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Relation of contrast sensitivity with binocularity, eye dominance and interpupillary distance in healthy adults

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ABSTRACT

Aim: To investigate the relationship of contrast sensitivity (CS) with binocularity, eye dominance, and interpupillary distance at various spatial frequencies in healthy adults.

Method: Thirty-seven healthy adults (age range, 19-45 years; 27 males) were included. Binocular and monocular measurements of CS were performed with Automatize ClearChart 2 test on monocular (right and left) and both eyes at low- (1.5 cpd), mid- (6 cpd), and high- (18 cpd) spatial frequencies. Eye dominance was determined with the Hole-in-card test and interpupillary distance was measured with PlusOptics photo scanner, and the results were compared statistically.

Results: Eye dominance was identified in 35 (94.59 %) subjects with the right eye being dominant in 23 (65.7%) subjects. The logarithmic CS (logCS) in the dominant eye, non-dominant eye, both eyes were 2.58±0.29, 2.62±0.37, and 2.50±0.00, respectively at 1.5 cpd; 2.54±0.16, 2.50±0.00, and 2.50±0.00, respectively at 6 cpd; and 5.46±2.49, 5.26±2.61, and 3.82±1.82, respectively at 18 cpd. The logCS did not significantly differ between dominant and non-dominant eyes. Binocular logCS was lower than monocular logCS significantly at 18 cpd (p=0.001). The interpupillary distance (mean, 58.78±3.63 mm) was not correlated with binocular logCS.

Conclusions: Dominant eye was similar to non-dominant eye in terms of CS function at all frequencies in healthy adults. No functional relationship was detected between interpupillary distance and binocular CS. Binocular CS function showed individual differences at high-spatial frequency in healthy adults.

Key words: Binocularity, contrast sensitivity, eye dominance, interpupillary distance.

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Introduction

Contrast sensitivity (CS) is defined as the ability to distinguish between light and dark in a series of bands without clear boundaries and refers to the ability to perceive minimum variations of luminance between objects and areas in daily vision [1-3]. CS specifies how much contrast an individual needs to see a target. The required contrast decreases with increasing sensitivity. CS function is different from visual acuity. It has been reported that in some diseases, CS can be affected despite normal visual acuity and that testing the peak of CS provides additional clinical benefit to standard assessment of visual acuity [1-4].

Additionally, multifocal contact lens and intraocular lens applications create a new patient group independent of visual acuity [5]. To evaluate CS correctly in patients, it is important to first of all know the normal measurement values in healthy individuals and the physiological differences that affect them. The effect of the age factor has been studied frequently and it has been reported that CS decreases with advancing age [1,2,5].

Eye dominance is defined as the tendency to prefer visual input from one eye over the visual input from the fellow eye to accomplish fixation and attention or perception functions [6,7]. The dominant eye (right eye or left eye) differs between individuals. Investigation of superiority of dominant eye (DE) is an ongoing issue. Diverse outcomes have been reported on the superiority of DE concerning visual acuity, CS, and color discrimination functions [8-11]. Although the issue of eye dominance continues to be discussed in many aspects, knowing the DE is considered critical for clinical applications such as monovision surgery [12]. Interpupillary distance (IPD) as a physiological difference is the distance between the centre of the pupils and has been associated stereopsis.

The present study aimed to evaluate and compare CS in different physiological conditions of eye (binocular and monocular conditions (right eye, left eye, DE, and non-dominant eye [NDE]) and at different spatial frequencies. Whether presence a relation between interpupillary distance (IPD) and binocular CS was also investigated. The study was conducted in the adult age group as the age factor (being young or elderly) affects visual functions and tests in healthy individuals.

Materials and methods

The present prospective, comparative study, which was conducted between November 01, 2019 and June 30, 2020 in the Health Science University Antalya Training and Research Hospital, included healthy binocular individuals (health professionals and university students) aged between ≥19 years and ≤45 years who had a best corrected visual acuity (BCVA) of 20/20 (with or without correction). Individuals were excluded from the study based on the following criteria: presence of strabismus and amblyopia, presence of a history of ocular disease or presence of any disease (systemic or neurologic) affecting vision. All participants included in the study underwent a detailed ophthalmological examination through visual acuity test and slit lamp biomicroscopy. Stereopsis was assessed by the Titmus test and a stereoacuity of 60 arcsec was accepted as the threshold value. The tests (measurements of CS and IPD and detection of ocular dominance) performed in the study were repeated three times for test reliability. The study was approved by the Clinical Research Ethics Committee of Antalya Training and Research Hospital (Approval no: 23/6; Date: 24/10/2019) and was conducted in accordance with the Helsinki Declaration of 1975, as revised in 2000. Verbal and written consents of the volunteers were obtained.

Measurement of contrast sensitivity: Assessment of CS was performed by the automatized ClearChart® 2 Digital Acuity System (Reichert Technologies®, NY, USA). The contrast value of the last image for which the subjects correctly defined the direction of sinusoidal grating patterns (vertical, left cross or right cross) having gradually decreasing contrast was recorded as the logarithmic CS (LogCS). CS increases with decreasing LogCS. CS testing was performed by a single ophthalmologist at a standard light (80 cd/m^2) and at a standard distance (6 m), under binocular and right and left monocular visual conditions, and at low- (1.5 cycles per degree [cpd]), mid- (6 cpd), and high- (18 cpd) spatial frequencies [13].

Measurement of interpupillary distance: Measurements of IPD were performed by a single ophthalmologist using the PlusOptix photo screener (PlusOptix GmbH, Nuremberg, Germany) on the horizontal axis from distance of 1 m in a dark room [14].

Detection of ocular dominance: After the examinations and measurements performed by the ophthalmologist, the subjects were referred to another researcher for detection of DE was performed by using the hole-in-card test. A 20.0x12.8 cm card with a three centimeter hole in the middle was given to the subjects and the subjects were asked to look through the hole by holding the card with two hands with the arms extended forward. After the subject stated that he/she fixed the target point at distance of 2 m looking through the hole in the middle of the card, each eye of the subject was closed alternately by the observer. The eye with which the target point continued to be seen through the hole was considered dominant [15]. When the measurements were terminated, the logCS values recorded for the left and the right eyes were also classified according to the eye dominance.

Statistical analyses: All analyses were performed using the IBM SPSS Statistics for Windows, version 25.0 (IBM Corp, Armonk, NY). The variables were expressed as mean±standard deviation and percentage and frequency. The variables were evaluated after being tested for preconditions of normality and homogeneity of variances (Shapiro-Wilk and Levene Test). Comparisons of two groups were performed using the student's t-test for variables fulfilling the preconditions for parametric tests; otherwise, Mann-Whitney U test was used. The relationship between two continuous variables was analyzed using Pearson's correlation coefficient or, if the preconditions for parametric test were not met, using Spearman's correlation coefficient. The significance level was set at $p<0.05$.

Results

The study included 37 volunteer subjects with a mean age of 25.98±7.08 years (range, 19-45 years), of whom 27 (72.97%) were male and 10 (27.03%) were female.

Table 1. The logarithmic contrast sensitivity values and interpupillary distance in the study subjects according to sex.

Parameters	Males	Females
LogCS at LSF (1.5 cpd)	n=27	n=10
RE	2.69±0.44	2.57±0.22
LE	2.56±0.29	2.5±0
DE	2.61±0.34	2.5±0
NDE	2.64±0.42	2.57±0.22
BE	2.5	2.5
LogCS at MSF (6 cpd)	n=27	n=10
RE	2.55±0.19	2.5±0
LE	2.5	2.5
DE	2.55±0.19	2.5±0
NDE	2.5	2.5
BE	2.5	2.5
LogCS at HSF (18 cpd)	n=27	n=10
RE	5.52±2.74	4.96±1.3
LE	5.63±2.74	4.9±1.55
DE	5.39±2.8	5.69±1.3
NDE	5.52±2.9	4.47±1.25
BE	4±2	3.28±0.96
IPD	59.27±3.63	57.3±3.4

LogCS, logarithmic contrast sensitivity; LSF, low-spatial frequency; MSF, mid- spatial frequency; HSF, high-spatial frequency; RE, right eye; LE, left eye; DE, dominant eye; NDE, non-dominant eye; BE, both eyes; IPD: interpupillary distance; cpd, cycles per degree.

Table 2. Monocular and binocular logarithmic contrast sensitivity measured in all subjects.

	n	LogCS at LSF 1.5 cpd	n	LogCS at MSF 6 cpd	n	LogCS at HSF 18 cpd
Right eye	37	2.66±0.39	37	2.54±0.16	37	5.38±2.47
Left eye	37	2.54±0.25	37	2.50±0.00	37	5.46±2.51
Both eyes	37	2.50±0.00	37	2.50±0.00	37	3.82±1.82
Dominant eye	35	2.58±0.29	35	2.54±0.16	35	5.46±2.50
Non-dominant	35	2.62±0.37	35	2.50±0.00	35	5.26±2.61

LogCS, logarithmic contrast sensitivity; LSF, low-spatial frequency; MSF, mid-spatial frequency; HSF, high-spatial frequency; cpd, cycles per degree.

The mean stereopsis with Titmus test was 42.56±7.70 in the subjects. The DE could not be identified in two (5.41%) subjects. Of 35 (94.59 %) subjects in whom the DE was identified, the right eye was dominant in 23 (65.71%) subjects and the left eye was dominant in 12 (34.29%) subjects.

The logCS values, which were measured at different spatial frequencies and in different ocular conditions, and the IPD values in the study subjects according to sex are demonstrated in Table 1. The logCS values did not differ between the female and male subjects in any of the conditions (p>0.05 for all; Table 1). Other comparisons of the study were made within all individuals based on this result.

The monocular and binocular logCS values measured in all study subjects are presented in Table 2. The lowest logCS values (2.5±0) indicating the maximum CS were detected at low-spatial frequency (1.5 cpd) with binocular vision and at mid-spatial frequency (6 cpd) with binocular vision, left eye vision, and NDE vision. At high-spatial frequency (18 cpd), binocular logCS values (3.8±1.81) were lower than the logCS values measured in all monocular visions.

The logCS values measured in different ocular conditions were compared (Table 3). At low-spatial frequency (1.5 cpd), binocular logCS and the left eye logCS were significantly lower than the right eye logCS (p=0.034 and p=0.02, respectively). At mid-spatial frequency (6 cpd), the logCS values did not significantly differ between the right and left eye measurements, between the DE and NDE measurements, and between the binocular measurement and any of the monocular measurements (p>0.05 for all). At high-spatial frequency (18 cpd), the mean binocular logCS value (3.82±1.82) was significantly lower than each of the monocular logCS values (right eye, left eye, DE, and NDE) (p=0.001 for each).

In the whole study group, the mean IPD was 58.78±3.63 mm and the median IPD was 58.00 mm (range, 52-66 mm). No correlation was determined between IPD and binocular logCS measured at 18 cpd (r=0.050, p=0.760).

Discussion

The present study, in which CS of healthy adults was evaluated in different ocular conditions and at different spatial frequencies, revealed that, eye dominance and IPD did not influence the CS. Binocular CS function showed individual differences at high-spatial frequency in healthy adults.

It has been reported that CS decreases with age, as does in many visual functions [1,2,16,17]. Owsley et al. measured the threshold values for CS in adults aged 20-77 years for vertical sinusoidal gratings at different spatial

Table 3. Comparisons of the logarithmic contrast sensitivity measured in different ocular conditions.

Variables	LogCS	*P* value	LogCS at LSF (1.5 cpd)				
			RE	LE	BO	DE	NDE
			2.66±0.39	2.54±0.25	2.50±0.00	2.58±0.29	2.62±0.37
RE	2.66±0.39	*p*	N/A	0.034*	0.02*	N/A	N/A
LE	2.54±0.25	*p*	0.034*	N/A	0.107	N/A	N/A
BO	2.50±0.00	*p*	0.02*	0.107	N/A	0.059	0.16
DE	2.58±0.29	*p*	N/A	N/A	0.059	N/A	0.472
NDE	2.62±0.37	*p*	N/A	N/A	0.16	0.472	N/A
LogCS at MSF (6 cpd)							
			RE	LE	BO	DE	NDE
			2.54±0.16	2.50±0.00	2.50±0.00	2.54±0.16	2.50±0.00
RE	2.54±0.16	*p*	N/A	0.16	0.16	N/A	N/A
LE	2.50±0.00	*p*	0.16	N/A	0	N/A	N/A
BO	2.50±0.00	*p*	0.16	0	N/A	0.16	0
DE	2.54±0.16	*p*	N/A	N/A	0.16	N/A	0.16
NDE	2.50±0.00	*p*	N/A	N/A	0	0.16	N/A
LogCS at HSF (18 cpd)							
			RE	LE	BO	DE	NDE
			5.38±2.47	5.46±2.51	3.82±1.82	5.46±2.49	5.26±2.61
RE	5.38±2.47	*p*	N/A	0.784	0.001**	N/A	N/A
LE	5.46±2.51	*p*	0.784	N/A	0.001†	N/A	N/A
BO	3.82±1.82	*p*	0.001†	0.001†	N/A	0.001†	0.001†
DE	5.46±2.49	*p*	N/A	N/A	0.001†	N/A	0.48
NDE	5.26±2.61	*p*	N/A	N/A	0.001†	0.48	N/A

LogCS, logarithmic contrast sensitivity; LSF, low-spatial frequency; MSF, mid-spatial frequency; HSF, high-spatial frequency; RE, right eye; LE, left eye; BE, both eyes; DE, dominant eye; NDE, non-dominant eye; cpd, cycles per degree. * Significant at $p<0.05$, † significant at $p<0.01$.

frequencies and for different real-world targets and reported that age and mid- and low-spatial frequencies were determinative for real-world targets [18]. It has been reported that CS decreases in the advanced-age group at mid- and high-spatial frequencies but is independent of age at low-spatial frequencies [3]. In the present study, this issue was paid attention and the study was carried out in healthy adults aged 19-45 years to enable investigating the effects of binocularity, eye dominancy and IPD at different spatial conditions on CS independent of age. It was observed that all subjects had maximum CS (logCS, 2.5±0.0) at low- and mid-spatial frequencies with binocular vision and with BCVA but that individual differences occurred at high-spatial frequency. Measuring CS at high-spatial frequency might provide additional clinical information to visual acuity in healthy individuals. We thought that measuring CS at high-spatial frequency might be useful for assessment of competency in professions such as pilots, soldiers, and drivers. In the present study, firstly CS was measured for the right, left and both eyes and then eye dominancy identified. The CS values measured were re-grouped according to DE and NDE. Accordingly, the study was conducted free from participant and observer biases.

In the studies on eye dominance, the reliability of the tests used to identify DE and the agreement between different tests have been the topics discussed most frequently [19]. DE can be identified using different tests grouped as motor (sighting) tests and sensory (ocular prevalence) tests [12]. The hole-in-card test is in the group of sighting tests. Seijas et al. identified the DE in 51 emmetropic subjects using sighting tests (Hole-in-card test, Pointing-a-finger test, Kaleidoscope test, and Convergence near point test) and using sensory tests (Plus 1 D distance test, Worth test, Polarized test, Distance Stereotest, and Haidinger test) [12]. They investigated the agreement between different tests in normal subjects and reported the agreement between hole-in-card test and Plus 1 D distance as 58% in young adults and as 40% in older adults. They reported a correlation between the two tests, which was not statistically significant. The agreement between hole-in-card test and Haidinger test were reported as 42.3% in the young group and as 28% in the older group. Consequently, Seijas et al. determined no statistically significant correlation between sighting tests and sensory tests [12]. Accordingly, they pointed out two striking conclusions: either there is no eye dominance or none of the tests is able to detect DE correctly [12]. On the other hand, studies have also been conducted with the novel methods that have higher reliability and identify the suppression between two eyes [20]. Johansson et al. compared the binocular sighting test, variable-angle mirror test, and hole-in-card test to identify the DE and reported that the hole-in-card test was still reliable with its limitations to be kept in mind [15]. Accordingly, the hole-in-card test remains to be the one used most widely [11,12]. In the studies in which DE was identified using the hole-in-card test, the rate of right eye dominance was reported to be 65.6% and 62.2% [15,21]. In the present study, the rate of right eye dominance was 65.7%; this finding was consistent with the results of the previous studies.

In addition to the studies reporting that DE is better in visual acuity, CS and color vision functions, there are also studies reporting different outcomes [9,10]. Pekel et al. investigated eye dominance and CS in 45 subjects aged 40-60 years and found slightly higher CS in DE with no statistical significance [11]. Yang et al. also reported that eye dominance was not reflected in the outcomes of the monocular CS measurements [20]. Both Pekel et al. and Yang et al. used the hole-in-card test to identify DE [11, 20].

It has been stated that binocular vision provides not only stereopsis but also a wide range of vision by the effect of summation and that binocular vision reduces detection threshold as compared with monocular vision [22,23]. Deficiency in CS summation has been reported in some ocular patient groups such as those with intermittent exotropia and those with multiple sclerosis with optic neuritis [24,25]. In the present study, CS was found to be higher in binocular conditions than in monocular conditions at all spatial frequencies with being significant at high-spatial frequency. Binocular CS summation might have provided more superiority at high-spatial frequency.

In the present study, IPD was measured to detect the correlation between binocular CS and IPD. There are several studies on IPD in population of Turkey. Yıldırım et al. measured IPD for distant vision (far IPD) in individuals of different age groups for assessing the effects of age factor [26]. They reported far IPD as

60.03±3.7 mm in the 20-30-year age group and as 63.0±3.6 mm in the 31-50-year age group [26]. In the present study conducted in subjects aged 19-45 years, the IPD was measured for near IPD and found as 58.78±3.63 mm. To the best of our knowledge, the relation between IPD and binocular CS in healthy adults was investigated for the first time in the present study. The results of the present study revealed no functional relationship between IPD and binocular CS.

Conclusions

Dominant eye was similar to non-dominant eye in terms of CS function at all frequencies in healthy adults. No functional relationship was detected between interpupillary distance and binocular CS. While binocular CS function with BCVA was at the highest levels at low- and mid-spatial frequencies, it showed individual differences at high-spatial frequency in healthy adults. More comprehensive studies are required to better understand the effects of binocularity, eye dominance and IPD on CS.

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