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On the 'Speckle' Movements

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Since the second half of 1900 century, after the diffusion of the first He-Ne Lasers, several 'reading key' on relative movements while seeing a speckle pattern depending on the eye ametropias have been proposed. This paper quotes the development of these different approaches to this phenomenology, as a historical survey, and shows that a complete explanation must involve the vision psychophysics and the retinal structure.

Keywords: Speckle patterns; historical survey; physical optics; vision.

1. INTRODUCTION

"*Speckle*" or "*speckle pattern*" are terms that have become common in the undergraduate and school Physics laboratory a long time ago, mainly due to the diffusion of He-Ne lasers and more recently to convenient semiconductor lasers having various wavelength. For *speckle* [1], we mean the granular structure of a laser light diffused by a surface appearing thickly dotted with lighting and black dots. The size of these bright and black dots, when estimated by the observer's eye, grows with the observation distance; at a distance of a few meters, the dots become irregular light spots in the dark field [2]. At a fixed distance, the light dots become irregular spots in a dark field when the eye is diaphragmed, that is, by looking at the speckle pattern through holes having decreasing diameter [2,3].

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However, the phenomenological aspect that immediately catches the observer's attention is the sliding movement of the speckle itself when the observer moves the head in a direction parallel to the illuminated surface. According to the observer's eye ametropias, the speckle also flows either in the same direction of the head movement or in the opposite direction [2-7]. Therefore, it is unusual that an observer does not perceive those sliding movements, although he perceives equally random movements within the illuminated area. This is what has been stated by observers with an ametropic or emmetropic eye. The explanation for this global flow is not unique and *three* different explications were proposed: some Authors [6] give an explanation based essentially on a geometric model, other Authors [2-4] provide a simple hint of an explanatory model based on a *parallax* effect. On the other hand, other authors [5] observe that the visual movement explanation should be sought on a model based on the Physical Optics, but that explanation is only limited to a sentence.

Therefore, more than half a century after the first pioneering investigations, the need for a concrete and convincing explanation can still appear to be of interest. In this paper, some observations on the descriptive models of the above mentioned phenomenology will be made with reference to some easily achievable experiments and/or observations, able to discriminate the adherence or not between the model and the phenomenology.

2. THE PHENOMENOLOGY RELATED TO THE SPECKLE

We report some experimental facts concerning the speckle phenomenological aspects, some of which are explicitly mentioned in the above quoted Literature, while others follow from further observations.

a. A diffusing surface, illuminated by the beam from a He-Ne laser and expanded by means of a lens, has a granular structure studded with very bright points and dark spots [2]. The same happens by looking at the same spot of an unexpanded Laser beam impinging on a diffusing surface; i. e. a ground glass.
b. Despite the effort to keep the vision 'fixed' or relaxed, by increasing the viewing distance, the granular structure increases in size and the light and dark granules enlarge, thus, looking like a spot [2]. A presbyopic observer with eyes differing of two or more diopters perceives (without glasses) different subjective dimensions of the single speckle-spot. By increasing the distance, each spot is seen with the same refractive effects happening in the observation of a luminous background through a hole in a cardboard, i.e. the observer "sees" the local defects and opacities of its own eye lens in the single speckle-spot [8].
c. Lateral movements of the head cause the perception of the whole speckle pattern sliding [2]. Let us consider a presbyopic observer. He sees the whole speckle moving in the same eye movement versus, while a myopic observer sees the movement in the opposite direction. Then, a long-sighted observer experiences the phenomenology of a short-sighted person when wearing his reading glasses.
d. Further features, related to our previous findings, are given by the following observation. A finely grounded glass slide is placed to intercept the beam of a laser; and the light is transmitted on a glossy paper screen where an *objective speckle* appears. Due to light diffusion, a *subjective* speckle is visible in the spot on the ground glass.
e. Printed characters and fine details appear confused and unintelligible. Slight movements of the head in the viewer's vision or slight movements of the printed sheet do not cause confusion anymore [2].
f. On the surface of a milk glass, no speckle is observed.
g. Let us consider an observer (for example presbyopic) seeing a *subjective* speckle pattern through holes with decreasing diameter. He sees an increase in the size of the speckle grains [2, 3]. In addition, if he moves the head, after seeing a movement of the speckle grains in the same direction of the head, the movement perception becomes more and more chaotic as the holes become narrow, namely a tenth of a millimeter, and the observation distance is around one meter or more.

3. SHORT REVIEW OF THE EXPLANATORY MODELS

The term *parallax* used by the Authors of Ref. (2), (3) is substantially employed in its narrow sense to explain the speckle sliding movements. As a hypermetropic eye would adapt the vision *behind* the surface illuminated, while the shortsighted eye would fit the vision *before* of the illuminated surface, one would thus perceive a relative motion of one of the two surfaces with respect to the other.

Moreover, the Authors of Ref. (3) and Ref. (4) do not agree on what is perceived by a "normal" observer (emmetropic eye). "*The movement is a result of parallax*" is the interpretation by Rigden and Gordon [3] and, taken literally, shifts the attention to another issue typology related to optical perception problems. The eye normally 'accommodates' itself *behind* (i.e. presbyopic eye) or *before* (i.e. myopic eye) a 'speckling surface' and perceives the sliding of one surface to another. This interpretation is also assumed in Ref. (4).

The Δr_o dimension of the "speckle grain" (formed on the eye retina) is similar [10] to the Fraunhofer diffraction given by a circular opening, that is:

$$\Delta r_o \approx 1.22 \frac{\lambda z}{d} \quad (1)$$

where λ is the wavelength, z is the distance between the circular aperture (usually the pupil) and the retina, d is the diameter of the circular aperture, and Δr_o is the radius of the first diffraction minimum of a 'centric' function. As d decreases by looking at speckle through small holes, a hypermetropic observer perceives a slower and less definite speckle movement until is no longer able to perceive the flow but only the random movement. However, if we take into account the depth of field L of the diaphragmed eye, this observation is not critical for the parallax model

$$L \propto \frac{4p^2}{zd} \quad (2)$$

because L is inversely proportional to the diameter d of the aperture and its distance z from the retina at the same distance or from the "object point"p. The increase in the field depth would in fact determine a decrease in the eye ametropia and the speckle sliding movement effect. From the above observations, it is evident how an attempt to analyze a phenomenon (i.e. the parallax explication) has determined the shift of the main problem into other ones related to the eye accommodation psychophysical processes. In addition, it remains unexplained why the subjective speckle sharpness does not depend on the eye ametropiae (point d in Sect. 2).

In 1972 Ingelstam and Ragnarsson [5] proposed a different explanation of the speckle sliding movement, namely without any criticism towards the previous parallax model. In order to avoid any misunderstanding, their sentence is literally reported below:

> "*The property of the speckles to appear to move with respect to the surface as the observer moves his head or the surface is moved in a direction perpendicular to the line of sight is explained from the fact that the speckles are just interferences created on the observer's retina.*"

The third model comes by the Authors (6), and is the only one reported (1) and synthetically described in Fig. 1. Let us consider a single "ray" reaching parallel the eye optical axis; this ray is refracted by the crystalline lens. By moving the eye upwards, the previous beam moves to the position A to the position B shown in Fig.1. If the retina r is in focus F, the light stimulus remains in the same spot (eye ametropic), if the retina is behind F (myopic eye) the stimulus passes from the bottom to the top and the vision psychophysical process reverses its verse from the movement.

To the presbyopic eye, the retina is in front of F, through which the luminous stimulus on the retina passes from top to bottom and it is the vision psychophysics process that reverses its direction. This model received some criticism [7] not only for the related optometric methods, but also because it would not explain the reason of the speckle sharpness independence from the eye ametropias. The difficulties in Ref. (6) arise from the fact that the speckle perceived by the observer is a subjective perception of the circular opening amplitude overlap in the diffraction figures (i.e. the pupil). An observer having hypermetropic (or myopic) eyes with a vision difference of two diopters or more, can still use both eyes to evaluate the phenomenon, as the contrasting sharpness (clarity in Ref. (7)) of the dots bright swarm appears qualitatively the same to both eyes. Another unexplained aspect is the precise meaning of the expression "*reference ray*" (used in Ref. (6)) with which the ray was built parallel to the optical axis in Fig. 2.

Some years ago, a fourth model finally appeared on an educational journal [13]. It seems to clarify the mechanism of the speckle movements in full agreement with the phenomenology. For a correct problem posing, it should be noted that:

a) The eye lens are in a relaxed state;

b) The speckle is not located *in any particular plane* but in the whole space (i.e. the eye has *no* spatial references);
c) An *objective speckle* is still *into the plane* containing the eye pupil.

However, this last sentence, highlighted by Ennos (13), still presupposes the coherence of the light source yielding the speckle. Considering the diffusing plane as an overlap of N two-dimensional sinusoidal gratings, at randomly variable frequency in the pupil plane, the optical input is substantially a set of N functions translated by a_i and b_i

$$\sum_{i=1}^{N} \delta(x - a_i, y - b_i) \tag{3}$$

This means an input with a single spatial frequency towards the optical axis.

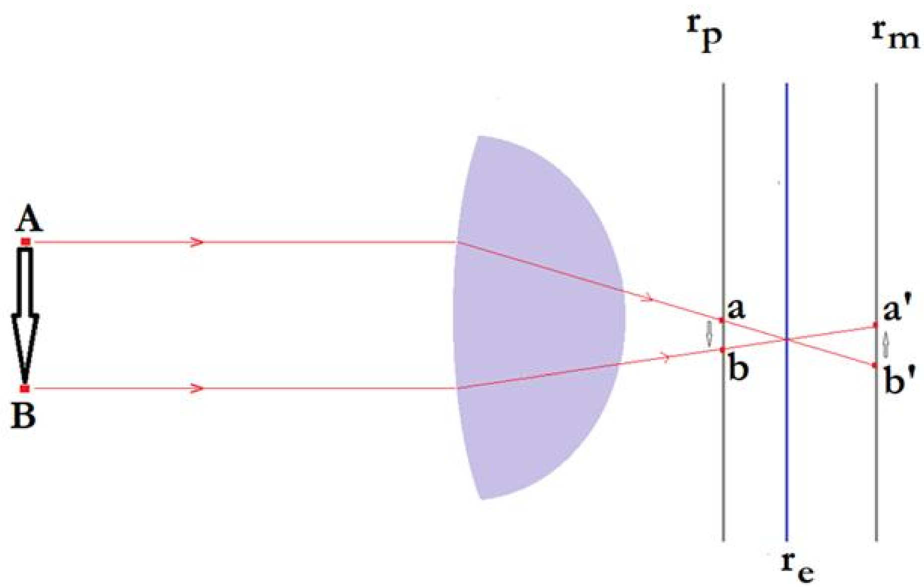

Fig. 1. The speckle movement as explained in Ref. (6).

When a 'speckle dot' (reference ray in the quoted paper) moves from A to B, on the retina r_e of an emmetropic eye, there are no movements. Presbyopic eye retina r_p is before an emmetropic retina r_e; even a myopic observer has his retina behind an emmetropic retina. The image moves from a to b for a presbyopic and from b' to a' for a myopic. Authors consider that the brain inverts unconditionally what formed on the retina.

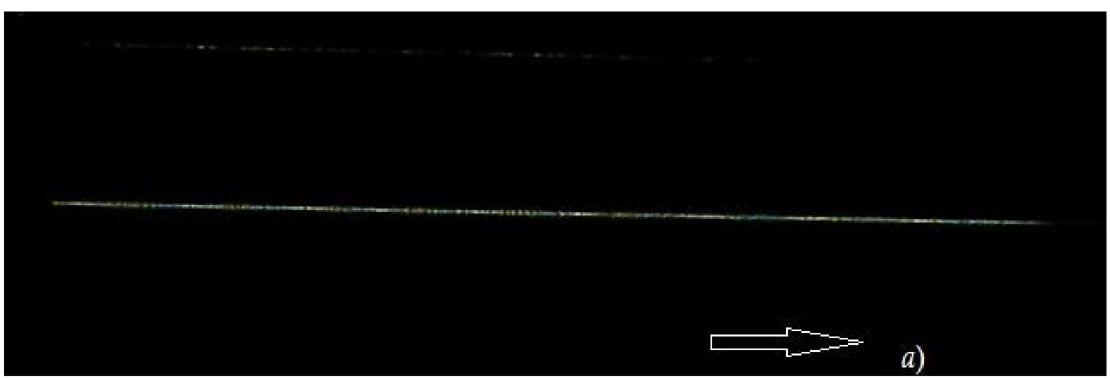

Fig. 2. A 'super-macro' image of a new 'tube LED lamp' reflected on the convex black glossy surface of a computer keyboard.

The array of reflected sources moves in the same direction of the eye movement (arrow a) to a presbyopic observer and in the opposite direction to a myopic observer.

The intensity output in the focal plane is apart from amplitude, phase and magnification factors a set of functions:

$$J(r_o) = \left[\frac{J_1\left(\frac{klr_o}{2f}\right)}{\frac{klr_o}{2f}}\right]^2 \qquad (4)$$

Where J_1 is the functional dependence of the Bessel function of order 1, *k* the wave number, *l* the diameter of the pupil, r_o is the coordinate (which refers to a circular symmetry) in the image plane (i.e. the retina) and *f* the focal length. If we apply Eq. (1) to the reduced eye (a pupil of diameter *d* ≈4 mm, a wavelength λ = 633 nm and a distance pupil-retina typical of standard anatomic data z ≈ 23 mm) the diffraction spot diameter on the macula lutea ‘mosaic’ is about 4μm, thus having the dimensions of a single photoreceptor. Therefore, this reading key is in agreement with Mohon and Rodemann’s main conclusions [6]: it explains why the speckle ‘sharpness’ does not depend on the ametropias and explains the speckle movement mechanism according to the eye ametropias. The proposed model in Rif (13) still assumes that the image inversion on the retina is unconditioned when the image of the speckle granule involves the single photoreceptor on the retina (with a pupil diameter of about 4 mm) and the movement is perceived when this spot "jumps" from an excited photoreceptor to a non-contiguous one. It seems that this observation dates back to a late 1800 pioneering study [14].

One last question remains open. As explained above, sliding movements with similar features are also found in situations in which the coherence attribute of the light source is absent [15]. In Fig. 2 there is an array system reflection of white LED ‘point’ lights (located on the ceiling) on a computer keyboard. The lamps are around three meter distant and the reflection on a glossy convex surface provides a small sources row. For the presbyopic observer, the sources run towards the head movement. As a counter-proof, the presbyopic observer sees through his *reading glasses* the light reflected from the keyboard and, in this case, he becomes a *myopic* observer. Indeed, this ‘speckle movement’ occurs in the opposite direction from the head movement.

This phenomenon is astonishing and well reproducible if you have a new “LED tube lamp” and a glossy convex surface, but an attentive observer can find *everywhere* colored ‘*speckle movements*’, in particular, on surfaces obliquely illuminated by unfiltered sunlight [9], like metalized and convex surfaces in bodyworks of cars, condensed vapor droplets, its own nails or intense point lamps [10]. In addition, this evidence suggests that the spatial and temporal source coherence is not strictly essential to the debate on the visual movement phenomenon.

4. CONCLUSIONS

More than half a century from the phenomenology observations related to the speckle, we have found several explanations about the subjective speckle movement. From a speculative point of view, this matter appears to be interesting and deserves more in-depth investigations. Our major conclusion is that:

a) the sliding movement according to the eye ametropias does not depend on the temporal coherence of the light yielding a speckle pattern;
b) the ‘*speckle movements*’ also involve psycho-physical visual aspects appearing every time the brain is confused because it cannot locate "*small*" light sources against the reference system, i.e. the surrounding environment. This last observation constitutes the basic content and the major motivation to report this paper.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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