Looking through a Pinhole: Physical and Physiological Phenomena
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Abstract- A rich phenomenology could be studied in the misfocused vision through a pinhole or a system of pinholes punched on a black cardboard. Some of the observations we describe here can be also found in the ancient Literature. In this paper, we aim to rediscover and discuss some particular effects in light of a new perspective which provide an answer to interesting zero-cost experiments. In particular, in this paper we explain a fringing effect from the early contemporary Literature through an alternative geometrical model.

Key Words: Physiological Optics, Eye Vision, Ametropias, Diffraction, Eye-Lens.

1. INTRODUCTION

There are certain experiments concerning the vision process in which the observer’s eye looks through a pinhole (or a system of pinholes) punched on a black cardboard. The entire vision process is involved because the space between the pinhole and the eye introduces an element of confusion for the brain, as shown by the so-called phenomenon of the inverted pinhead shadow.

This experiment from the ancient Literature [1-3] was recalled many times in the early contemporary Literature because of its pedagogical value [4-8]: indeed, it can be regarded as the direct proof that retinal image is upside-down and the brain reverses it upside. Another experiment regarding the retinal image inversion employs a pinhole on a screen, which can be seen through two pinholes on a cardboard both entering the eye pupil aperture [9]; in this case it is possible to extend the experiment to some test on the observer’s sight as shown in the next section.

This paper illustrates a new perspective thanks to these experiments: in particular, we explain a fringing effect found in early contemporary Literature by means of an alternative geometrical model.

2. OLD AND NEW OBSERVATIONS

In the pinhead shadow experiment, an unnoticed aspect could be the subjective appearance of dark spots in the defocused vision visual field through the unobstructed pinhole. Once the pinhole diameter is fixed, these spots become more evident if the screen, where the pinhole is punched on, is brought further away from the eye. As it happens in the pinhead shadow experiment, these spots project their shadows on the retina. They are regarded as centres of local opacities (cataracts) and their shadows are projected upside-down on the retina.

This observation could be seen as an auto-diagnostic test for your eye-lens status and your ophthalmologist might possibly diagnose little cataracts [10] as shown in Fig. 2. This phenomenon is subjective because different observers give different descriptions about what they see by looking through those same pinholes placed at an equal distance from their eye.

If two close pinholes are punched on the cardboard, we will see what is represented in Fig. 2 as doubled and so on: the only condition for that to happen is that all holes enter in the eye pupil. Now, if we imagine the hole as sequences of different holes (disposed straight), the hole becomes a slit of the same width d of the pinhole aperture diameter d, and our opacity now will be seen as a straight line. It is a simple explanation of an optical phenomenon quoted in an introductory Physics book [11] and observed on a daily basis.

If we observe the tiny space between our finger and the thumb when they are almost touching, we will see thin dark lines having different thickness. Also, we can notice a single dark line or a set of dark lines when the background is the blue sky or a source of white diffused light as well as many alike dark lines by looking through a single slit (a set of two razor blades spaced 0.25mm–1mm). This phenomenology received a careful mathematical analysis [12] and these fringes are caused by the combined effect of Fresnel diffraction and the misfocused vision in incoherent light.

This phenomenon explanation is unclear because if we use the same eye at a fixed distance from the slit and rotate the slit itself (i.e. from vertical to horizontal direction in the plane in front of the eye), the fringe pattern can change its appearance remarkably. In addition, this fringing effect changes dramatically by passing from the right to the left eye and especially the description on the observed fringes is different according to who observes it. In order to test the above-given simple geometrical explanation, an experiment will be performed in the next section.

The second classical experiment is a pinhole observation in a screen viewed through a pair of pinholes in a screen very close to the observer’s eye observer and both entering the eye.
Fig. 1: (a) The pinhead observation through a hole in a screen. G: ground glass lighten by incoherent white light; H: black cardboard where a pinhole (diameter 0.5 – 1 mm) is punched; E: ‘reduced eye’. (b) What the observer ‘sees’. A movement towards the arrow is ‘seen’ as a shadow moving in the opposite direction.

Fig. 2: What you can see through a pinhole in a cardboard. In the figure, a clock face is superimposed. If you see a single opacity near ‘your hours 5’ through a pinhole punched in a cardboard, your ophthalmologist will diagnose a (single) opacity symmetrically located near hours 1. It happens the same in the pinhead shadow phenomenon.

pupil. Simply by looking through the pair of pinholes against a white light source (i.e. the computer screen) the defocused images of two holes are partially superimposed but our brain is still able to distinguish the right from the left hole (or the upper hole from the down one).

The experiment schematics is shown in Fig. 3. Let us suppose you are a presbyopic observer. If you look through a pair of pinholes in a screen very close to your eye and both entering your pupil, you will see the pinhole doubled and aligned with the pair of pinholes against your eye.

Now, if we cover one of the two pinholes, i.e. the upper pinhole, in the double image of the pinhole acting as light source, the lower image disappears because the brain inverts unconditionally the retinal image. As it happens in the pinhead shadow phenomenon, this experiment shows as well that the brain inverts the retinal image. The ‘element of confusion’ is the screen with the two pinholes.

Fig. 3: ‘Double pin’ experiment by Helmholtz. G: ground glass before a source of white light; S1: screen with a pinhole; S2: screen where two pinholes H1 and H2 are both entering the pupil’s aperture A of the eye; L: Eye lens; R1 retinal position of a presbyopic observer; R2: retinal position of emmetropic observer; R3: retinal position of a myopic observer. Let suppose the distance between S1 and S2 as a distance of eye accommodation. Ametropic observers see pinhole in S1 here doubled and aligned with H1 and H2. If we close the pinhole H1 a presbyopic observer will see vanish the doubled image below, whereas a myopic observer will see vanish the upper image. The ray tracing in the figure shows that in both cases (presbyopic or myopic observer) the brain inverts the images (two luminous spots on the retina).
3. EXPERIMENTS ON VISUAL OBSERVATIONS

The fringing effect obtained by looking through a single slit (i.e. a set of two razor blades spaced (0.25 mm – 1 mm), described in Sect. 2, appears as a subjective phenomenon for the reasons aroused. We can then complete an experiment where a lens (acting as the eye lens) and a screen (acting as the retina) replace the human eye.

The major aim of our experiment is to test if the simple modeling proposed in Sect. 2, and illustrated in details in Fig. 4, can give an effect which is similar to the ones observed by the vision through a single slit against the eye. The only difference is the different response to the light intensity of the human retina and a CCD system.

Thus, some China ink spots (less than 1 mm in diameter) are deposited on a microscope slide which is placed immediately before a photographic camera objective. A single slit is placed in front of the camera objective (i.e. 0.25 – 0.5 m) in order to have a misfocused image on the CCD, while a white luminous background of a fluorescent lamp illuminates the ‘vision system’ (i.e. the slit, the photographic camera lens having in front a few dark spots simulating little cataracts and the CCD).

Fig. 4: A geometrical model to explain the fringing effect seen in the white incoherent light in order to show the subjective character of the phenomenon that is differently described by various observers. Let us suppose an eye-lens having three opacities. In the vision through a single hole of diameter d, these opacities project three upside-down shadows on the retina as shown in figure. Now, if we imagine extending the hole as sequences of (an infinite) holes (straight disposed), the hole becomes a slit of width d and your opacity will be now seen as a straight line.

Fig. 5: Image of a slit of width d = 0.08 mm at a distance z = 0.25 m against the lens of a Fujifilm Finepix 52000HD digital camera, used in manual mode. The zoom is employed in order to have a misfocused image, so focal length in Eq. (1) is unknown. Exposure time 1/25 s, aperture F7.

The aim of our experiment is simply to control whether the image of a single ink spot immediately before the lens is ‘viewed’ through the slit, or is ‘prolonged’ as a line parallel to the edges of the slit in agreement to the geometrical model given in Fig. 4. In our experiment, a CCD Fujifilm Finepix 52000HD digital camera was used in manual mode. We fixed the same zoom in order to have a misfocused image of the slit and the same diaphragm and time in order to have the same intensity of light. Both photographs were unretouched.

Figs. 5 and 6 both show the misfocused image of the slit and the image of a single ink spot immediately before the camera lens. The surprisingly well-defined dark line, parallel to the edges of the slit, is in agreement with the geometrical modelling that extends a single pinhole having a diameter d in a single slit (of width d)as an infinite sequence of the pinhole as shown in Fig. 4. The sharpness of the ‘fringe’ in Fig. 6 can be explained by the increased depth of the lens field. The depth of the lens field having a diaphragm d is given by the equation [13]:

Fig. 6: A microscope slide having a ink spot of about 0.8 mm is placed immediately before the camera lens. The spot is ‘viewed’ as an opaque line parallel to the edges of the slit in full agreement with the geometrical model shown in Fig. 4 and therefore in agreement with the geometric reading key of the described ‘fringing effect phenomenon’. Exposure time, aperture and zoom did not change from Fig. 5. Both images are unretouched. Obviously, a smaller spot will give a finer and still very sharp line.

Fig. 7: The misfocused image of the candle flame when we move the plane, where the well sharp image is formed, forward or backward. Lens diameter 38 mm, focal length 100 mm. Photograph is taken on the back of a glossy paper - racing screen.
\[ \Delta = \frac{4o^2}{fd} \varepsilon \]

where \( o \) is the distance between the object and the lens, \( d \) is the diaphragm aperture, \( f \) the focal lens length and \( \varepsilon \) is the defocused spot diameter of an ideal image-point giving a defocused but acceptable sharp image. Eq. (4) may be extended to the single slit of width \( d \), giving the same field depth of a hole of diameter \( d \) (the model given in Fig. 4 is still recalled).

If a demonstration experiment is required, we can use a lens and a tracing-paper screen in a well-obscured classroom instead of a photographic camera.

Also, the second experiment (i.e. the vision of a light point-source through a pair of pinholes in a screen close to the eye and both entering the eye pupil) can be subjected to a direct test. Like the previous experiment, the pedagogical value of this direct experiment is given by the important roles of the Geometrical-Optics laws and the vision process.

As a source point, a candle substitutes the first pinhole in the screen S1, the eye lens becomes a lens of focal length \( f \), and the pinholes become two holes in a black screen. A tracing-paper screen replaces the human retina and it can be put at various distances from the lens in order to have a presbyopic or a myopic ‘sight’. By using a lens having focal length \( f = 0.1 \) m and a candle as object placed \( 0.6 \) m \( \pm 0.005 \) m in front of the lens, a real sharp upside-down image of the candle appears on a tracing-paper screen at a distance \( i = 0.12 \) m \( \pm 0.002 \) m.

This image becomes unrecognizable if the screen is moved to 10-12 mm forward or backward to or from the lens. Fig. 7 shows this ‘defocused image’ when the screen is moved 12 mm forward (or backward) to or from the lens. Now the lens is covered with a screen where two holes are punched (i.e. diameter 3 mm and 23 mm distance each other in such a manner as to enter in the aperture of the lens used). We can move the tracing-paper screen forward or backward to or from the lens in an interval up to 0.1–0.15 m and consequently the candle image also appears doubled forward or backward to or from the lens, and is well defined and reversed upside-down as shown in Fig. 8.

The differences between the presbyopic or myopic vision are demonstrated if we cover one of the two lenses: We placed the screen slightly before the plane of the sharp image formation. Turning back to Fig. 3, if the right/left hole is closed, the corresponding right/left image disappears. In the case of the presbyopic human vision, the brain inverts unconditionally the image and we see disappear the left/right image and vice versa.

Then, we placed the screen slightly behind the plane of the sharp image formation. Turning back to Fig. 3, if the right/left hole is closed, the corresponding left/right image disappears. In the case of the myopic human vision, the brain inverts unconditionally the image and we see disappear the left/right image and vice versa.

4. CONCLUSIONS

In this paper, we aim to rediscover and analyse a number of old experiments in light of their hidden phenomenology. The innovative and main point here is the new explanation provided for a ‘fringing phenomenon’ which is viewed against a white and extended incoherent source of light in order to demonstrates that it surely is linked to the vision process. The experiments we performed here give reason for the imaging differences in the Geometrical Optics and the vision processes.

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