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The Relationship between Binocular Summation in Contrast Sensitivity and Stereopsis: Cross-Sectional Study

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Original Article

Abstract

Introduction: Binocular summation occurs in the presence of normal visual function of both eyes. Stereopsis is considered to be the finest function of binocular vision. Therefore, the aim of this study was to investigate the effect of binocular summation on contrast sensitivity and its relationship with stereopsis.

Materials and Methods: In this cross-sectional study, 60 students of Zahedan University of Medical Sciences, Zahedan, Iran (17 men and 43 women) with a mean age of 21.20 ± 1.45 years were selected by convenience sampling method. Monocular and binocular contrast sensitivity were measured with the best corrected vision in photopic conditions using the Metrovision test for spatial frequencies of 0.75, 1.75, 3, 6, 13, and 20 cycles per degree. Stereopsis was also measured by TNO and Titmus tests. Statistical analysis was performed using the repeated measures analysis of variance (ANOVA) and multiple linear regression.

Results: The results of repeated measures ANOVA showed that binocular vision compared to monocular vision significantly increased contrast sensitivity ($P < 0.001$). But there was no significant difference between the contrast sensitivity of right and left eyes ($P = 0.266$). Pearson corralation test did not show a significant relationship between stereopsis measured by crossed and uncrossed methods in Titmus and TNO tests with binocular contrast sensitivity at all spatial frequencies ($P = 0.114$).

Conclusion: Binocular summation in presence of normal binocular function can improve visual functions such as the increased binocular contrast sensitivity compared to monocular contrast sensitivity which confirms the importance of treating binocular anomalies such as amblyopia.

Keywords: Contrast sensitivity; Binocular vision; Monocular vision; Stereopsis; Regression analysis

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Introduction

Contrast sensitivity refers to the capability of distinguishing objects based on various contrasts (1). Contrast sensitivity is a crucial vision function that is commonly utilized in clinical examinations and research (1-5). In our daily lives, we encounter various lighting conditions, such as driving through fog or under bright sunlight, which can impact our visual abilities (3, 4). Additionally, our environment consists of objects with varying sizes and contrasts. As a result, contrast sensitivity assessment is a precise measure of our visual performance under realistic conditions, surpassing other tests like acuity (1-5).

Binocular summation is when binocular vision is superior to monocular vision, resulting in a significant improvement in acuity and contrast sensitivity (6). This depends on various factors, including the performance of each eye (7, 8), spatial frequency (9, 10), and age (11). Studies have shown that binocular summation is lower for the elderly and in the peripheral visual field (6, 12). Abnormal binocular vision may be caused by issues with the interaction between the eyes, such as fusion, which can be due to structural disorders like anisometropia or functional disorders like amblyopia (lazy eye) (13, 14). In cases of fixed strabismus, stable binocular

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vision is lacking, and there is no binocular summation. For intermittent strabismus, whether binocular vision is possible during the test interval determines binocular summation (13).

Our eyes are capable of perceiving depth and distance with great sensitivity. Stereopsis, which is the ability to distinguish between two points that are close in depth, is considered the highest function of binocular vision. This is because stereopsis combines the visual information from both eyes to create a three-dimensional view of the world around us (15). When our central vision is healthy, objects that we focus on appear clearly in the center of both eyes with very little difference in depth (16-18). Objects that are farther away from the point of focus will appear slightly shifted and closer objects will appear shifted in the opposite direction. However, our brain is able to combine these slightly different images to create a cohesive and three-dimensional view of the world. Tests for stereopsis can be done locally, using images with horizontal displacement, or globally, using random points (17). However, local tests are not always reliable as they can be affected by factors such as monocular depth perception (17). This means that a person with a lack of binocular vision, such as a clear astigmatism, may still be able to perform well on local tests. On the other hand, global tests like the TNO test do not rely on monocular depth perception and can only be performed well if a person has normal binocular vision (17, 18).

Binocular summation can occur even when individuals have normal binocular vision and minimal differences in eye function, such as no differences in binocular acuity and contrast sensitivity. Stereopsis, which is the highest level of normal binocular vision, is also involved. Previous studies have examined the relationship between binocular summation and stereopsis in individuals with eye disorders (19, 20). Research has shown a significant relationship between binocular summation and stereopsis in individuals who underwent eye surgery to correct strabismus (19). However, there has been no research on the relationship between binocular summation for contrast sensitivity at different spatial frequencies and standard stereopsis tests in healthy individuals. Therefore, the aim of this study was to investigate the relationship between stereopsis and contrast sensitivity summation among healthy individuals with normal acuity.

Materials and Methods

A cross-sectional study was conducted on students at Zahedan University of Medical Sciences, Zahedan, Iran, using convenience sampling method. Those who were interested in participating were invited to take part in the project at the entrances of the university's faculties and dormitories. The Ethics Committee of Zahedan University of Medical Sciences approved the study, which adhered to the Declaration of Helsinki for human research. Additionally, all participants were required to sign a written informed consent form. Using G*Power software version 3.1.5 (University of Düsseldorf, Düsseldorf, Germany), the sample size was estimated to be 43 individuals with a power of 0.95, alpha of 0.05, and repeated measurements taken three times (right eye, left eye, and both eyes).

To begin with, all individuals were asked to fill out general and eye health questionnaires. Eye health assessments, such as ophthalmoscopy with a direct ophthalmoscope (Heine ophthalmoscope K180, HEINE Optotechnik, Germany) and a slit lamp (Topcon slit lamp, Topcon Optical Co., Tokyo, Japan), were conducted at Al-Zahra Ophthalmology Hospital in Zahedan. Refractive errors were corrected first in all eye evaluations. Therefore, an autocrator refractometer (Topcon, type KR-1, Tokyo, Japan) was used to measure the refractive errors of all individuals, and subjective refraction was carried out to determine the best-corrected vision with chart E at a distance of 6 meters. Exclusion criteria for the study included having systemic diseases such as diabetes and high blood pressure, a history of eye surgery, eye trauma, strabismus, amblyopia, and glaucoma. Furthermore, individuals with refractive errors higher than 5 were excluded from the study due to the effects of magnifying glasses in high numbers on the results of the contrast sensitivity test (22). The inclusion criteria were complete ocular and systemic health and corrected vision of 10/10 or better.

Stereopsis Evaluation Method: To measure stereopsis with the TNO test (Lameris Instrumenten, Groenekan, The Netherlands), subjects first wore green-red glasses with correction. Then, the test screen was placed at a distance of 33 cm, so that the visual axis of the person was perpendicular to the test screen. First, the notebook was placed in the usual state (crossed disparity) and then rotated 180 degrees to create non-crossed disparity, and in this case, stereopsis was measured again and the results were recorded in seconds on the bow (17, 18). This test includes fixed points, has no monocular guidance, and consists of 7 pages, the first three pages of which are screening pages (17, 18).

In order to measure stereopsis with the Titmus test (Stereo Optical Inc., Chicago, IL, USA), which is one of the local tests, people first put on polarized glasses with correction. Then, the test plate was placed perpendicular to the glasses plate at a distance of 33 cm. First, the notebook was placed in the usual mode (crossed disparity) and then rotated 180 degrees to create non-crossed disparity; stereopsis was measured in two modes and the results were recorded in seconds. It should be noted that in all stages of the examination, the light in the room was in standard conditions (600 lux) (17, 18). Figure 1 shows how the test was performed on one of the participants.

Figure 1. How to perform the TNO (right) and Titmus (left) tests

A Metrovision device (Metrovision 2002, Monelci, France) was used to measure the contrast sensitivity with the best-corrected vision. Contrast sensitivity was measured under photopic conditions of 53.8 lux for 6 spatial frequencies of 0.75, 1.75, 3, 6, 13, and 20 cycles/degree. First, the black and white bands were shown at the lowest contrast. Then, their contrast was increased until the first place the strips were seen by the patient and the patient pressed the alarm button. This contrast level was recorded as the sensitivity for the indicated spatial frequency (23). Contrast sensitivity was recorded monocularly and binocularly in each person.

The study provided descriptive statistics in the form of mean, standard deviation (SD), mean difference, and a 95% confidence interval (CI) of the mean difference. Before analyzing the data, the Shapiro-Wilk test was conducted and it was found that the data followed a normal distribution. Therefore, the effect of binocular summation and spatial frequency on contrast sensitivity was investigated using repeated measures analysis of variance (ANOVA). To compare the effect of monocular and binocular vision on contrast sensitivity, a pairwise comparison with Bonferroni correction was performed. Additionally, Pearson's correlation test was used to examine the relationship between depth of vision and binocular contrast sensitivity. Lastly, paired t-test was utilized to compare the refractive errors of the two eyes. The data were analyzed using SPSS software (version 16, SPSS Inc., Chicago, IL, USA). A significance level was considered P < 0.05.

Results

Among the 62 students who came to the hospital through the call, all had perfect systemic and eye health, and only 2 had a refractive error above 5. Thus, 60 students of Zahedan University of Medical Sciences (17 men and 43 women) with an average age of 21.20 ± 1.45 years were selected. The average refractive errors of the right and left eyes of the participants are shown in table 1.

Table 1. Average refractive errors in the right and left eyes

Refractive error	Right eye	Left eye	P*
Sphere (diopter)	-0.54 ± 1.07	-0.55 ± 1.10	0.788
Cylinder (diopter)	-0.19 ± 0.26	-0.25 ± 0.32	0.092
Equivalent sphere	-0.63 ± 1.09	-0.67 ± 0.10	0.198

*Significant at P < 0.05 level
Data are reported as mean ± standard deviation (SD)

Based on the results of the paired t-test, there was no significant difference in the refractive errors of the right and left eyes (P > 0.050). In addition, based on the results of previous studies (24), the results of the tests examined in this research were not affected by the gender of the participants.

Figure 2 shows the average contrast sensitivity in different spatial frequencies in monocular and binocular mode.

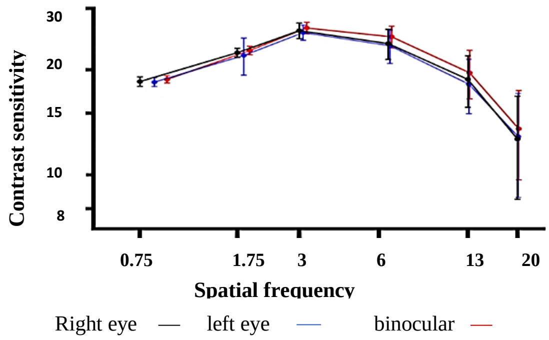

Figure 2. Average contrast sensitivity in right and left eyes and binoculars

The results of repeated measures ANOVA showed that spatial frequency had a significant effect on contrast sensitivity (P < 0.001). Paired t-test with Bonferroni correction indicated that contrast sensitivity was different in all spatial frequencies (P < 0.001). Moreover, binocular vision compared to monocular vision significantly increased contrast sensitivity (difference between binocular vision and monocular vision: P < 0.001, mean difference: 0.635 with 95% CI: 0.298-1.010), but no significant difference was observed between the contrast sensitivity of the right and left eyes (P = 0.266, mean difference: 0.253 with 95% CI: -0.107-0.612). The interaction of binocular summation with spatial frequency on contrast sensitivity was significant (P = 0.023); this means that the increase in binocular contrast sensitivity was different in different spatial frequencies.

Table 2 shows the average depth of vision in two types of measurement tests in crossed and non-crossed mode. Based on the results, there was no difference between crossed and non-crossed stereopsis (P = 0.479, mean difference: 1.83, 95% CI: 3.31-6.98), but a significant difference between stereopsis measured by the Titmus and TNO tests (P = 0.001, mean difference: 38.58, 95% CI: 15.90-61.25).

Table 2. The average depth of vision (crossed and non-crossed mode)

Test	Cross-over (arcsec)	Non-crossover (arcsec)	P
TNO	80.25 ± 9.76	83.25 ± 10.72	0.159
Titmus	42.83 ± 4.96	43.50 ± 5.27	0.556
P value	0.003*	0.001*	

*Significant at P < 0.05 level
Data are reported as mean ± standard deviation (SD)

Pearson's correlation test did not show a significant correlation between stereopsis measured by crossed and non-crossed methods in Titmus and TNO tests with binocular contrast sensitivity in any of the spatial frequencies (P = 0.114).

Discussion

The current research found that binocular summation of contrast sensitivity had a greater impact on stereopsis (the highest-level vision function) compared to monocular summation. However, the study did not report a significant relationship between binocular contrast sensitivity and stereopsis in healthy individuals. This study aimed to explore the correlation between binocular summation and stereopsis in normal subjects using two different stereopsis tests, which had not been previously studied. It is important to note that previous research has shown that binocular summation is superior to monocular vision. However, the present study discovered a new finding in healthy individuals, which is the lack of relationship between stereopsis and binocular contrast sensitivity.

The present study found that binocular contrast sensitivity was superior and increased compared to monocular contrast sensitivity, which is consistent with previous research (6-8). Previous studies have also shown binocular summation even when there is no difference in binocular vision (6, 12, 23). However, this study did not investigate this issue because all participants had normal binocular vision according to the inclusion criteria. It is important to note that if there is a significant difference in contrast sensitivity between the two eyes, binocular summation may not occur and binocular contrast sensitivity may even be lower than monocular vision (7-9). While the participants in this study were not amblyopic, the goal of treating lazy eye is to equalize binocular vision. The results showed that if binocular vision was equalized, binocular summation would occur and performance would be improved. This highlights the importance of treating lazy eyes and equalizing visual function in both eyes. Patients with lazy eyes can benefit from the advantage of binocular vision, which improves performance compared to monocular vision.

From the information presented in figure 1, it is observed that binocular contrast sensitivity is more effective than monocular sensitivity at higher spatial frequencies (above 6 cycles/degree) compared to lower ones (0.7, 0.75, and 1.75 cycles/degree). This suggests that the impact of binocular summation on contrast sensitivity is greater at high spatial frequencies than at low ones. However, in a different study, the impact of binocular summation on spatial frequency was only observed in older people, where at 1 cycle/degree, binocular summation was better than at 6 cycles/degree (11). This difference could be attributed to the equal vision of the participants' eyes in the present study and the variations in the contrast sensitivity test carried out in both studies. It is essential to conduct further studies at different ages with varying degrees of difference between the visions of both eyes to investigate the dependence of binocular summation on spatial frequency.

The result of this study revealed a significant difference in stereopsis measured by the TNO and Titmus tests, but there was no significant difference between the measured values of crossed and non-crossed stereopsis in the two types of tests, which is in line with the findings of Momeni-Moghaddam et al. (18). When evaluating stereopsis in patients experiencing binocular vision symptoms, no distinction was found between crossed and non-crossed stereopsis. Additionally, the mean stereopsis measured during the TNO test was greater than that of the Titmus test (18).

In this study, no significant correlation was found between binocular contrast sensitivity and stereopsis. Previous research on individuals with cataracts has shown that undergoing surgery can improve contrast sensitivity, depth of vision, and overall quality of life (25). While previous studies have indicated that increasing contrast sensitivity in both eyes can improve depth of vision, the lack of significant correlation between binocular contrast sensitivity and stereopsis in this study may be due to all participants having 10/10 or better vision. It appears that the lack of correlation between contrast sensitivity and stereopsis may be due to the fact that there was no significant difference in contrast sensitivity between the two eyes. This is because when there is a dissimilarity in contrast sensitivity between the two eyes, such as in cases of cataracts (7), lazy eye (13, 26) or age-related macular degeneration (8), binocular contrast sensitivity may be poorer than monocular contrast sensitivity in the better eye. As a result, binocular summation decreases as the difference in contrast sensitivity between the two eyes increases (26). The unequal performance of the two eyes can have an impact on binocular vision abilities, such as stereopsis. Previous studies have demonstrated that as one ages and the eye's media become more opaque and asymmetric cataracts develop in both eyes, stereopsis declines (15, 27). Therefore, future research should focus on evaluating individuals with functional differences between their eyes, such as lazy eyes or anisometropia, to obtain a more precise assessment of the correlation between binocular contrast sensitivity and stereopsis.

Limitations

A limitation of the current study was that it did not include patients with various levels of binocular vision disorder, such as lazy eye and anisometropia. As a result, it was not possible to compare their results with those of individuals with normal binocular vision.

Recommendations

To further explore the correlation between stereopsis and binocular contrast sensitivity, it is recommended to conduct a study involving patients who exhibit varying levels of visual function in each eye, such as patients with anisometropia and lazy eye. This would allow for a comparison and statistical analysis to be made between this group of patients and healthy individuals.

Conclusion

Previous studies have explored the link between binocular summation and stereopsis in individuals with binocular vision disorders. However, the current study aimed to investigate this connection in healthy individuals. The results showed that individuals with normal binocular vision had higher binocular contrast sensitivity compared to monocular contrast sensitivity. Nevertheless, the study did not find a significant association between binocular vision and stereopsis. These findings highlight the importance of treating patients with visual dysfunction between both eyes, such as lazy eyes, as an increase in binocular contrast sensitivity was observed.

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Authors' Contribution

Study design and ideation: Monireh Mahjoob
Getting financial resources for the study: Monireh Mahjoob
Scientific and executive support of the study: Monireh Mahjoob, Farkhondeh Shahri
Data collection: Monireh Mahjoob, Farkhondeh Shahri
Analysis and interpretation of the results: Monireh Mahjoob
Specialized statistics services: Monireh Mahjoob
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Conflict of Interest

The authors declare that they have no conflict of interest.

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