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Entoptics Phenomenon-The origin of Colored fringes in light disks seen when looking towards bright objects

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Abstract

The paper presents a rarely noted optical phenomenon in the field of entoptic vision. The entoptic vision structures studied here are light disks crisscrossed with multicolored fringes that are seen when looking at bright lights, especially the sun. I discuss the various properties of the structures, methods to photograph them, and possible mechanisms that produce these structures. Our research suggests that these phenomena are caused by wave interference of light. This interference is produced when light is reflected from the microscopic pattern on the surface of eyelashes. This analysis has potential advantages in video game design. The improved knowledge and understanding from our research can lead to enhanced realism in virtual reality.

Keywords: Entoptics, Retina, pupil, diffraction, interference

I. INTRODUCTION

From very early on in my youth, I've had a fascination with colorful light disks appearing in my vision while looking at bright lights, such as the sun. As I've gotten older, I have continued to see these phenomena, and my wonder and curiosity have never diminished. What precisely are these light disks? What is the mechanism by which they are produced? And would it be possible to reproduce them in something tangibly observable, such as a photograph?

This research strives to answer the aforementioned questions. This kind of phenomenon has been termed as entoptic vision. Entoptic vision phenomena are created from sources within the eye as opposed to real objects that exist in the world outside the eye.

Entoptic phenomena such as floaters and flashes have fascinated and intrigued scientists and common people for a long time. Floaters are vaguely shaped clusters of circles that seem to float in the vision field especially when looking at a uniformly Illuminated blue field, such as the sky.

Physicists have successfully explained the mechanism with which floaters, flashes etc. are produced but in my review of existing literature I did not find any mention of the colorful light disks that I have often observed. Consequently, I decided to attempt to explain this phenomenon using principles of optics. I observed that the light disks moved with movement of eyelashes. It logically followed that the eyelashes were involved in the mechanism of production of these light disks.

Fig. 1: Photograph of light disk containing multicolored fringes

In this paper I will explain the mechanism of production of these light disks, starting with describing how the eye works. Then I will explain entoptic phenomena, after which I will describe the surface of hair which plays an important role in this process. Diffraction and wave interference are part of the pathway so diffraction will be discussed as well. Finally, I will bring it all together to explain the complete mechanism. I will also describe the experiments I performed to test my hypothesis and then I will conclude with my results, interpretations and applications.

II. HOW THE EYE WORKS:

In order to understand the results of this research one must first understand how the eye works. The eye works by focusing incoming light onto the retina. The eye lens is flexible and can change its shape to vary its focal length. This ability is called accommodation of the eye, which allows the eye to make focused images of different objects at varying distances from the eye. However, the eye has a near limit. Objects that are closer than the near limit (about 25 cm) cannot be focused onto the retina. This produces blurred vision and is called out of focus vision [5].

III. ENTOPTICS:

Entoptic means images arising from sources within the eye. Floaters are a kind of entoptic phenomenon. They are caused by shadows of protein clusters in the vitreous fluid within the eyeball.

Another entoptic phenomenon is flashes. These are caused by physical pressure on retinal nerves that gets transmuted into electrical signals which the brain interprets as flashes of light. Another is Blue Field entoptic phenomenon. then someone looks at a blue colored field of vision, they see white bright particles move in a squiggly or curved path. These visions are produced by white blood cells moving in the retinal blood vessels. The white blood cells are light colored and are bigger in size than red blood cells, so when a WBC is in the blood vessel it creates a sort of traffic jam, causing an accumulation of RBCs behind the WBC. The contrast between the dark colored RBCs and light-colored WBC makes it look like bright points of light moving around.

The definition of entoptic phenomena could be expanded to include sources external to but within very close proximity of the eye, such as eyelashes and eyelids. In the next section I will discuss the surface structure of hair. This aspect will be an integral part of my results.

IV. METHODOLOGY

It is my hypothesis that the entoptic phenomena of light disks are produced by eyelashes and so I performed an experiment to test my hypothesis. In the experiment I used strands of my scalp hair in lieu of eyelashes since eyelashes are harder to obtain and, in my investigation, I concluded that the structure of scalp hair is functionally identical to eyelashes, The studies on scalp hair are also more numerous than studies of eyelashes and they bear out the fact that eyelashes have a similar surface and internal structure to scalp hair. For this reason, I will use the model of scalp hair for my analysis as well.

Before the hairs were incorporated into my experiment I experimented with my own eye, looking in the direction of the sun and studying the structure of the light disks and colored fringes in detail.

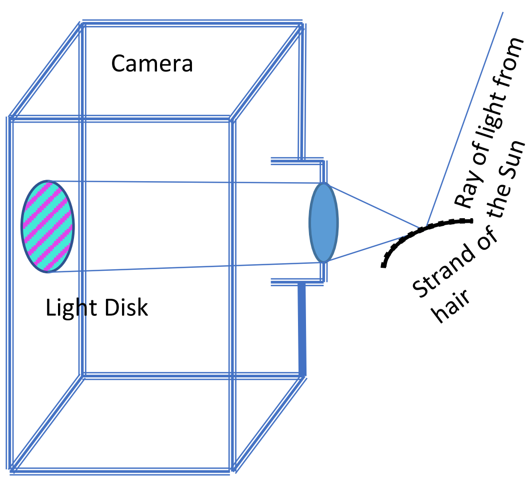

Fig 2: Experimental setup. Strand of hair is held in front of camera lens at a distance of 3-4 mm while the camera faces in the general direction of bright source of light, in this case the sun.

Next, I held strands of my scalp hair very close to my eyes while looking in the direction of the sun and observed the same kind of light disks. After that I held the strands of hair in front of a camera lens. I positioned them very close (3-4 mm) to the lens to mimic the positioning of eyelashes in front of the eye lens and to create out of focus images. I was able to capture images which exactly recreated the light disks that are the subject of this paper.

Other types of fibers and objects were also examined with the same setup to see if they would produce the same effects as hair, but they failed to exactly recreate the same light disks which I am investigating.

V. WHY THE EYE PRODUCES LIGHT DISKS

There are two components to my findings about the light disks. One is an explanation for the circular shape of the disks and the other is an explanation for the production of colored fringes that fill the disks. Both effects are produced from different mechanisms. I will address the circular shape of the disks here and the rest of the paper will be devoted to the analysis of production of the colored fringes.

When the object is close to the eye lens (or camera lens as in the experiment), the lens cannot converge the rays enough to make them intersect and therefore produce a focused and well-defined image of the object. In case where the object is extremely close to the lens the rays of light are barely converged and they end up projecting the shape of the pupil onto the retina (Fig 3b), which is circular for humans. This is the reason for the circular shape of the disks.

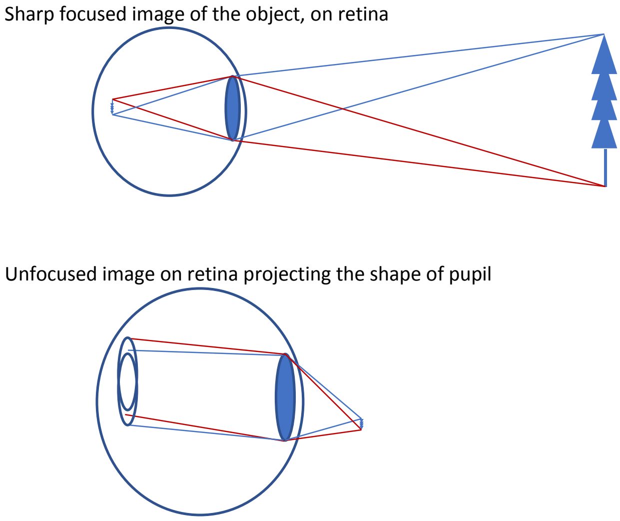

Fig 3a and 3b: Rays from far away object converge to form a sharp image on retina. Rays from a very close object do not come to a sharp focus but project the shape of pupil.

A camera is functionally and structurally very similar to the eye and therefore can reproduce this effect as seen in my experiment. A particular case of out of focus imaging is already well known as bouquet effect in photography. The inability of the camera lens to focus very far-off sources of light produces colored disks of solid color unlike the multicolored disks captured by the eye.

VI. STRUCTURE OF HAIR:

As I was trying to understand the mechanism that produces the colored fringes in the light disks, I looked for studies on the structure of hair. The surface of the hair is not smooth like it looks to the naked eye, but it is rough and jagged consisting of overlapping cuticles as shown in Fig 4. This stepped structure of the hair plays a very important role in our result.

In my literature review I found two categories of papers which were relevant to my research. One category of papers dealt with the study of hair structure from the point of view of cosmetology. The purpose of these studies was to analyze the effect of various hair treatments on the health of hair [1].

The second category of papers mathematically modelled the structure of hair for purposes of computer graphics. The purpose of these studies was to recreate the look of hair more realistically in computer graphics and animation [2].

The common feature in both types of studies which I found relevant to my investigation was the pattern of overlapping cuticles on the surface of the hair. These overlapping cuticle scales are an important feature of the optical properties of hair. The light reflected off adjacent cuticles can have path difference which in turn can produce colors through constructive and destructive interference of light. The details of this mechanism are explained in the next section.

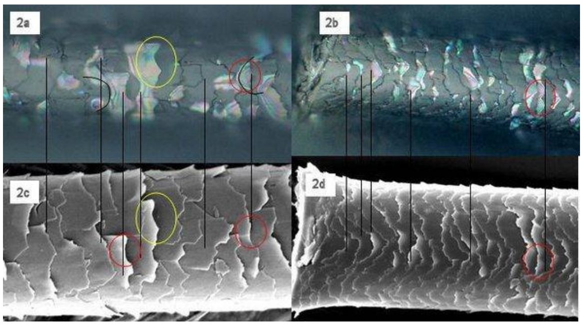

Fig 4 Microscopic image of hair cuticles [1]

VII. DIFFRACTION AND INTERFERENCE

In order to understand the origin of colored lines in the disk we need to understand the concepts of diffraction and interference. Diffraction is the process by which waves spread around corners. This is a very important property of waves and light exhibits this property since it is an electromagnetic wave. The famous double slit experiment proved the wave nature of light and this experiment hinged on the ability of light to diffract around corners.

According to Huygens [3] wave theory of light, each point in the path of the light can be considered as a point source radiating the wave outwards. In particular, points at which waves are reflected can play this role and lead to interference effects.

Waves by nature have crests and troughs. When two waves are travelling side by side they interfere by superposition. When the crest of a wave interferes with the crest of another wave then the intensity of the wave is increased, and we call this constructive interference. When the crest and trough of adjacent waves meet then the intensity is reduced to zero and we call that destructive interference.

With monochromatic light (single color or one wavelength) this produces maxima and minima (bright and dark spots). With white light which is a composed of many wavelengths (all the colors of spectrum) some wavelengths undergo constructive interference and other wavelengths undergo destructive interference, producing a colorful pattern such as that seen in soap film bubbles. When different parts of a light wave diffract from points close to each other then they interfere.

VIII. ANALYSIS

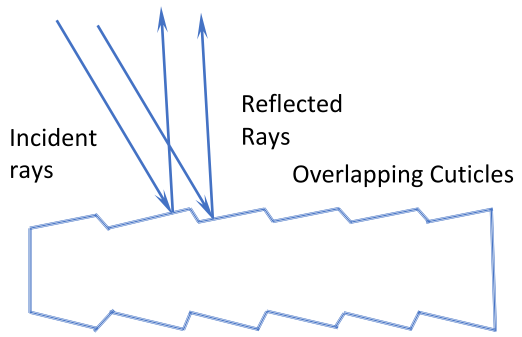

Fig 5: Light reflected from adjacent steps interferes to produce different colors by wave superposition

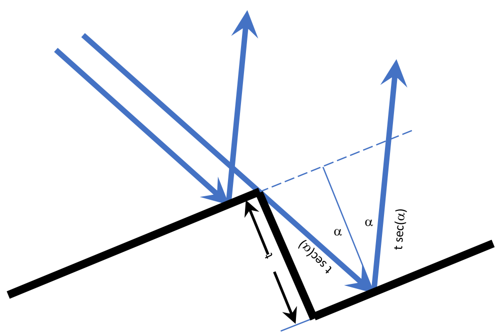

Fig. 6: Condition for constructive interference: path difference = n λ=2t sec(α)

The following section describes in detail how diffraction and interference of sunlight on the cuticle on the surface of hair produce the colored fringes in the light disks. The shape of the light disks is governed by the shape of the pupil and is a result of the out of focus projection on retina. This will be explained in more detail in a different section.

Each cuticle is about 2 mm higher than the one underneath it. When adjacent parts of the wave land on the higher point and the lower point then the path difference in the reflected waves that is produced is about four micrometers (4000 nm). The green light in the visible spectrum has a wavelength of 532 nm. For the case of normal incidence, the angle of incidence is zero.

The path difference of 4000 nm equals (4000 / 532) = 7.5 λ seven and a half wavelengths of this green light. Since the path difference between adjacent waves is not a whole number of wavelengths the two waves will meet in opposite phases and therefore interfere destructively, reducing the intensity of green light to zero. Since the white light is a certain mixture of the spectrum colors, the absence of green component changes the overall color of the specific fringe to a different color (in this case magenta).

At this order of path difference the waves will interfere destructively and therefore the green light will be absent for this reflection. However, at 780 nanometer the path difference will be 4000/780 equals 5 λ, almost a full complete 5 wavelengths, so the wave will have constructive interference in red. Similarly, the wave will have a constructive interference in the violet end of the spectrum the absence of green and presence of blue and red produces magenta color which is a very typical color observed in white light interference such as in soap bubbles. The part difference changes at different angles sometimes giving constructive interference for green wavelength and destructive interference in red and blue in this way there could be various combinations which could lead to various colors being produced.

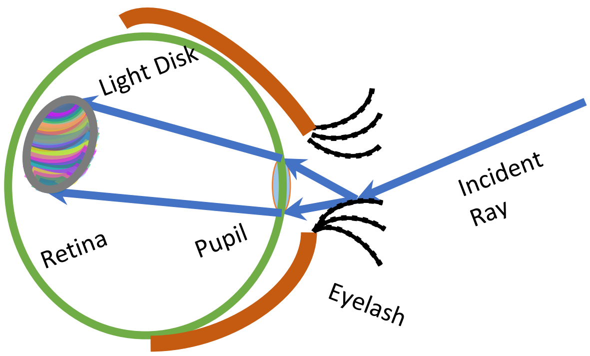

Fig 7: How light disks are formed on retina. Pupil shape produces the circular shape of disks. The colored lines come from diffraction of light by overlapping cuticle scales.

The colored fringes are produced because of Fresnel diffraction and interference of specularly scattered light from the cuticles of the scales. The colored rings mostly seem random because of the different colors which are highlighted by constructive interference from reflections.

These phenomena are caused by wave interference of light which is reflected from the roughness of the surface of hair at a microscopic level. The two waves interfere with each other and depending on the phase difference, the different wavelengths interfere destructively or constructively. The wavelengths that interfere destructively are subtracted out of white light and we see a subtractive color. The path differences are different in different directions and so colored lines of different colors are produced. When the colored fringes are very close to the eyes then they pass through the circular aperture of the eyes, thereby producing circular light disks containing colored light fringes.

IX. APPLICATIONS:

This research has potential applications in animated films and virtual reality. This research could produce greater realism in movies. Adding a glare effect in a scene where a character looks at the sun or a bright light increases the realism of the character's perspective. In the same manner adding the light disks calculated using the accurate optics principles described here would further enhance the realism.

Another effective application of this research would be in virtual reality. This kind of addition to realism in the VR headsets would be highly valued by users of the headsets. Flight simulators can have light disks to create a more realistic scenario so the trainee can encounter a more realistic view of glare produced when bright objects are in vision field and be prepared for it.

This research can be applied to helping those negatively impacted by light disks. It is well known that Floaters hinder quality of life for some people. It is possible that light disks may as well contribute to hindering the quality of life or job performance for some individuals where acuity of vision is highly needed. According to [1] some kinds of chemical and other treatments or conditions applied to scalp hair can damage them and cause the cuticles to lift from the base. This causes the hair to produce a stronger colored reflection. Same principles can be applied to eyelashes to determine which treatments can enhance or diminish the light disks.

Some potential factors that could come into play when thinking about this issue could be if there are some types of facewash and soaps that have a higher likelihood of damaging the eyelashes in a way that they produce more light disks. When light disks are a detrimental factor, one could think of treatments for eyelashes that would repair the cuticles of eyelashes in a way to reduce the light disks.

Another potential application would be some novelty optical illusion products. There is a market for products like rainbow glasses, fireworks glasses and Christmas light glasses. They dramatize the visual light effects by making them more vivid and vibrant. This research could be used to develop products that enhance the visibility of the light disks in a similar way.

Colored disks stand out more against darker hair and therefore the coloration of hair and eyelashes is a factor in determining who is more likely to notice the light disks. More research can be done to confirm this statement.

Not everybody notices these disks, but for those that do see these disks in their vision, if it is bothersome enough to be a distraction or annoyance, then the understanding of the principles described here could lead to finding a way to reduce or eliminate them.

X. CONCLUSION AND FUTURE RESEARCH:

In this paper the mechanism by which colored disk lights appear in entoptic vision has been clearly described as a function of the shape of the pupil and the microscopic surface structures of the eyelashes. One further line of research would be to develop codes to simulate these structures for virtual reality applications.

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