· Clinical Research ·

Effect of astigmatism and spherical equivalent correction on contrast sensitivity

Maryam Saffarizadeh[1], Saeed Rahmani[1], Alireza Akbarzadeh Baghban[2], Mohammad Ghassemi-Broumand[1]

[1]Department of Optometry, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran 1616913111, Iran
[2]Proteomics Research Center, Department of Biostatistics, School of Allied Medical Sciences, Shahid Beheshti University of Medical Sciences, Tehran 1971653313, Iran
Correspondence to: Saeed Rahmani. Department of Optometry, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran 1616913111, Iran. medicalopto@yahoo.com
Received: 2024-01-30 Accepted: 2024-06-24

Abstract
● **AIM:** To investigate the effect of astigmatism and spherical equivalent (SE) correction on contrast sensitivity (CS).
● **METHODS:** In this cross-sectional study, 103 visually normal subjects aged 18 to 36y with bilateral regular astigmatism in range of 1.00 diopter cylinder (DC) to 4.00 DC and normal best-corrected visual acuity (20/20) were recruited. Binocular CS was assessed by linear sine-wave gratings at 1.5, 3, 6, 12, and 18 cycles per degree (cpd), before correction of astigmatism, after full correction of astigmatism by cylindrical spectacle lenses, and after SE of refractive error. The repeated measures ANOVA and Bonferroni test were used to compare the effects of astigmatism correction on logCS.
● **RESULTS:** Totally 39 patients were male and 64 patients were female with the mean age of 28.25±5.38y. The average degree of astigmatism in right and left eye was 2.03±0.83 and 2.10±0.78, respectively. Increases in uncorrected astigmatic power correlated with decreases in the logCS, especially at high spatial frequencies. A statistically significant difference in logCS was found between these three cases: before correction of astigmatism, after SE of refractive error, and after full correction of astigmatism by cylindrical spectacle lenses at all frequencies ($P<0.001$), except at 18 cpd. At 18 cpd, there was no statistically significant difference between logCS before and after SE of refractive error ($P=1.0$). Also, there was no statistically significant difference in mean CS between with-the-rule (WTR) and against-the-rule (ATR) astigmatism, before correction of astigmatism, after correction of astigmatism with cylindrical lenses, and after SE of refractive error.
● **CONCLUSION:** Binocular astigmatism defocus decreases CS depending on the degree of astigmatism power; correction of this will improve patent's quality of vision. Although high astigmatism refractive error (more than 2.00 DC) that is fully corrected by cylindrical spectacle lenses doesn't increase the CS to the maximum value, especially at higher spatial frequencies (12 and 18). Also SE refractive error effects on improving CS in low astigmatism power (less than 2.00 DC), especially at lower spatial frequencies.
● **KEYWORDS:** astigmatism; contrast sensitivity; spherical equivalent
DOI:10.18240/ijo.2024.12.12

Citation: Saffarizadeh M, Rahmani S, Akbarzadeh Baghban A, Ghassemi-Broumand M. Effect of astigmatism and spherical equivalent correction on contrast sensitivity. *Int J Ophthalmol* 2024;17(12):2243-2247

INTRODUCTION
Astigmatism is one of the most common refractive errors, worldwide[1]. The major source of astigmatism is the anterior surface of the cornea. This could also be due to the posterior surface of the cornea or the crystalline lenses. Uncorrected astigmatism leads to blurring of the retinal image and can cause a significant decrease in visual performance and a wide range of visual difficulties[2]. When a patient cannot tolerate an astigmatism prescription spherical equivalent (SE), may be helpful[3].

Measuring contrast sensitivity (CS) helps the clinician understand the patient's complaint of poor vision, especially when the patient's visual acuity is normal. Impaired CS is associated with a range of visual performance problems, including problems with movement, reading, driving (especially at night), the ability to recognize people's faces, and a range of daily tasks such as using tools and finding objects[4-5]. Measuring CS is different from measuring visual acuity. Nowadays, visual acuity tests such as Snellen test are

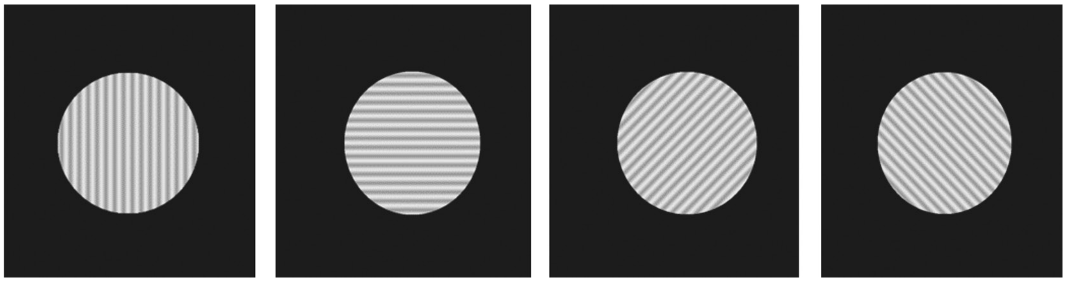

Figure 1 The images for spatial frequencies at different direction were used in this study.

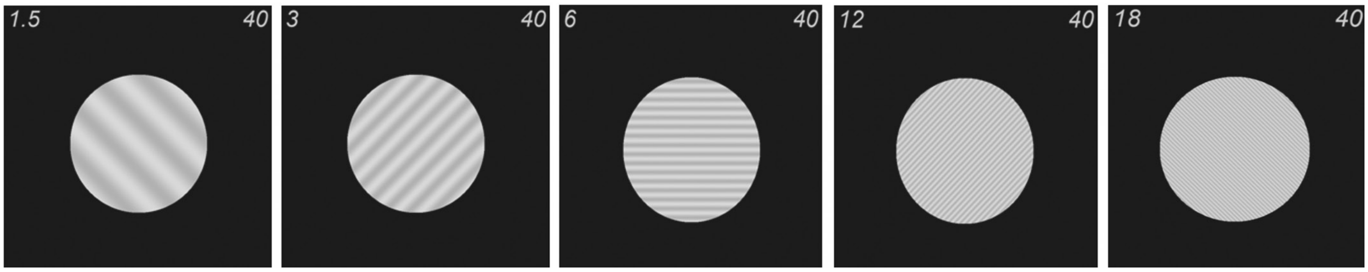

Figure 2 The different spatial frequencies of contrast sensitivity (1.5, 3, 6, 12, and 18 cpd) used in this study.

widely used to evaluate patient's vision in optometric clinics. But the visual acuity test only measures patient's visual quantity and it does not evaluate the visual function in daily life[6].

While previous studies have usually investigated the effect of induced astigmatism on CS, the purpose of this study is to investigate the real effect of astigmatism refractive error and its correction by cylindrical lenses and its SE on CS function.

PARTICIPANTS AND METHODS

Ethical Approval This study was carried out in accordance with the tenets of the Declaration of Helsinki and was approved by the Ethics Committee of the University (Approval number: IR.SBMU.RETECH.REC.1400.1192). A written informed consent was obtained from all participants.

Study Population In this cross-sectional study, 103 patients (39 males and 64 females) were assessed. All patients had regular astigmatism range -1.00 diopter cylinder (DC) to -4.00 DC with no more than 1.00 DC aniso-astigmatism between the two eyes. Those patients whose type of astigmatism (with or against the rule) was the same in their both eyes were assessed and all the patients should have worn their correction regularly during the previous 6mo. The inclusion criteria for this study were corrected distance visual acuity of 20/20 or better, less than 5.00 diopters of spherical refraction, and age between 18 to 45y. Exclusion criteria considered in this study were any corneal irregularity, binocular problems, amblyopia, presence of ocular diseases, and a history of intraocular or corneal surgery.

Patient Examinations After obtaining the consent of the patients to participate in the study, they underwent comprehensive routine ophthalmic examinations including uncorrected visual acuity (UCVA), monocular and binocular distance best-corrected visual acuity (BCVA), slit-lamp examination, fundus examination, refractive error measurement, corneal topography, and binocular investigations.

Astigmatism value was measured using TOPCON RM8900 (Tokyo, Japan) Auto refractometer. Astigmatic eyes were divided into 3 groups, based on the astigmatism power: group 1 or low astigmatism (-1.00 to -1.75 DC); group 2 or medium astigmatism (-2.00 to -2.75 DC); and group 3 or high astigmatism (-3.00 to -4.00 DC). Also, we investigated CS in patients who have either with-the-rule astigmatism (WTR), or against-the-rule astigmatism (ATR), in two separate groups.

Contrast Sensitivity Measurement For measuring contrast sensitivity function (CSF), linear sine-wave grating test (M&S Technologies, http://www.mstechmstecheyes.com/) was used. CSF was tested using a four-alternative forced-choice (vertical, tilted right, horizontal, or tilted left; Figure 1) and five spatial frequencies were assessed: 1.5, 3, 6, 12, and 18 cycles per degree (cpd) at 3 m distance (Figure 2). First, we started asking 1.5 cpd, and then other spatial frequencies (SF) were checked, respectively. Demonstration time for each target was between 5 to 10s. In each SF, contrast was reduced progressively (maximum 100%, logCS: 0 and minimum 0.8%, logCS: 2.09). The lowest contrast level that its direction was detected by the patient was recorded separately for each SF in logarithm unit (logCS).

In the first step, the patient's refractive error was corrected in form of SE. In the second step, the farsightedness or nearsightedness of the patient was completely corrected by spherical lenses, and the patient's astigmatism was completely corrected by cylindrical lenses. CS was evaluated in each step binocularly.

Table 1 Comparison of logCS before and after correction of astigmatism in different spatial frequencies

Parameters	Before astigmatism correction	After SE of refractive error	Full correction of astigmatism by cylinder	P^a
1.5 cpd				<0.001
Low	1.93±0.25	2.01±0.17	2.08±0.04	
Medium	1.75±0.29	1.86±0.25	2.07±0.05	
High	1.76±0.28	1.84±0.27	2.05±0.13	
Total	1.84±0.28	1.93±0.23	2.07±0.07	
3 cpd				<0.001
Low	1.86±0.34	1.97±0.20	2.08±0.03	
Medium	1.67±0.36	1.75±0.35	2.07±0.04	
High	1.59±0.34	1.65±0.34	2.05±0.13	
Total	1.75±0.36	1.84±0.31	2.07±0.07	
6 cpd				<0.001
Low	1.51±0.35	1.62±0.31	1.97±0.21	
Medium	1.32±0.36	1.40±0.35	1.89±0.25	
High	1.14±0.27	1.18±0.29	1.84±0.31	
Total	1.38±0.36	1.47±0.36	1.92±0.25	
12 cpd				<0.001
Low	0.92±0.30	1.0±0.28	1.35±0.32	
Medium	0.78±0.33	0.81±0.34	1.19±30	
High	0.62±0.31	0.65±0.32	1.06±0.37	
Total	0.82±0.33	0.88±0.33	1.24±0.34	
18 cpd				<0.001
Low	0.47±0.27	0.56±0.26	0.92±0.26	
Medium	0.44±0.38	0.40±0.22	0.84±0.24	
High	0.47±0.27	0.56±0.26	0.92±0.26	
Total	0.42±0.31	0.45±0.28	0.85±0.29	

Cpd: Cycle per degree. [a]Measure test (before and after 2 form of correction).

Statistical Analysis Data were analyzed using Statistical Package for Social Sciences (IBM SPSS version 26; IBM, Armonk, New York, USA). To compare the effects of astigmatism correction by cylindrical lenses and SE of refractive error at each SF on logCS, repeated measures ANOVA and Bonferroni pairwise comparisons were used. Also, independent *t*-test was used to compare mean CS between WTR and ATR astigmatism. $P<0.05$ was considered statistically significant.

RESULTS

Of 103 examined patients, 39 patients were male and 64 patients were female with the mean age of 28.25±5.38y. Totally 79 patients (76.7%) had with the rule (WTR) astigmatism and 24 patients (23.3%) had against the rule (ATR) astigmatism. Also 52 participants (50.5%) had low astigmatism, 20 participants (30.1%) had medium astigmatism, and 20 participants (19.4%) had high astigmatism. The mean of astigmatism power in the right and left eyes were 2.03±0.83 and 2.10±0.78, respectively.

The average degree of CS in each SF and in all 3 groups of astigmatism severity are mentioned in Table 1. Based on Table 1, as the power of astigmatism increases, its effect on CS also increases.

The results of the repeated measure test to evaluate mean CS, before and after astigmatism correction and after SE of refractive error in each SF has shown that in all SF a significant difference has been observed between the mean CS before and after astigmatism correction by cylindrical lenses and after SE of refractive error in all astigmatism severities ($P<0.001$). Also, there was a significant difference in the mean CS among all 3 groups of astigmatism severity ($P<0.05$).

Based on Figure 3, CS has been improved after SE of refractive error in SF of 6 cpd (right), but has been deteriorated after SE of refractive error in SF of 18 cpd (left). After full correction of astigmatism by cylindrical lenses, CS was improved in both frequencies. The diagram for SF 1.5 and 3 cpd was similar to diagram for 6 cpd, and the diagram for SF 12 cpd was similar to diagram for SF 18.

Furthermore, the result of the paired comparison Bonferroni test of logCS before and after astigmatism correction by cylindrical lenses or SE of refractive error showed that a statistically significant difference was found between logCS before correction of astigmatism, after SE of refractive error, and after full correction of astigmatism by cylindrical spectacle lenses in all spatial frequencies ($P<0.001$), except at 18 cpd. At

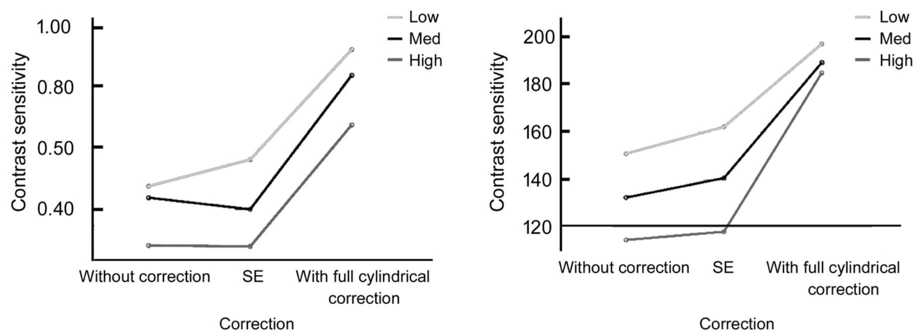

Figure 3 Changes of CS in spatial frequencies of 6 and 18 cpd after spherical equivalent of refractive error and after full correction of astigmatism by cylindrical lenses CS: Contrast sensitivity.

18 cpd, there was no statistically significant difference between logCS before and after SE of refractive error (*P*=1.0).

Additionally, there was no statistically significant difference between mean CS in WTR or ATR astigmatism in all the SF before correction of astigmatism, after SE of refractive error, and after full correction of astigmatism by cylindrical lenses (*P*>0.001).

DISCUSSION

In this study, under the presence of binocular astigmatic defocus, binocular CS was assessed before and after correction of astigmatism by cylindrical lenses and also after SE of refractive error.

The results of this study have shown that uncorrected astigmatism will reduce CS in all SF; but the more the power of astigmatism increases, the more the lower SF are affected—the reason may be due to the distortion and defocus image on the retina. These findings support previous studies which showed that uncorrected astigmatism reduced CS[7-9]. In addition, CS at all SF, was less than maximum value (2.09 logCS) before correction of astigmatism and after SE of refractive error. Also, at higher SF (6, 12, and 18), CS did not reach to 2.09 logCS after full astigmatism correction by cylindrical lenses.

Astigmatism refractive error that was corrected by cylindrical lenses affected CS spatially at higher frequencies (12 and 18); therefore, patients with astigmatism refractive error who their astigmatism was corrected by cylindrical spectacle lenses may have some difficulties in low contrast environments. To the best of our knowledge, this is the first study that investigates the effect of corrected astigmatism on CS. In the study by Savini *et al*[10] normative values of mean CS in healthy subjects with minor refractive error have been reported. They used Vison Chart (CSO) for measuring CS. The normative values in SF of 1.5, 3, 6, 12, and 18 cpd was 2.25, 2.25, 2.25, 2.09, and 1.84 in log units, respectively. Comparing the results of that study with the results of the current one shows that mean CS, before astigmatism correction, was lower than normative value in all SF and also, mean CS has not reached to the maximum value after full correction of astigmatism by cylindrical lenses in SF of 12 and 18 cpd.

Several studies have proved that astigmatic defocus results in reductions in far and near visual acuity and different visual functions like reading performance, night driving, and stereo acuity[11-14]. Previous studies have investigated the relationship between CS and refractive errors. Based on these studies, CS has been reduced when myopia or hyperopia are present[15-17]. Also, several studies investigated the effects of induced astigmatism on CS, but in most of these studies, astigmatism was induced artificially by placing cylindrical lenses in front of the eyes- which may disturb the results. Also, there has been no research on the effect of astigmatism refractive error that is corrected by cylindrical lenses and SE of refractive error on CS. In this study, we investigated the effects of patient's astigmatism before and after correction by cylindrical spectacle lenses and also the effects of SE of refractive error on CS. The results of this study may provide evidence for the progress of clinical guidelines for astigmatism correction.

SE refractive error will improve CS in lower spatial frequencies and in low degrees of astigmatism. For example, SE of refractive error improves CS at SF of 1.5, 3, and 6 cpd, but in frequency of 18 cpd, CS has been deteriorated after SE by spherical lenses, especially in moderate to high degrees of astigmatism power (2.75 cpd or more). So, SE of refractive error will effect on improving CS in lower astigmatism power.

Also, our findings have shown that there was no significant difference between WTR and ATR astigmatism in mean CS before and after astigmatism correction and after SE of refractive error by using the sinusoidal gratings test. In other word, CS is affected by astigmatism refractive error, and these effects do not have a strong axis orientation dependence. Some studies reported the same results. For instance, Watanabe *et al*[14] reported that ATR and WTR astigmatism reduced CS equally by using the low contrast visual acuity chart. In another study, Bradley *et al*[18] reported that differences in CS between WTR and ATR astigmatism were present when using Pelli-

Robson low contrast letter chart; but there was no difference in CS between WTR and ATR astigmatism by using Vistech CS grating chart. Wolffsohn *et al*[8] also reported that binocular ATR astigmatism reduced CS more than WTR astigmatism by using low contrast visual acuity chart. Similarly, Hasegawa *et al*[7] reported that by using the OPTEC 6500 Vision Tester (grating test), binocular ATR astigmatism deteriorates CS more than WTR astigmatism. Accordingly, the different results may due to the CS chart characteristics. To our knowledge, this is the first study in which the astigmatism axis had no effect on CS functions by using the grating test. Also, this is the first study in which the astigmatism was not induced by cylindrical lenses. So, it's possible that the difference in CS between two types of astigmatism, in previous studies, is related to the cylindrical lenses that has been used to induce astigmatism.

This article has two strengths: one is using true astigmatism, rather than simulated one, the other is considering the adaptation period to corrective cylindrical lenses. And also, our study had some limitations. First, we didn't investigate the effects of astigmatism with oblique axis (*i.e.* negative cylinder axis between 30 and 60 or 120 and 150 degrees), due to the presence of corneal irregularities in most cases with this type of astigmatism. Second, we didn't investigate the effects of pupil size and other ocular aberrations that are known to effect on visual acuity of astigmatism patients, on CS[19-20]. Future studies need to be conducted with a larger sample size, with a wider range of cylindrical powers, and in astigmatism with oblique axis.

In conclusions, uncorrected astigmatism of 1.00 DC or more results in reduction in CS, and correction of astigmatism by cylindrical spectacle lenses increases the quality of vision. In patients with high degrees of astigmatism refractive error, CS has not reached to maximum values, especially at higher frequencies, even after full correction by cylindrical spectacle lenses. So, the effect of other methods of astigmatism correction, for example gas permeable or soft toric contact lenses, on CS needs to be investigated in future studies.

ACKNOWLEDGEMENTS

Conflicts of Interest: Saffarizadeh M, None; **Rahmani S,** None; **Akbarzadeh Baghban A,** None; **Ghassemi-Broumand M,** None.

REFERENCES

1 Kanclerz P, Bazylczyk N, Lanca C. The prevalence of astigmatism and spectacle wear in Polish schoolchildren. *J Binocul Vis Ocul Motil* 2023;73(4):124-130.

2 Read SA, Vincent SJ, Collins MJ. The visual and functional impacts of astigmatism and its clinical management. *Ophthalmic Physiol Opt* 2014;34(3):267-294.

3 Enaholo ES, Musa MJ, Zeppieri M. The spherical equivalent. 2023 May 11. In: *StatPearls*. Treasure Island (FL): StatPearls Publishing; 2024.

4 Owsley C. Contrast sensitivity. *Ophthalmol Clin North Am* 2003;16(2): 171-177.

5 Liu LL, Gong LP, Xu YY, Zhu X, Chen KK, Liu WF. Relationship between contrast sensitivity and corneal shape following overnight orthokeratology. *Int J Ophthalmol* 2019;12(2):275-279.

6 Ginsburg AP. Contrast sensitivity and functional vision. *Int Ophthalmol Clin* 2003;43(2):5-15.

7 Hasegawa Y, Hiraoka T, Nakano S, Okamoto F, Oshika T. Effects of astigmatic defocus on binocular contrast sensitivity. *PLoS One* 2018;13(8):e0202340.

8 Wolffsohn JS, Bhogal G, Shah S. Effect of uncorrected astigmatism on vision. *J Cataract Refract Surg* 2011;37(3):454-460.

9 Atchison DA, Mathur A. Visual acuity with astigmatic blur. *Optom Vis Sci* 2011;88(7):E798-805.

10 Savini G, Calossi A, Schiano-Lomoriello D, Barboni P. Precision and normative values of a new computerized chart for contrast sensitivity testing. *Sci Rep* 2019;9(1):16537.

11 Wills J, Gillett R, Eastwell E, Abraham R, Coffey K, Webber A, Wood J. Effect of simulated astigmatic refractive error on reading performance in the young. *Optom Vis Sci* 2012;89(3):271-276.

12 Black AA, Wood JM, Colorado LH, Collins MJ. The impact of uncorrected astigmatism on night driving performance. *Ophthalmic Physiol Opt* 2019;39(5):350-357.

13 Kobashi H, Kamiya K, Shimizu K, Kawamorita T, Uozato H. Effect of axis orientation on visual performance in astigmatic eyes. *J Cataract Refract Surg* 2012;38(8):1352-1359.

14 Watanabe K, Negishi K, Kawai M, Torii H, Kaido M, Tsubota K. Effect of experimentally induced astigmatism on functional, conventional, and low-contrast visual acuity. *J Refract Surg* 2013;29(1):19-24.

15 Karatepe AS, Köse S, Eğrilmez S. Factors affecting contrast sensitivity in healthy individuals: a pilot study. *Turk J Ophthalmol* 2017;47(2): 80-84.

16 Hashemi H, Khabazkhoob M, Jafarzadehpur E, Emamian MH, Shariati M, Fotouhi A. Contrast sensitivity evaluation in a population-based study in Shahroud, Iran. *Ophthalmology* 2012;119(3):541-546.

17 Wang JF, Liu XT, Huang J, Deng RY, Zhao SJ, Chen YL, Chen ZH, Wang YL, Rong Y, Liu Q, Qu J, Mao XJ. Reduced contrast sensitivity function is correlated with changes to cone photoreceptors in simple high myopia. *Front Neurosci* 2024;18:1274651.

18 Bradley A, Thomas T, Kalaher M, Hoerres M. Effects of spherical and astigmatic defocus on acuity and contrast sensitivity: a comparison of three clinical charts. *Optom Vis Sci* 1991;68(6):418-426.

19 Kamiya K, Kobashi H, Shimizu K, Kawamorita T, Uozato H. Effect of pupil size on uncorrected visual acuity in astigmatic eyes. *Br J Ophthalmol* 2012;96(2):267-270.

20 de Gracia P, Dorronsoro C, Marin G, Hernández M, Marcos S. Visual acuity under combined astigmatism and coma: optical and neural adaptation effects. *J Vis* 2011;11(2):5.