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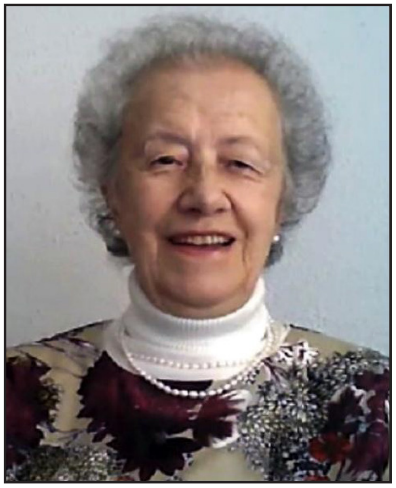

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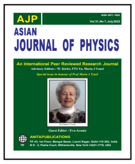

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Optics and stereopsis

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Dedicated to Prof Maria J Yzuel

Stereopsis is a key aspect to analyze 3D information of our surrounding. Two important variables characterize the stereopsis quality: stereoacuity and maximum disparity (disparity range). Both are the limits of stereoscopic vision. In the last years, stereopsis has received the input of optical advances by aberrometry and adaptive optics. In this work, we do a review of relevant studies that have improved the knowledge we have about stereopsis and binocular vision. © Anita Publications. All rights reserved.

Keywords: Optics, Vision, Stereopsis, Stereoacuity, Maximum Disparity.

1 Introduction

In this paper we want to show the relation between optical aspects of our eye system and a neuronal function important for depth discrimination: stereopsis.

1.1. Foundations of Stereopsis

Stereopsis is one of the most developed functions of our visual system, as it enables us to discriminate spatial location of objects around us [1-6]. It is an essential property in many animal species for which it is fundamental to have tridimensional vision in order to adapt and to survive, i.e., it is crucial to accurately determine positions and distances (especially for non-long distances) [1-5]. With only one eye, depth perception is still possible, but not as effective and efficient as stereopsis. The information on depth without stereoscopic information is obtained from monocular cues [1-6], which are founded on psychological aspects like learning. Thus, relative movement of the observer with respect to the object (movement parallax), relative movement of objects with respect to the observer, shadows, relative size and aerial perspective are monocular cues that partially allow depth perception; despite monocular cues do not have the same accuracy as stereopsis. Not all monocular cues are equally effective and efficient, and thus relative movement of the observer with respect to the object and shadows, for example, are more powerful monocular cues, while relative size and perspective are less effective monocular cues. Also, the mechanism of convergence-accommodation offer minor information to deduce objects position because of its low accuracy [1-6].

1.2. Disparity

Stereoscopic vision is based on disparity. This is a geometric function that depends on the spatial positions of objects with respect to the fixation point. Thus, two points placed in different spatial positions originate different angles with respect to each retina (Fig 1) [1-4]. For example, it can be observed in Fig 1 that the points A and B originate angles α and β, respectively. The difference between the two angles ($\alpha - \beta$) is known as disparity between A and B (Fig 1).

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The detection of disparity has its neurophysiological foundations. Our visual system has neurons tuned to disparity information. Different models propose that we have neurons sensitive to positive, negative, and zero disparity [7-8]. Our visual system obtains tridimensional information from the visual scene given by these disparity neurons. Mistakes in detection of one or more of these neurons provoke problems or difficulties to obtain our 3D information [1-5,7,8].

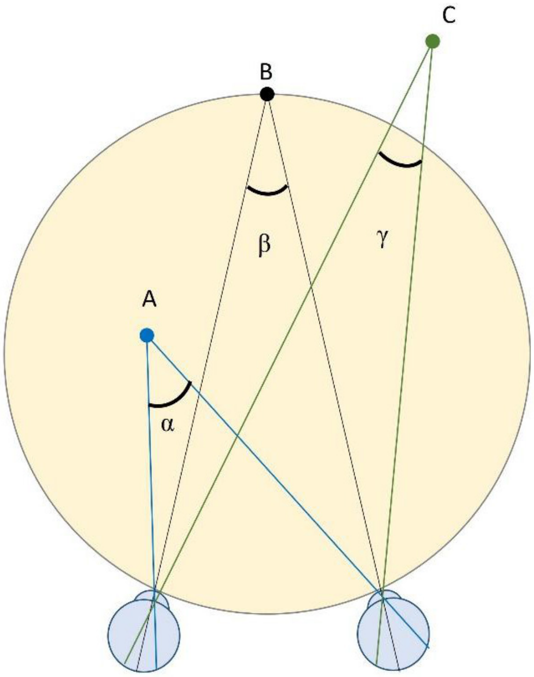

Fig 1. Two points B and A originate a geometrical difference (β – α) that is the disparity between A and B. C and A and B and C also originate a geometrical disparity.

1.3. Disparity computation

To know how the visual mechanisms can determine the disparity map of a visual scene is a very difficult task in which the final evidence is still unclear. The problem of determining the disparity map of a visual scene is also known as the stereo-correspondence problem [1-3], because from the disparity map we can know which point in one retina corresponds to that in the other to get simple and unified vision. In a normal scene, from the points of the image on a retina, there may be millions of pairs corresponding to those of the other retina but there is only one real valid correspondence. This real correspondence generates the disparity map associated with the scene being viewed. The visual information at different spatial frequencies can help to solve the stereo-correspondence problem [1,2].

There have been a few studies on stereoscopic vision in relation to optical quality, this is due, among other reasons, to the fact that having poor or no stereopsis is not accepted as an issue by many optometrists and ophthalmologists. Other symptoms, such as blurred vision, diplopia or headaches, are symptoms with which the patient is very familiar and often give rise to more complaints. Many people are not even aware that they have no stereopsis, despite that they may be having difficulties in manipulating objects, for example often dropping things being handled manually. In fact, some emmetropization techniques such as monovision [9,10], cancel or partially limit stereopsis to give the patient acceptable near and far vision even at the cost of reduced 3D vision.

1.4. Limits of stereoscopic vision

The range of disparities that can be detected by a patient enables us to know the region where the observer or patient can perceive stereoscopically. A greater disparity range permits a larger spatial region in which the observer perceives stereoscopically [1-6,11-13]). The disparity range of each observer enables the definition of two parameters of stereoscopic vision quality: the minimum disparity perceived, or stereoacuity; and the upper disparity limit, or maximum disparity or range of disparity [11-13].

Stereoacuity shows the region near the fixation point where we can perceive stereoscopically. A lower stereoacuity would indicate higher stereoscopic vision quality, as it allows sharper depth discrimination for points near the fixation point [1,2].

A high maximum disparity value would also indicate a more effective and efficient stereopsis, since a large maximum disparity value indicates a large spatial region around the fixation point where stereoscopic perception can be made, therefore providing a more effective depth discrimination [11-13].

Concerning both limits of stereoscopic vision, stereoacuity has traditionally been the parameter most studied when exploring stereopsis, especially in clinical practice, where different tests have been used to evaluate it, although many of these tests did not have high accuracy [1-7].

2. Optics and stereoacuity (*minimum disparity*)

As indicated before, stereoacuity is the minimum disparity that a patient or observer can detect and this minimum disparity corresponds with the smallest depth difference that can be seen stereoscopically. It can be measured with different methods and experimental devices. Typical values of stereoacuity are obtained under laboratory conditions as (2"-6") [1,2]. In clinical optometric practice, values around 40" are normal for practical purposes.

2.1 Stereoacuity (*minimum disparity*) *and optical factors*

The study of the influence of optical factors in stereoacuity has traditionally been focused on questions concerning interocular differences in low-order aberrations (defocus and astigmatism), natural interocular differences in ametropia or interocular differences induced by different emmetropization techniques (lenses, contact lenses, monovision, surgery, etc.) and their effects on stereopsis [1-4].

The development of adaptive-optics devices has allowed to extend the study of stereoacuity but in this subsection, we briefly review the effect on stereoacuity of interocular differences in low-order aberrations where no adaptive optics has been used.

Most experiments confirm that monocular or binocular defocus deteriorates stereoacuity and this deterioration is proportional to the magnitude of the defocus [14,15] although monocular defocus generates worse stereoacuity than binocular defocus [16]. This deterioration has been confirmed with different devices (real and projected-test). Some authors have shown that a stereoacuity of 40 sec is maintained for 0.5 to 1.0 D of monocular defocusing, whereas other authors [17] have found that 80% of subjects undergo a complete loss of stereoacuity for 1.0 D of monocular defocusing.

This effect of monocular defocus on stereoacuity can appear with monovision [9,10], one of the refractive-error correction techniques used for the correction of presbyopia. Monovision consists basically of setting the refraction of one eye for far vision (mostly, the dominant eye) while the other eye is corrected for near vision (usually, the non-dominant eye), originating an interocular difference in defocus that diminishes stereoacuity.

2.2 Stereoacuity and higher-order eye aberrations

Some authors [18,19] used a binocular adaptive-optics simulator to simultaneously control eye aberrations and the effect on stereopsis by studying the stereoacuity for two observers under different binocular aberration combinations and natural viewing conditions. These experiments on monocular and binocular defocus provide stereoacuity deterioration, as did results shown in previous experiments. They used different stereoscopic tests.

The adaptive-optics simulator was used to test more complex optical conditions using random-dot stereograms to estimate stereoacuity in the presence of high-order aberrations for one subject. These experiments constitute evidence of the effects of aberrations on stereoacuity, revealing a deterioration when higher-order aberrations are increased in one or two eyes, although the study [18,19] was limited to the trefoil aberration and only one observer participated in the experiments. We think that more aberrations and patients are needed to obtained conclusions. This has far-reaching implications from the clinical standpoint, as many emmetropization techniques increase higher-order aberrations and therefore can affect binocular vision and stereopsis in a negative way.

2.3. Stereoacuity with improved optics

Other researchers [20] have investigated the way in which the optics of the eye affects stereopsis, studying the effect by a stereoacuity task. For this, they have compared stereoscopic performance with normal, well-focused optics and with optics improved by eliminating chromatic aberration and correcting higher-order aberrations. Stereoacuity of human stereopsis is not limited by the optics of the well-focused eye. However, in these experiments, contrast sensitivity and visual acuity were also measured with normal well-focused optics and improved optics, resulting in better performance for contrast sensitivity and visual acuity with improved optics.

Binocular adaptive-optics simulators can draw information about different surgical and non-surgical techniques of emmetropization concerning stereoscopic aspects. Some authors [18] indicated the utility of simulators for studying the effect on stereoacuity correcting presbyopia with the monovision technique and using a small aperture inlay in one eye. These experiments are a good example of the importance of binocular adaptive optics for testing binocular vision before treatment (surgical or not). It is expected that the clinical use and research on these setups will enable better characterization of stereopsis and binocular vision, providing more knowledge on the visual system that has been limited until now to monocular studies, as only in the last few years new studies have begun to delve into the binocular aspects, including stereopsis.

Other authors [13] also measured stereoacuity pre- (best-corrected) and post-LASIK but with a random stereotest (including Titmus stereofly, Wirt rings, and random-dot targets). Although these tests are not very sensitive, a deterioration of stereoacuity that could be influenced by higher-order aberrations changes was observed in 8 patients.

3 Optics and maximum disparity

Different studies have shown evidences that interocular differences in higher-order aberrations could influence maximum disparity [12-13] for normal observers (Fig 2).

For normal observers, one study [12] showed that interocular differences in higher-order aberrations correlate with the upper (maximum) disparity limit. For a group of emmetropic subjects it was found a significant descending correlation between maximum disparity and interocular differences in higher-order eye aberrations (total RMS (Root Mean Square), spherical and coma aberrations). This shows that higher, the interocular-differences in eye aberrations, the lower the upper disparity. The results show the sensitivity of the maximum disparity limit to interocular differences in higher-order interocular aberrations, stereo-correspondence being more effective with lower higher-order interocular differences in eye aberrations.

Experiments with patients operated on with LASIK (laser in situ queratomileusis) confirm this tendency found for normal observers [13]. It is well known that LASIK generates great changes in the cornea, which usually increases eye aberrations. The results for a group of 23 people indicate that the maximum disparity limit diminishes after successful LASIK (Fig 3). This deterioration is significantly correlated with an increase in the postsurgical interocular differences in higher-order aberrations (RMS, spherical and coma). Other emmetropization techniques like corneal inlay [22] is shown that also affects stereopsis.

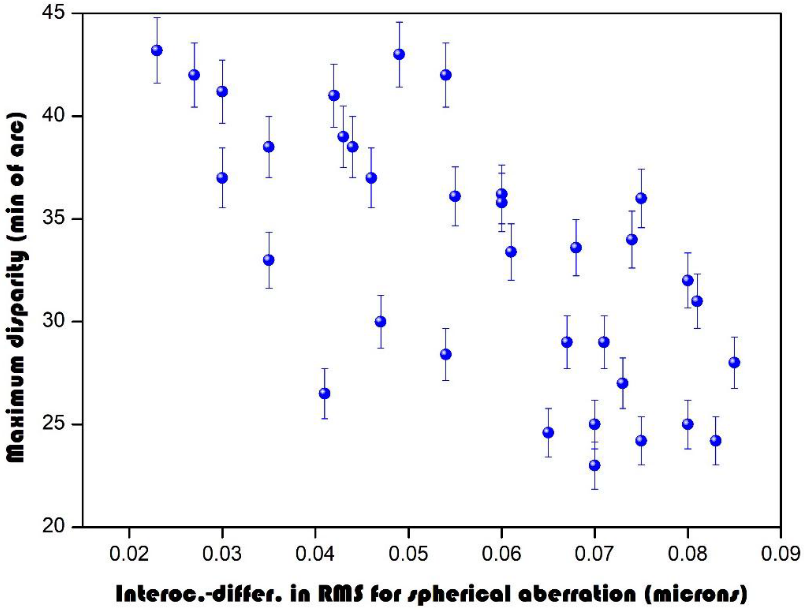

Fig 2. For normal observers, maximum disparity diminishes as interocular-differences in spherical aberrations increase (RMS: Root Mean Square). The correlation reaches 0.65.

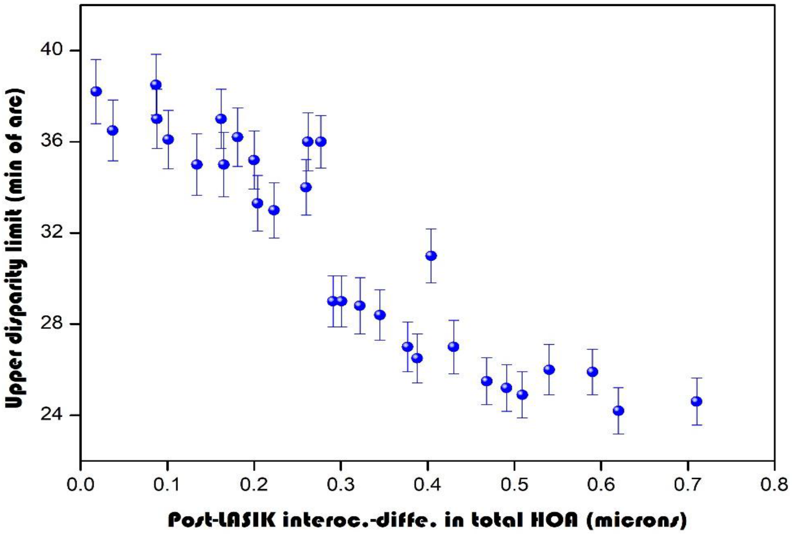

Fig 3. Patients operated by LASIK to correct myopia and astigmatism show smaller upper disparity limit for large values of the generated interocular differences HOA (High order aberrations).

In this study, we have analyzed some optical factors that affect stereopsis, but it is also well-known that there are some other factors like alcohol [23], cannabis [24] and halos [25] which can further deteriorate stereopsis.

4 Conclusion

We can conclude that the role of optical factors in stereopsis, although not studied exhaustively earlier, is essential to make a complete characterization of binocular vision. The examples given in this study proved its importance and help in clarifying the role of optics in stereopsis and binocular vision.

Acknowledgements

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