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Research Article

Binocular Interaction Measurement in Non-Strabismus Patients

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Abstract

The purpose of this study was to assess the binocular fusion values under free haploscopy in non-strabismus patients. One hundred seventy people (the age was from 20 to 60 years; objective refraction range 6.0D to +6.0D) were examined. The measurement of the binocular fusion under free haploscopy was performed in patients with physiological diplopia. To investigate the fusion and calculate the area of binocular interaction (ABI), we used the binarimeter, a diploptic device. The normative database of ABI in non-strabismus patients was presented. The mean area of ABI in emmetropic patients was 266.08 ± 99.53 cm2, in myopic patients -164.90 ± 118.60 cm2 (p < 0.001) and in hypermetropic patients -160.46 ± 126.47 cm2 (p < 0.001). The ABI was significantly correlated with accommodation amplitude, refraction value and age. We concluded that the ABI is an individual parameter and may be an indicator of neuroplasticity.

Keywords: Binocular Vision; Binocular Interaction Visual Processing; Fusion

Abbreviations

UCDVA: Uncorrected Distance Visual Acuity; UCNVA: Uncorrected Near Visual Acuity; AA: Accommodation Amplitude; PF: Proximal Fusion Border; DF: Distal Fusion Border; CF: Convergence Fusion Border; DivF: Divergence Fusion Border; ABI: Area of Binocular Interaction; L: Length of Binocular Interaction Zone; W: Width of Binocular Interaction Zone; Em: Emmetropia; M: Myopia; Hm: Hypermetropia; M: Mean Value; SD: Standard Deviation

Introduction

Binocular vision is the high point of human visual perception. The development of spatial vision and binocular fusion (sensitive period) starts in the human infant at the age of 3-4 months. Many factors determine the development of normal binocular vision. The compliance between vergence status and accommodation is the basis of normal binocularity. Normal visual development requires unimpeded and coordinated input from each eye to the visual cortex during an early critical period of cortical maturation, and the full maturation of a binocular system and the balance among all motor forces are achieved by the age of nine years [1,2]. Normal binocular development leads to progressive refinement of monocular visual acuity, stereoacuity and fusion of images from both eyes. At the end of the critical period, structural and functional brakes such as dampening of acetylcholine receptor signalling and formation of perineuronal nets limit further synaptic remodelling [3].

Normal binocularity is possible only in a condition of high visual acuity, iseikonia and bifoveal fusion. Panum's fusional area is the locus of all objects on a surface, when images either fall on corresponding retinal points in each eye or are obtained from objects close to the visual axes. The fusional area permits single perception of the object of regard, even while the motor vergence adaptation system is responding to, and controlling, any fixation disparity, and the images must be sufficiently similar in size, brightness and sharpness to permit sensory fusion [4,5]. Individuals are quite different because of their peculiarities in the visual sensory system and motor factors. Refractive disorders, retinal and neurological diseases and ageing can be accompanied by stereovision loss [6-9]. Non-strabismic accommodative and vergence dysfunctions are common vision anomalies encountered frequently and are usually associated with extensive near work [10,11]. The individual level of binocular cooperation in non-strabismus people depends on many factors, including visual acuity, contrast sensitivity, accommodation, vergence, proprioception, brain activity and so on [3,12,13].

A variety of binocular vision problems have been reported after refractive surgery, including aniseikonia related to induced anisometropia and decompensated heterophoria [14]. Binocular vision and stereoacuity should always be considered when a surgeon decides to modify the optics of the human eye [15].

The limits of bifoveal fusion in non-strabismus people have not been completely investigated yet. This is largely because the most commonly used methods aim to identify binocular anomalies in patients with strabismus. The assessment of binocular cooperation assessed by the Worth 4-dot test or synoptophore is based on the principle of rigid haploscopy, whereas the binarimeter makes it possible to investigate binocular cooperation under natural conditions without separation of the monocular vision fields, with the use of spatial visual effects when assessing for physiological diplopia [16-19]. The assessment of binocularity with the use of the binarimeter has high diagnostic significance because it can detect less-severe changes of fusion than those detected by the Worth 4-dot test or synoptophore studies in the same patients [20]. Rabichev (1998) showed that the virtual binocular image obtained with a binarimeter is a measure of binocular interaction. Later, the method of spatial reconstruction of the area of binocular interaction (ABI), which enables calculation of the area of fusional field, was proposed [21,22], but the normative database of ABI under free haploscopy in non-strabismus patients is absent.

The purpose of this study was to access the binocular fusion values under free haploscopy in non-strabismus patients.

Materials and Methods

Subjects

The study adhered to the tenets of the Helsinki Declaration and was approved by the Institution Research and Ethics Committee (protocol number 7/18 from 15/12/2018). All the patients were adequately informed and they signed a consent form; 170 people were examined. The inclusion criteria of this study were: the objective refraction from -6.0D to +6.0D, the heterophoria degree was no greater than 5 prism dioptres, the absence of ophthalmological and neurological pathology was present. The exclusion criterion were: the asthenopia, the stereoblindness, the absence of near physiological diplopia.

Measurements

All the patients underwent a full ophthalmological examination, including the evaluation of eye anatomy, visual processing and binocularity.

The refractive error was the average spherical equivalent of five cycloplegic measurements taken with an autorefractor/keratometer (KR8800, Topcon, Japan).

The Distance Visual Acuity was measured with the Bailey-Lovie logical geometric scale (phoropter Topcon, Japan) and was converted into a decimal scale.

The Amplitude of Accommodation (AA) was measured with the help of the minus lens method. The subjects were asked to fixate on an N8 target at a distance of 40 cm, and then minus lenses were introduced in 0.25 D steps until the patient reported the first sustained blur that could not be cleared by further conscious effort. This procedure was done for each eye first monocularly and then binocularly. The total AA was estimated as the endpoint value of the minus lens, with which it was possible to see the target at 40 cm under binocular conditions. The AA measurement in people with presbyopia was done with the near addition lens.

The Lang I & II stereovision test and the bifoveal fusion under free haploscopy were examined. The bifoveal fusion under free haploscopy was fixed to account for the presence of physiological diplopia; thus, we used the original device (AVIS 01, Krasnogvardeec, Russia) to investigate binocular interaction under natural conditions without the accommodation response, but with the different vergence load.

The subject's head was fixed with a chin rest. To induce physiological diplopia, we asked the patient to look in the far distance (5 m), and then we introduced a close stimulus to him or her. We fixed the subjective perception of double virtual objects (patient answered yes or no). The stimuli to be fused were represented by two round black discs 10 mm in diameter, with bars. The images were held on a chariot that could be displaced on a 1-metre-long, graduated rack. Generally, the first point of the measurement (n) was 30 cm. The chariot had rotating buttons that allowed separation of the images to be adjusted from about 20 mm to about 120 mm At first the distance between the disc centers (p) was an equal distance between the pupils. When the two images were correctly fused, the patient had to see the virtual binocular image with two aligned bars that went through the central disc (Figure 1). This virtual binocular image could lie in front of or behind the plane of single stimuli.

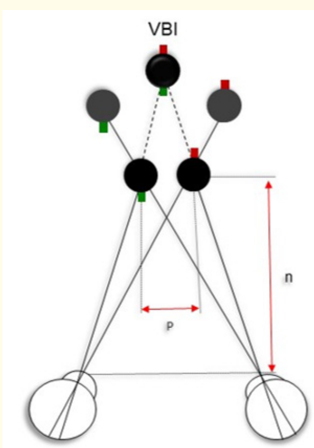

Figure 1: The perception of Virtual Binocular Image (VBI).

The change of the distance between the centres of the fusion stimuli and the distance from the eyes to the targets made it possible to define the fusion limits in space. Then the targets were moved increasingly inward and outward, to points of maximum convergence and divergence, to force a vergence response (Figure 2). The fusion stimuli were then laid on the middle distance between the maximum convergence point and the maximum divergence point, and the chariot with the targets was moved close to the patient to define the proximal border and far from the patient to define the distal border of the fusion reflex. The patient reported the visual images, which were recorded.

The following parameters were analysed:

- The Proximal Fusion (PF) border and distal fusion (DF) border were determined while two targets were at minimum and maximum distances from the eyes when the patient kept the virtual binocular image. The difference between these parameters corresponds to the Length (l) of the binocular interaction zone.
- The Convergence Fusion (CF) border and the Divergence Fusion (DivF) border were determined with the help of the decrease and increase of the distance between two targets (the point of the measurement is 40 cm from the eyes). The difference between these parameters corresponds to the Width (W) of the binocular interaction zone.
- Finally, we performed the calculation of the Area of Binocular Interaction (ABI) in cm^2 (Figure 2) with the formula:

$$ABI = L\ (in\ cm) \times W\ (in\ cm)$$

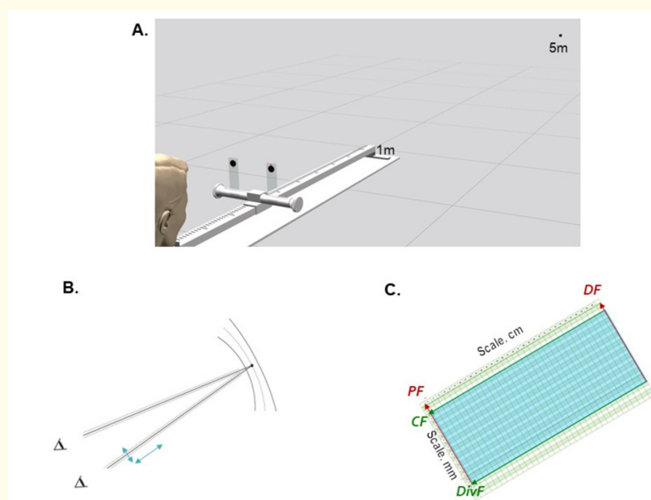

Figure 2: The method of the ABI measurement: A. - Presentation of two double stimuli for fusion; B. – stimulus presentation zone for binocular fusion; C. - schematic mapping of the binocular interaction zone. Abbreviations are presented in the text.

Statistical analysis

All the data were analysed with the help of a spreadsheet application (Statistica ver. 8.0; StatSoft Inc., USA). The statistical data were represented as the mean value ± standard deviation (M ± SD). The Shapiro-Wilk test was used for the assessment of the normality distribution. The comparison analysis (T-test), one-way ANOVA and regression models were done. The critical level of significance (p) upon the examination of statistical hypotheses was 0.05. Intraclass Correlation Coefficient (ICC) was a measure of correlation for data of repeated measurements.

Results and Discussion

General description of the study group

All the participants of this study were Caucasians; 40% were male and 60% were female. The mean age was 38.5 ± 14.9 years (range: minimum 18 years, maximum 66 years). The mean spherical equivalent of refraction was -1.06 ± 2.48 D (range: minimum -6.0 D, maximum 6.0 D). All patients had normal binocular vision without manifest eye deviations. The mean prism equivalent of distance heterophoria was -1.2 ± 0.2 PD (range: minimum -5.00 PD, maximum 5.0 PD). The monocular Best Corrected Distance Visual Acuity (BCDVA) was 0.98 ± 0.08 (range: minimum 0.90, maximum 1.2); the monocular Best Corrected Near Visual Acuity (BCNVA) was 0.88 ± 0.08 (range: minimum 0.80, maximum 1.00). The values of uncorrected visual acuity are shown in Table 1. The mean AA was 2.92 ± 2.15 D (range: minimum 0.50 D, maximum 10.00 D).

All people of the study group had binocular vision during the Worth 4-dot testing. The mean stereo test value was 1035 ± 324 sec (range: minimum 600 sec, maximum 1200 sec). Mean fusion limit values (n = 170) are presented in Table 2.

	Valid number	Mean	Min.	Max.	Std dev.	Kolmogorov-Smirnov test	
						D	P
UCDVA monocular, decimal scale	340	0.52	0.02	1.00	0.41	0.22361	<0.01
UCDVA binocular, decimal scale	170	0.62	0.05	1.20	0.42	0.21861	<0.01
UCNVA monocular, decimal scale	340	0.64	0.10	1.00	0.34	0.21111	<0.01
UCNVA binocular, decimal scale	170	0.71	0.10	1.00	0.33	0.24865	<0.01

Table 1: Vision acuity values in studied group (descriptive statistics).

	Valid number	Mean	Min.	Max.	Std Dev.	Kolmogorov-Smirnov test	
						D	P
Proximal fusion border (PF), cm	170	15.23	0	60	10.28	0.18131	<0.01
Distal fusion border (DF), cm	170	68.86	26	100	26.19	0.18206	<0.01
Convergence fusion border (CF), 10^{-1} cm	170	42.41	24	56	12.28	0.14049	<0.01
Divergence fusion border (DivF), 10^{-1} cm	170	57.35	30	68	17.87	0.17002	<0.01
Length (L) of binocular interaction zone, cm	170	51.34	1	96	29.02	0.17206	<0.01
Width (W) of binocular interaction zone, 10^{-1} cm	170	28.61	1	55	13.91	0.18267	<0.01
Area of binocular interaction (ABI), cm^2	170	176.3	6	480	136	0.10954	<0.01

Table 2: Fusion Limits of in Studied Group (Descriptive Statistics).

Repeatability of fusion parameters was determined, there was no statistically significant difference between two repeated measurements (p > 0.05). The ICC for all parameters ranged from 0.864 to 0.927.

ABI in relation to age

The ABI was significantly correlated with age (Pearson r = -0.628, P < 0.0001). The highest value in the ABI (-347.1 ± 45.9 cm^2) was in people 25-29 years old. It was statistically greater than in people 20 years old (258.1 ± 104.5 cm^2, p < 0.0001). The high level of fusion remained in the patients aged 30-34 (ABI was 327.56 ± 65.25 cm², in comparison with 20-24 year-old people p < 0.001). The 35-39 year-old people showed a decrease in the ABI that was equal to the values of the 20-24 year olds (248.25 ± 108.58 cm², p >0.05). The 40-44 year olds exhibited ABI equal 175.87 ± 73.27 cm². The people 45 years of age and older showed stable low values in ABI, with mean values less than 150 cm².

The ABI values in different age are shown in Figure 3.

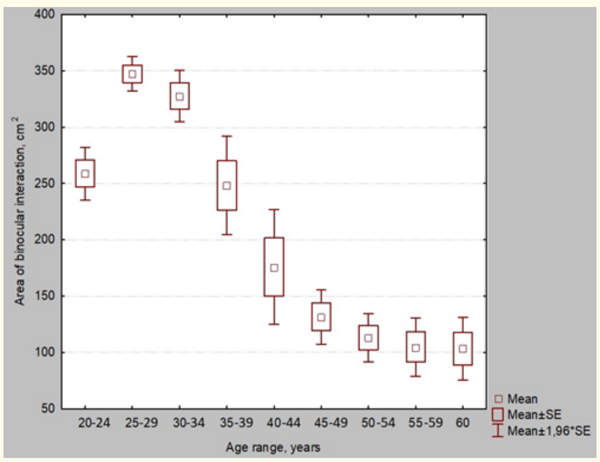

Figure 3: ABI dispersion depending on age.

ABI in relation to refraction

The ABI mean value in emmetropic patients was 266.08 ± 99.53 cm²; in myopic patients - 164.90 ± 118.60 cm² (p < 0.001); in hypermetropic patients - 160.46 ± 126.47 cm² (p < 0.001). The ABI mean value was not statistically different between the two groups of patients with myopia and hypermetropia. An extreme decrease in the ABI was revealed in patients with myopia more than 5D and in patients with hypermetropia 4D or more (Figure 4).

ABI in relation to refraction and accommodation

The relationships between the ABI value and accommodation amplitude varied in different refractive groups. The close interdependence between ABI and accommodation amplitude was estimated in all refractive groups, meanwhile the emmetropic and myopic patients had stronger relation (R = 0.80, p = 0.001 and R = 0.74, p = 0.001) than hypermetropic patients (R = 0.46, p = 0.001). The regression trends are shown in Figure 5.

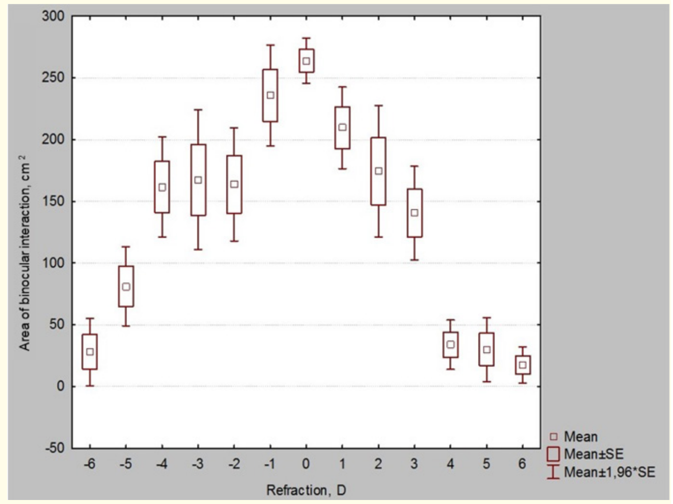

Figure 4: ABI dispersion depending on refraction.

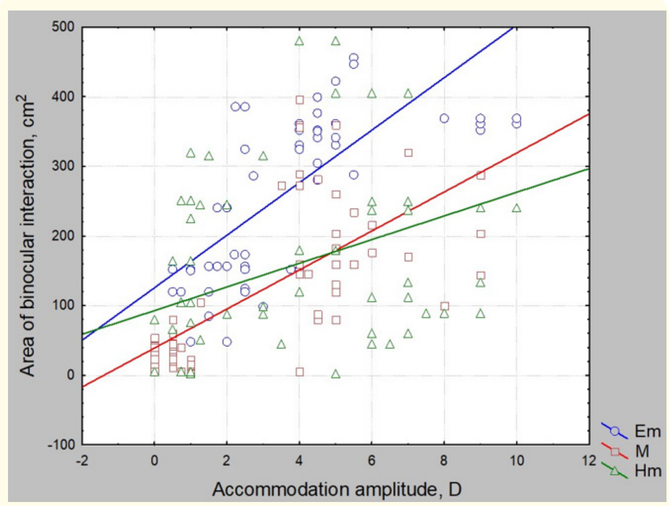

Figure 5: ABI depending on the accommodation amplitude in different refractive groups (regression analysis).

Discussion

New method of binocular interaction measurement gives the opportunity to measure the individual disparate fusion ability which have been perceived after provocation of the physiological diplopia.

In this study we presented a normative database for fusion limit values under free haploscopy in the largest cohort of non-strabismus participants. This is the first paper to report normal fusion values for all four spatial limits fixed under free haploscopy: the proximal fusion border, the distal fusion border, the convergence fusion border and divergence fusion border, the length, the width and the area of the binocular interaction zone.

The results showed that the ABI is an individual parameter and correlates with age, refraction and accommodation. According to the binocular activity, we found five life periods: the period of mature binocular vision (20-24 years), the period of peak activity (25-34 years), the period of the first decreasing signs (35-44 years), the period of decrease (45-49years) and the period of profound decrease (50 years and more). The 25-30 year-old people showed the highest ABI value. This data corresponds to the neurophysiological findings that development of higher-order visual abilities continues to mature through the young adult years [23]. The period of the peak binocularity activity (25-34 years) corresponds to the structural imaging studies of humans that show that intracortical myelination continues into the third decade of life [24-28]. People 35-39 years old developed a decrease in the fusion ability, and it can be connected to the beginning of demyelination and the slowing of processing speed [23]. The period of decrease (45-49 years) and the period of profound decrease (50 years and more) is equal to the formation of presbyopia and brain plasticity loss. In our opinion, the ABI reduction can be viewed as the result of neuroadaptation and inhibition of ambiguous visual information in visual perception deficit due to the refractive disorder and accommodation loss.

Fusion ability is a result of binocular synthesis in the brain cortex (area V1). At the same time, neurobiological studies have shown that the V1 cortical region is not only the zone that processes visual information; it is also the zone that reflects individual neuroplasticity in different periods of life [23,29-36]. So, the presented data suggest that the area of binocular interaction may be the indicator of individual brain activity. The variance of values in different life periods may be due to the peculiarities of the neurobiological mechanisms.

Our findings have shown the character of binocularity changes in non-strabismus patients in different refractive groups. Emmetropic patients had the greatest ABI value. There was a close relationship between ABI and AA in all refractive groups, but the highest regression coefficient was found in the emmetropic patients.

The results of our investigation suggest that the correction of refractive disorders in the window of good neuroplasticity may positively influence the neurobiological processes in the cortex and may be the next step in the research. Besides this, the results of the study can be helpful in refractive surgery, because patients' dissatisfaction can be connected with low binocularity and neuroplasticity. That is why the binocular status can have an effect on the outcome of refractive surgery [14,15,37,38].

The individual differences provide a large yet seldom-opened window into the mechanisms and processes underlying how we see [12]. From a clinical point of view, ABI can be considered a sign of individual neuroplasticity, but this hypothesis requires evidence.

Conclusion

New method of binocular interaction measurement gives the opportunity to measure the individual disparate fusion ability. The ABI is the fusion field have been perceived after provocation of the physiological diplopia. The normative database of binocular interaction values in non-strabismus people was presented. The ABI has significant correlations with age, refraction and accommodation.

Acknowledgements

None.

Conflict of Interest

The authors declare no conflict of interest.

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