditions, such as weather, country, time of day, the light input is never constant. Since light has a huge impact on vision the differing light intensities must have falsified my data to a great extent.
To improve the method, the experiment should be conducted under lab conditions, with light as a constant variable.

The size of the dot on the pointer is a very important factor that needs to be kept constant at all times, since size and distance of the 'object' (in this case the card and the dot) determine the visibility of it.

CONCLUSION

1.1) As predicted in my hypothesis, the efficiency of rods and cones decreases with age. this is due to organismal senescence of the photoreceptors themselves and the tissue/cells/nerves that link the photoreceptors with the brain.
Rod efficiency starts decreasing at the age of 40, whereas cone efficiency decreases constantly from pre-puberty onwards. WHY?

1.2) Against my prediction in my hypothesis, the L-cone is most efficient, followed by the S-cone and lastly the M-cone out of the three different types of cone cells. This is probably due to a combination of the following factors:

- the cone distribution on the retina
- the number of each type of cone
- the sensitivity of each type of cone

The rate of decrease in efficiency is the same for all three cones.

The ability to perceive colours decreases by roughly 50 % from pre-puberty (Group I) until old age (Group V).

1.3) As predicted in my hypothesis, rod cells are more efficient than cone cells. However, I was **not** able to obtain a correct factor by which rods are more efficient than cones.

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2.1) As predicted in my hypothesis, rod and cone efficiency seems to be better for females than for males. However, the evidence is not strong, thus a **final** conclusion **cannot** be derived.

The peak in rod and cone efficiency for males is during puberty, whereas the peak in rod and cone efficiency for females is during pre-puberty. This difference in efficiency must be due to hormonal differences.

ACKNOWLEDGEMENTS

I would like to thank every person who has participated in the experiment. I appreciate the interest a lot of people have showed in this topic and the time many people have sacrificed by volunteering as test subjects.

Moreover, I want to express a big thank-you to my Extended Essay supervisor John Gasparini, who has helped and encouraged me throughout the whole experiment.

Last but not least, I would like to thank the Science Department of the UWCSEA for providing equipment as well as source material for me.

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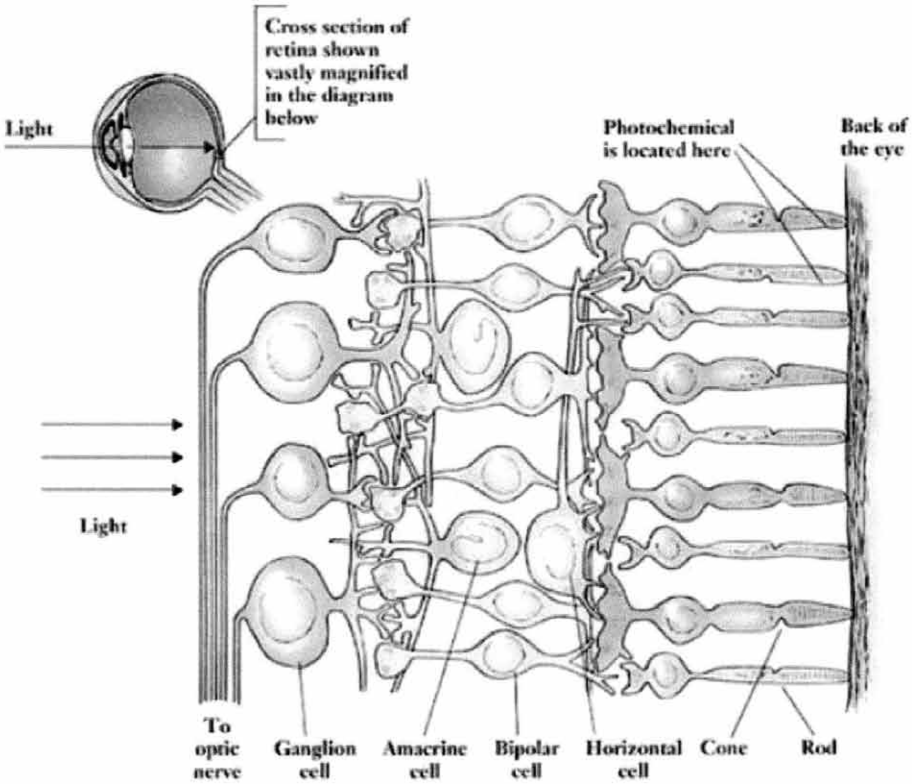
APPENDIX

A The main cellular components of the retina



http://www.psych.ndsu.nodak.edu/rob_gordon/lec07.pdf

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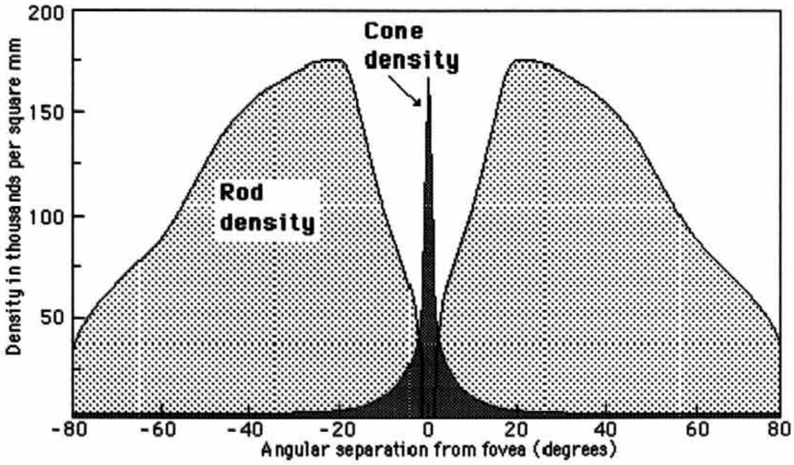
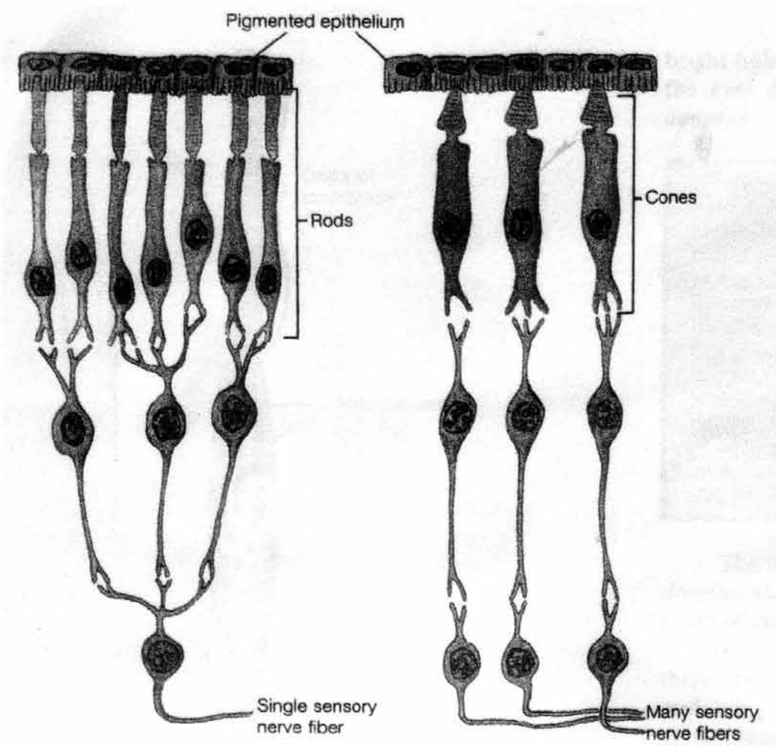
B **Rod and Cone distribution/density**



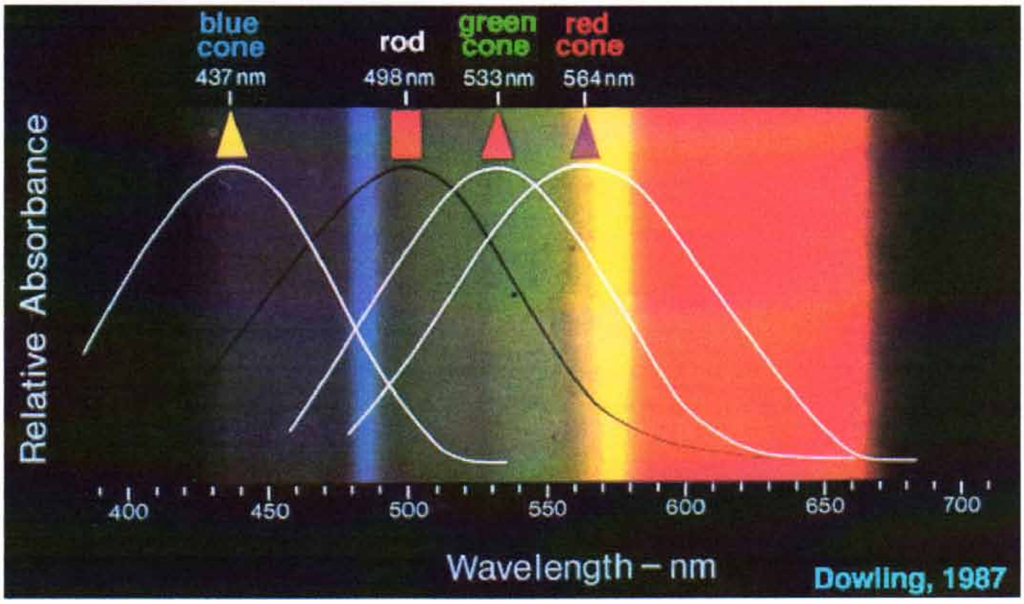
http://hyperphysics.phy-astr.gsu.edu/hbase/vision/rodcone.html

C **Rod convergence**



D Absorbance of photoreceptors

http://retina.umh.es/Webvision/imageswv/spectra.jpeg



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E **Instructions: How to map the visual field**

IBH BE Core Practical 2006

MAPPING OF THE VISUAL FIELD

This practical may assess DC, DPP, CE

Background

Your eye is sensitive to light. At the back of your eyeball is a layer called the **retina**. This contains receptor cells (called **rods** and **cones**) which send impulses along the optic nerve, to the brain, when stimulated by light rays falling on them. Only the cones can detect colours. These impulses are interpreted by the brain as 'pictures'.

How much of your surroundings that can be seen when looking straight ahead is known as your **visual field**.

It is impossible in the time available to map the entire visual field, but we can explore a horizontal plane through the visual field. If you were to stare straight ahead with only your right eye open, there is a limit to how far you can see to the right and to the left of your point of focus, using your peripheral vision. The vision discs provided allow you to find the angle of peripheral vision for each eye. Using different pointers it is also possible to find the limit of peripheral vision for the primary colours.

Your job

To map the horizontal plane for each eye to discover:

- the total field of vision
- the field of vision for each of the primary colours.
- collect class data and complete the write-up.

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F Raw data

Age Group 1:		9 to 13 (pre-puberty and first stages)																					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Av
Right eye closed	Sex	F	F	M	M	F	M	M	M	F	F	F	F	F	F	F	F	F	F	M	F	F	
--> Left eye	Age	12	9	10	13	10	10	10	9	10	12	10	10	10	10	9	10	9	9	10	10	10	10
Periphery	left	75	93	78	82	95	71	68	74	61	84	87	89	94	86	98	74	85	71	88	89	89	82
	right	60	51	37	51	71	29	54	46	64	56	55	61	72	54	54	53	67	52	59	60	57	55
left	red	55	37	39	65	39	46	40	29	35	40	47	31	51	43	44	47	47	44	59	54	30	44
	green	32	51	31	61	32	35	23	48	34	35	44	34	37	46	49	41	37	47	46	54	22	40
	blue	37	42	31	53	41	45	29	39	30	34	34	38	50	38	58	42	46	54	40	44	33	41
right	red	52	35	29	20	32	32	21	26	20	57	32	33	33	42	34	22	45	20	42	32	35	33
	green	40	36	20	26	35	23	37	21	31	48	26	38	28	33	34	23	36	20	40	38	29	32
	blue	43	41	28	41	30	29	30	26	34	46	32	33	30	29	42	33	45	23	39	41	28	34
Range	peripheral	135	144	115	133	166	100	122	120	125	140	142	150	166	140	152	127	152	123	147	149	146	**138**
	red	107	72	68	85	71	78	61	55	55	97	79	64	84	85	78	69	92	64	101	86	65	**77**
	green	72	87	51	87	67	58	60	69	65	83	70	72	65	79	83	64	73	67	86	92	51	**71**
	blue	80	83	59	94	71	74	59	65	64	80	66	71	80	67	100	75	91	77	79	85	61	**75**
Left eye closed --> Right eye																							
Periphery	left	53	60	52	50	59	54	55	49	62	57	53	69	75	61	54	57	63	52	57	52	82	58
	right	96	76	62	86	96	73	57	83	88	95	91	86	86	95	96	76	89	98	78	84	91	85
left	red	38	30	38	36	45	19	19	36	19	43	34	36	21	26	20	20	38	19	43	29	32	31
	green	43	30	30	34	53	21	18	15	19	44	26	41	34	22	25	25	36	18	31	32	22	29
	blue	43	27	26	40	49	24	26	28	20	49	32	44	32	29	27	28	44	34	39	30	27	33
right	red	57	59	44	37	67	41	31	30	31	63	57	62	33	47	51	31	36	44	41	42	48	45
	green	75	47	32	35	66	28	24	36	18	59	39	59	24	40	46	23	44	47	44	36	15	40
	blue	82	42	33	53	73	25	26	31	28	51	48	63	26	40	42	33	42	52	40	40	42	43
Range	peripheral	149	136	114	136	155	127	112	132	150	152	144	155	161	156	150	133	152	150	135	136	173	**143**
	red	95	89	95	73	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	**100**
	green	118	77	62	69	119	49	42	51	37	103	65	100	58	62	71	48	80	65	75	68	37	**69**
	blue	125	69	59	93	122	49	52	59	48	100	80	107	58	69	69	61	86	86	79	70	69	**77**

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Age Group 2:	14-20 (Growth Phase)																								
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Av.
Right eye closed	Sex	F	F	M	M	M	F	M	M	M	F	M	F	F	F	M	M	M	F	F	M	F	F	F	F	
> Left eye	Age	17	17	17	18	18	16	17	17	17	17	18	17	17	18	18	17	17	17	16	17	16	17	17	16	17
	left	53	86	97	97	74	88	74	87	96	82	66	90	74	85	90	60	92	84	75	84	94	89	63	98	82
Periphery	right	52	57	61	62	56	52	48	58	51	44	43	54	49	64	85	52	48	76	43	59	57	64	59	65	57
	red	28	72	39	59	49	24	39	62	33	48	39	36	24	34	44	38	40	63	39	58	45	52	35	31	43
	green	23	66	52	63	37	20	36	35	47	65	27	42	23	25	46	37	59	69	40	34	24	27	23	31	40
left	blue	22	76	59	60	29	23	32	27	35	44	31	37	24	26	44	36	57	53	49	44	36	41	30	37	40
	red	24	48	23	26	34	22	21	28	27	36	27	21	21	23	38	36	26	61	23	22	21	35	17	18	28
	green	16	43	35	28	38	14	24	26	27	32	35	19	20	22	29	33	38	61	20	27	17	18	22	18	28
right	blue	27	48	36	27	25	25	28	30	32	37	31	25	20	26	35	39	34	54	23	30	24	30	18	26	30
	peripheral	105	143	158	159	130	140	122	145	147	126	109	144	123	149	175	112	140	160	118	143	151	153	122	163	**139**
	red	52	120	62	85	83	46	60	90	60	84	66	57	45	57	82	74	66	124	62	80	66	87	52	49	**71**
	green	39	109	87	91	75	34	60	61	74	97	62	61	43	47	75	70	97	130	60	61	41	45	45	49	**67**
Range	blue	49	124	95	87	54	48	60	57	67	81	62	62	44	52	79	75	91	107	72	74	60	71	48	63	**70**
Left eye closed																										
> Right eye																										
	left	58	58	76	70	56	58	46	46	65	50	64	58	49	64	65	56	65	56	48	55	65	67	53	77	59
Periphery	right	73	83	93	81	95	73	65	82	101	75	83	68	54	84	86	82	72	86	87	85	93	92	77	101	82
	red	20	49	46	29	22	26	18	26	24	20	44	17	20	36	39	43	23	54	52	32	25	37	20	16	31
	green	29	52	47	39	30	31	15	29	22	37	36	15	22	30	39	44	36	52	28	38	20	20	15	16	31
left	blue	29	46	34	29	29	23	23	25	26	25	33	21	23	32	37	45	35	43	30	31	26	29	15	25	30
	red	35	62	36	49	51	34	27	47	37	42	49	34	25	33	51	42	49	80	52	56	33	69	30	33	44
	green	21	65	42	51	57	25	24	35	36	84	39	18	22	26	47	59	49	83	53	37	27	26	26	22	41
right	blue	35	52	47	51	50	42	32	41	30	38	39	28	22	34	50	45	46	76	48	34	39	47	24	25	41
	peripheral	131	141	169	151	151	131	111	128	166	125	147	126	103	148	151	138	137	142	135	140	158	159	130	178	**142**
	red	55	111	82	78	73	60	45	73	61	62	93	51	45	69	90	85	72	134	104	88	58	106	50	49	**75**
	green	50	117	89	90	87	56	39	64	58	121	75	33	44	56	86	103	85	135	81	75	47	46	41	38	**72**
Range	blue	64	98	81	80	79	65	55	66	56	63	72	49	45	66	87	90	81	119	78	65	65	76	39	50	**70**

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Age Group 3:		21 to 40										
		1	2	3	4	5	6	7	8	9	10	Av.
Right eye closed	Sex	F	M	M	F	M	M	F	F	M	M	
> Left eye	Age	32	37	28	25	34	34	34	37	30	20	31
Periphery	left	90	86	93	80	89	93	94	91	78	86	88
	right	46	50	62	59	48	49	50	57	58	53	53
left	red	32	39	36	36	32	48	65	43	19	25	38
	green	27	19	18	21	9	33	37	45	10	24	24
	blue	30	27	37	29	28	44	80	44	19	26	36
right	red	23	25	29	23	17	21	20	17	14	17	21
	green	32	19	23	16	12	33	16	16	8	24	20
	blue	33	20	39	13	22	32	13	37	13	26	25
Range	peripheral	136	136	155	139	137	142	144	148	136	139	141
	red	55	64	65	59	49	69	85	60	33	42	58
	green	59	38	41	37	21	66	53	61	18	48	44
	blue	63	47	76	42	50	76	93	81	32	52	61
Left eye closed > Right eye												
Periphery	left	54	55	59	47	51	51	52	64	57	64	55
	right	81	86	93	90	88	65	82	86	74	76	82
left	red	25	21	26	25	15	19	23	19	13	13	20
	green	20	25	21	19	17	34	16	10	11	19	19
	blue	44	21	31	28	19	24	13	15	16	21	23
right	red	35	25	58	36	27	28	35	37	25	29	34
	green	32	24	25	33	25	29	49	17	10	23	27
	blue	41	19	36	32	18	37	46	19	24	26	30
Range	peripheral	135	141	152	137	139	116	134	150	131	140	138
	red	60	46	84	61	42	47	58	56	38	42	53
	green	52	49	46	52	42	63	65	27	21	42	46
	blue	85	40	67	60	37	61	59	34	40	47	53

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Age Group 4:		41 to 60												
		1	2	3	4	5	6	7	8	9	10	11	12	Av.
Right eye closed	Sex	F	M	F	M	M	F	F	F	F	F	M	M	
>Left eye	Age	40	53	42	49	52	53	54	55	49	58	50	55	51
	left	96	69	89	95	81	66	83	76	80	71	60	57	77
Periphery	right	62	51	52	56	57	53	47	57	44	51	32	53	51
	red	59	27	35	65	27	25	28	22	27	29	19	17	32
	green	39	11	16	31	18	29	10	12	27	20	9	8	19
left	blue	51	24	33	42	28	30	24	21	31	35	22	12	29
	red	48	16	14	22	40	23	15	15	20	12	13	15	21
	green	42	16	9	51	35	18	12	16	19	9	17	12	21
right	blue	43	16	18	43	34	23	16	24	19	16	23	24	25
	peripheral	158	120	141	151	138	119	130	133	124	122	92	110	128
	red	107	43	49	87	67	48	43	37	47	41	32	32	53
	green	81	27	25	82	53	47	22	28	46	29	26	20	41
Range	blue	94	40	51	85	62	53	40	45	50	51	45	36	54
Left eye closed														
> Right eye														
	left	66	57	59	64	53	45	43	52	47	60	39	44	52
Periphery	right	79	79	84	74	80	74	81	79	69	76	59	79	76
	red	21	26	17	29	22	18	18	20	17	16	14	18	20
	green	35	10	8	25	17	19	9	16	16	12	20	16	17
left	blue	36	19	20	32	26	22	13	19	21	18	25	15	22
	red	34	32	31	43	37	33	25	29	34	28	26	31	32
	green	46	19	11	27	30	32	11	24	21	9	17	19	22
right	blue	33	21	20	40	30	33	19	26	28	24	27	19	27
	peripheral	145	136	143	138	133	119	124	131	116	136	98	123	129
	red	55	58	48	72	59	51	43	49	51	44	40	49	52
	green	81	29	19	52	47	51	20	40	37	21	37	35	39
Range	blue	69	40	40	72	56	55	32	45	49	42	52	34	49

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Age Group 5:	61 to 80 (eldery age)									
		1	2	3	4	5	6	7	8	Av.
Right eye closed	Sex	M	F	M	F	M	M	F	F	
> Left eye	Age	76	71	75	69	72	68	69	72	72
Periphery	left	52	52	60	71	67	86	86	61	67
	right	24	43	40	54	57	58	39	46	45
left	red	22	26	19	8	24	18	28	45	24
	green	7	37	16	6	15	12	20	19	17
	blue	13	43	20	5	21	22	25	24	22
right	red	19	30	19	10	15	17	19	32	20
	green	11	24	10	3	9	15	18	18	14
	blue	12	32	20	5	11	15	18	21	17
Range	peripheral	76	95	100	125	124	144	125	107	112
	red	41	56	38	18	39	35	47	77	44
	green	18	61	26	9	24	27	38	37	30
	blue	25	75	40	10	32	37	43	45	38
Left eye closed										
> Right eye										
Periphery	left	33	44	45	50	47	37	49	38	43
	right	50	64	52	73	61	72	77	68	65
left	red	27	19	15	7	13	19	20	18	17
	green	15	30	12	5	8	18	14	24	16
	blue	17	33	17	6	12	18	16	22	18
right	red	19	31	21	8	12	19	40	31	23
	green	11	32	10	5	9	17	16	27	16
	blue	12	33	25	6	9	18	30	29	20
Range	peripheral	83	108	97	123	108	109	126	106	108
	red	46	50	36	15	25	38	60	49	40
	green	26	62	22	10	17	35	30	51	32
	blue	29	66	42	12	21	36	46	51	38

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			Group I		Group II		Group III		Group IV		Group V	
			females	**males**	**females**	**males**	**females**	**males**	**females**	**males**	**females**	**males**
	Range	peripheral	144	123	138	140	142	141	132	122	113	111
		red	78	75	69	73	65	54	53	52	50	38
		green	73	69	62	74	53	39	40	42	36	24
Left eye		blue	77	72	68	73	70	56	55	54	43	34
	Range	peripheral	150	126	139	144	139	137	131	126	116	99
		red	102	95	73	76	59	50	49	56	44	36
		green	74	58	67	77	49	44	38	40	38	25
Right eye		blue	81	65	67	74	60	49	47	51	44	32
	Range	**peripheral**	**147**	**125**	**139**	**142.0**	**141**	**139**	**132**	**124**	**115**	**105**
	L-cone	**red**	**90**	**85**	**71**	**74.5**	**62**	**52**	**51**	**54**	**47**	**37**
	M-cone	**green**	**74**	**64**	**65**	**75.5**	**51**	**42**	**39**	**41**	**37**	**25**
average	**S-cone**	**blue**	**79**	**69**	**68**	**73.5**	**65**	**53**	**51**	**53**	**44**	**33**

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