· Clinical Research ·

Effect of polarized sunglasses on visual functions

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Received: 2025-03-04 Accepted: 2025-08-25

Abstract
● **AIM:** To evaluate the effects of polarized and non-polarized sunglasses on visual functions, including distance and near visual acuity, phoria, stereopsis and contrast sensitivity across five spatial frequencies (1.5, 3, 6, 12, 18 cycles/degree).
● **METHODS:** A before-after study was conducted on 45 emmetropic students from Shahid Beheshti University of Medical Sciences. Visual acuity, contrast sensitivity, stereopsis and phoria were measured under three conditions: without sunglasses, with non-polarized sunglasses and with polarized sunglasses. Tests were conducted under controlled glare conditions to simulate outdoor environments.
● **RESULTS:** A total of 45 participants were evaluated, comprising 17 males (37.8%) and 28 females (62.2%). The mean age was 21.67±2.31y (range 18-27y). The mean of distance and near visual acuity in all three conditions were equal to 0.00 logMAR. Contrast sensitivity generally decreased slightly with the use of non-polarized sunglasses compared to the no-sunglasses condition. The mean stereopsis with polarized sunglasses was 101.33±56.139 arc sec, which was worse than the no-sunglasses condition (94.33±46.632 arc sec) and better than the non-polarized sunglasses condition (105.67±58.965 arc sec), although these changes were not significant. In the phoria parameter, distance phoria appeared more affected than near phoria.
● **CONCLUSION:** Polarized and non-polarized sunglasses do not significantly affect visual acuity, stereopsis, or phoria under controlled glare conditions. Slight changes in contrast sensitivity are noted, but they are not statistically significant.

● **KEYWORDS:** sunglasses; polarization; visual acuity; phoria; stereopsis; contrast sensitivity
DOI:10.18240/ijo.2025.12.14

Citation: Ebrahimi F, Kangari H, Akbarzadeh-Bagheban A, Rahmani S. Effect of polarized sunglasses on visual functions. *Int J Ophthalmol* 2025;18(12):2325-2330

INTRODUCTION

Light, a transverse electromagnetic wave contains wide range wavelengths, comprises electric and magnetic fields oscillating perpendicular to its direction of propagation. The orientation of the electric field determines the polarization of light[1-3]. Typically, light waves oscillate randomly in various directions, resulting in unpolarized or natural light[1,4-5]. The waves are filtered to align and vibrate in a single plane, resulting in polarized light[6]. Polarization restricts this random oscillation, confining it to a specific plane. There are different forms of polarization[7]. When the electric field vector traces an elliptical path, the light is elliptically polarized[1,4,8-9]. Linear polarization, a special case of elliptical polarization, occurs when the electric field oscillates in a single plane. It also occurs both naturally and through artificial means[1-2,10-11].

When unpolarized sunlight reflects off various surfaces, it undergoes partial or complete polarization depending on the angle of incidence and the properties of the material. This polarization can be a cause of glare. Glare is defined as the presence of one or more intense light sources within the field of view, resulting in reduced contrast, blurred vision, and eye discomfort[9,12-14].

Reflected glare commonly occurs when light reflects off polished surfaces such as glossy magazine pages, water surfaces, snow, highways, and metallic surfaces within a person's field of view[8-9,15]. Due to glare, the reflected light provides no useful information about the color, texture, or other characteristics of the underlying surface. Not only are reflections annoying, but they can also seriously impair a person's vision. Glare can significantly reduce an individual's contrast sensitivity[9,16-17]. Additionally, glare may cause other adverse effects such as photophobia, tearing, conjunctivitis, or erythropsia (red vision), sneezing, and cataracts[18].

Conventional absorbent lenses such as sunglasses can partially alleviate glare and harmful rays which may help to improve vision[19-20]. These lenses uniformly reduce light intensity across the visible spectrum[8,15]. A study demonstrated that yellow and pink filters, as well as anti-reflective coatings, had no significant impact on improving visual performance in young, healthy individuals under glare conditions[21].

While conventional absorbent filters can reduce glare from reflections, for a more significant reduction in glare intensity compared to surrounding objects, a filter that absorbs the horizontal vibrational components of light would be beneficial[8,22]. Polarizers are filters that exhibit varying absorption based on the polarization direction of incoming light, blocking light from a specific portion of the target. Therefore, polarized filters are effective in controlling reflected glare due to their ability to filter polarized reflected light[3,23]. Various studies have identified polarized filters as the simplest method to eliminate light polarization, significantly reducing reflected glare[24]. These filters are also available for ophthalmic use, integrated into eyewear[8-9].

Reflected glare often originates from non-polarized sunlight striking horizontal surfaces at Brewster's angle. Since the reflected light becomes polarized with its vibration plane parallel to the reflective surface (*i.e.*, horizontal), polarized lenses in sunglasses are oriented to account for this. When the axis of the polarizing filter is aligned vertically, the reflected light is absorbed, thus eliminating the glare caused by reflection[4,15].

Since the effect of polarizing filters on colour vision has been investigated before, this research aimed to determine the effect of polarized sunglasses on visual functions, including far and near visual acuity, near and far phoria, stereopsis, and contrast sensitivity at five spatial frequencies: 1.5, 3, 6, 12, and 18 cycles per degree.

PARTICIPANTS AND METHODS

Ethical Approval Ethical considerations were followed under the instructions of the Ethics Committee of Shahid Beheshti University of Medical Sciences (Approval number: IR.SBMU.RETECH.REC.1402.243). A written informed consent was obtained from all participants.

This before-after semi-interventional study employed a non-random convenience sampling method among students of Shahid Beheshti University of Medical Sciences. Considering the inclusion and exclusion criteria (inclusion criteria: emmetropia, age between 18-30y; exclusion criteria: presence of obvious ocular deviations (tropia), presence of retinal and ocular problems and diseases such as amblyopia, retinal detachment, cataract, glaucoma, keratoconus, history of eye surgery (refractive and intraocular), inability to continue cooperation or withdrawal from the study.

In an examination room where we had created lighting similar in intensity to outdoor conditions, and using a luminance meter (Didactic GMH LEybold, Germany) to ensure that the lighting was within the desired range, we placed subjective refraction in front of the subject's eye. Since the study participants were emmetropic, their subjective refraction was plano, and they were essentially without optical correction. Distant visual acuity was measured monocularly and binocularly using a paper-based distance vision chart (TAK MEDICAL, Iran; due to the interference of polarization with digital charts and the polarizing filter), and near visual acuity was measured binocularly using a near vision chart (Binateb, Iran). Contrast sensitivity was measured and recorded using the Smart System M&S technologies contrast sensitivity test software at spatial frequencies of 1.5, 3, 6, 12 and 18 cycles per degree[25]. To measure stereopsis, the TNO stereopsis test, a random dot test performed using red-green glasses, was used (TNO test for stereoscopic vision, ninth edition, the Netherlands).

To measure phoria, the Von Graefe method was used. The subject was asked to fixate on a suitable target (one letter above the best visual acuity measured for the individual; for distance phoria testing, the target was placed 6 m away, and for near phoria testing, the target was placed 40 cm away). A 6 or, if necessary, 8 prism diopters base-down prism was placed in front of the right eye to induce a vertical misalignment. The subject was then asked to describe the relative position of the two images. If the upper image appeared to the left of the lower image, the deviation was classified as exotropia. If the upper image appeared to the right, the deviation was classified as esotropia. The prism's strength required to align the images was used to quantify the amount of phoria[23].

A pair of gray, non-polarized sunglasses, with a light transmittance between 8% and 40% was randomly selected and verified using a spectrophotometer (Cecil CE3055, UK). All previously mentioned measurements were repeated while the non-polarized sunglasses were placed in front of the subject's eyes. Subsequently, a pair of gray, polarized sunglasses, with conditions identical to the non-polarized ones except for their polarization, was used, and the tests were repeated to assess the impact of polarization on visual performance.

Statistical Analysis The data were analysed using SPSS version 26. The Shapiro-Wilk normality test was used to assess normality. Repeated measures ANOVA was employed for normally distributed data, while the Friedman K-related samples test was used for non-normally distributed data. Bonferroni correction was applied as a post hoc test to determine pairwise differences when the Friedman test was significant. A *P*-value of <0.05 was considered statistically significant.

RESULTS

A total of 45 participants were evaluated, comprising 17 males (37.8%) and 28 females (62.2%). The mean age of the sample was 21.67±2.31y, with a minimum age of 18 and a maximum age of 27y. All tests were repeated under three conditions: no sunglasses, non-polarized sunglasses, and polarized sunglasses. All minimum, maximum, mean, and standard deviation values for monocular and binocular distant visual acuity, and near visual acuity, were equal to 0.00 logMAR, with no significant changes observed across conditions.

Contrast sensitivity was measured at 5 spatial frequencies of 1.5, 3, 6, 12, and 18 cycles per degree. The results were reported as the logarithm of contrast sensitivity in Table 1.

The results of the Friedman non-parametric test for spatial frequencies of 1.5, 3, 6, and 12 are presented in Table 2.

The Friedman K-related samples test showed a significant difference in contrast sensitivity across the three conditions at spatial frequencies of 1.5, 6, and 12. However, no significant difference was found at spatial frequency 3.

Contrast sensitivity in pairwise comparisons using Bonferroni correction showed that non-polarized sunglasses, compared to no sunglasses, decreased contrast sensitivity. This difference was significant at the spatial frequency of 6. Although in spatial frequencies of 12 and 1.5 there was no significant statistical difference between any of the conditions but the greatest difference was observed between the non-polarized sunglasses and no sunglasses conditions, with lower contrast sensitivity in the non-polarized sunglasses condition compared to the no sunglasses condition.

A repeated-measures ANOVA was conducted to compare the logarithm of contrast sensitivity at the 18 cycles/degree spatial frequency across the three conditions. The results showed no significant difference in contrast sensitivity across the three conditions [$F(2, 88)=2.26$] and P-value ($P=0.11$), indicating that the use of polarized sunglasses did not significantly affect contrast sensitivity at this spatial frequency, similar to the lack of effect observed with non-polarized lenses (Figure 1).

Figures 2 and 3 present the results of a two-way repeated measures ANOVA to investigate the simultaneous effects of the experimental conditions and spatial frequencies.

Table 3 shows the stereopsis measurements (in arc seconds) for three conditions, measured by the TNO test.

A Friedman test was conducted to assess the effect of the three conditions on stereopsis. The analysis revealed no statistically significant difference in stereopsis across the three conditions.

The results of the investigation of phoria at both near and far distances using the Von Graefe method were recorded in three conditions and recorded as + (for esophoria), - (for exophoria), and 0 (for orthophoria). To avoid errors in calculating means and other statistical analyses, the results for samples with exophoria and esophoria were analysed separately.

In the initial measurement (without sunglasses) of phoria at far, 21 participants had exophoria, 12 had esophoria, and 12 were orthophoric. In the initial measurement of phoria at a near distance (without sunglasses), 36 participants had exophoria, 5 had esophoria, and 4 were orthophoric.

Table 1 Contrast sensitivity at spatial frequencies of 1.5, 3, 6, 12, and 18 cycles per degree

Frequencies and conditions	Mean	SD	Min	Max
Spatial frequency 1.5				
No sunglasses	2.029	0.228	1.397	2.390
Non-polarized sunglasses	1.979	0.223	1.522	2.390
Polarized sunglasses	2.026	0.236	1.522	2.390
Spatial frequency 3				
No sunglasses	2.128	0.242	1.397	2.390
Non-polarized sunglasses	2.077	0.224	1.619	2.390
Polarized sunglasses	2.118	0.216	1.619	2.390
Spatial frequency 6				
No sunglasses	2.047	0.223	1.397	2.390
Non-polarized sunglasses	1.949	0.228	1.397	2.390
Polarized sunglasses	1.963	0.222	1.522	2.390
Spatial frequency 12				
No sunglasses	1.715	0.258	1.000	2.390
Non-polarized sunglasses	1.617	0.243	1.000	2.096
Polarized sunglasses	1.646	0.215	1.000	1.920
Spatial frequency 18				
No sunglasses	1.256	0.415	0.200	2.096
Non-polarized sunglasses	1.186	0.327	0.200	1.795
Polarized sunglasses	1.219	0.365	0.301	2.096

SD: Standard deviation.

Table 2 Contrast sensitivity at spatial frequencies of 1.5, 3, 6, and 12 under three conditions

Spatial frequency	Test statistic	Significance level (P)
Spatial frequency 1.5	6.295	0.043
Spatial frequency 3	3.977	0.137
Spatial frequency 6	13.236	0.001
Spatial frequency 12	6.298	0.043

Table 3 Descriptive statistics of stereopsis measurements

Condition	Mean	SD	Min	Max
Without sunglasses	94.33	46.63	15	240
With non-polarized sunglasses	105.67	58.96	15	240
With polarized sunglasses	101.33	56.13	15	240

SD: Standard deviation.

Table 4 displays the outcomes of the phoria measurements obtained from the study participants. Therefore, Friedman tests were conducted to assess the effect of the three conditions on distance exophoria, distance esophoria, and near exophoria. The results showed no statistically significant difference between the conditions for any of these phoria types: distance exophoria [$\chi^2(2)=1.02$, $P=0.59$], distance esophoria [$\chi^2(2)=0.077$, $P=0.96$], and near exophoria [$\chi^2(2)=0.96$, $P=0.61$]. For near esophoria, a repeated-measures ANOVA

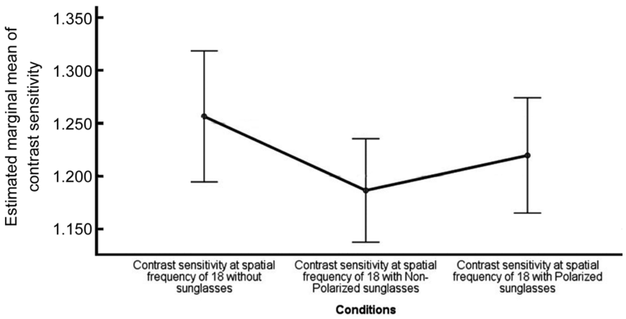

Figure 1 Estimated marginal means of contrast sensitivity at spatial frequency of 18.

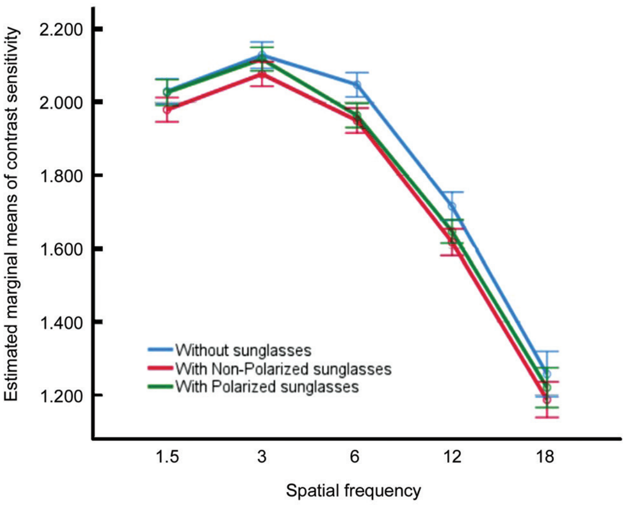

Figure 2 Simultaneous effects of the conditions and spatial frequencies on contrast sensitivity.

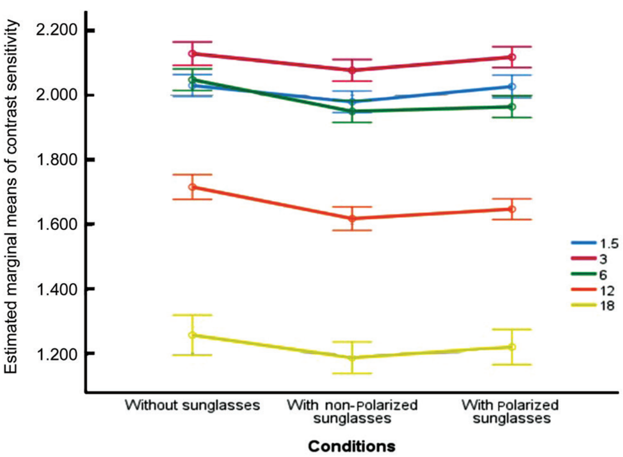

Figure 3 Simultaneous effects of the conditions and spatial frequencies on contrast sensitivity.

was conducted, revealing no statistically significant difference between the conditions [$F(2, 88)=2.36$, $P=0.17$].

DISCUSSION

The primary aim of this study was to determine whether polarized sunglasses influence key visual functions. Contrary to the hypothesized benefits of polarized lenses under glare condition, no significant differences were found in distance visual acuity (both monocular and binocular), near visual acuity, stereopsis, phoria at both distance and near, and contrast sensitivity at various spatial frequencies when comparing results obtained with polarized sunglasses to those obtained with and without non-polarized sunglasses under controlled glare.

Table 4 Distribution of mean, standard deviation, minimum, and maximum of phoria

Condition	Mean	SD	Min	Max	Count
Exophoria in distance					
Without sunglasses	-2.60	1.57	-0.75	-6.00	21
Non-polarized sunglasses	-2.64	2.18	-0.50	-8.00	21
Polarized sunglasses	-2.87	2.55	-0.50	-10.0	20
Exophoria in near					
Without sunglasses	-4.44	3.61	-0.50	-18,0	36
Non-polarized sunglasses	-4.81	4.21	-1.00	-18.0	36
Polarized sunglasses	-4.81	4.34	-0.50	-18.0	36
Esophoria in distance					
Without sunglasses	1.37	0.85	0.50	3.50	12
Non-polarized sunglasses	1.41	1.08	0.50	4.50	12
Polarized sunglasses	1.28	0.93	0.50	3.50	14
Esophoria in near					
Without sunglasses	0.90	0.41	0.50	1.50	5
Non-polarized sunglasses	1.50	0.89	0.50	3.00	6
Polarized sunglasses	1.20	0.57	0.50	2.00	5

SD: Standard deviation.

The results showed that neither monocular nor binocular distance visual acuity, nor binocular near visual acuity, changed with polarized sunglasses compared to the no-sunglasses and non-polarized sunglasses conditions. To be suitable for general use, sunglasses must attenuate incoming light; however, this attenuation must be balanced with the design principle of these lenses to maintain optimal visual clarity while mitigating glare, a principle supported by industry standards, manufacturers, and certification processes to ensure that the attenuation does not significantly reduce or impair visual function.

Contrast sensitivity is considered as one of the important functions of the eye[26]. As we found in this study, there was no significant difference in contrast sensitivity at spatial frequencies of 1.5, 6, and 12 cycles per degree between any of the conditions. However, the greatest difference was observed between the no-sunglasses condition and the non-polarized sunglasses condition, with lower contrast sensitivity found when wearing non-polarized sunglasses. In terms of contrast sensitivity at these frequencies, the use of polarized filters showed a slight advantage over non-polarized filters, although this difference was not significant.

In some studies, similar to the results obtained in this research, no significant difference was observed in contrast sensitivity between polarized and non-polarized gray sunglasses. However, unlike the findings of this study, non-polarized gray sunglasses performed better than both polarized sunglasses and no sunglasses, and the no-sunglasses condition also performed better than the polarized sunglasses condition[27]. Although none of the differences were statistically significant, this slight difference in results could be due to the identical light transmittance percentages and the similar categorization of the two types of sunglasses in this study, which may have minimized the confounding variable of differences between the two types of sunglasses, a factor that was not considered in the previous studies.

Ultimately, given that no significant differences were found in any of the studies, whether conducted under glare conditions or not, it can be concluded that, contrary to popular belief and manufacturers' claims, polarized sunglasses do not make a significant difference in contrast sensitivity in everyday daylight conditions. They may only be beneficial in specific situations and environments with excessive glare (such as fishing), Road sports or may be considered just for greater subjective comfort[12,28]. No significant difference in stereopsis was observed among the three conditions examined in this study. Previous research has yielded mixed results. In another study, no significant difference was found between polarized gray sunglasses and no sunglasses (with a slight increase in stereopsis with polarized sunglasses compared to no sunglasses), but stereopsis with non-polarized gray sunglasses showed a significant increase compared to both polarized and no sunglasses[27]. Given these conflicting findings, it's difficult to definitively conclude the impact of different types of sunglasses on stereopsis.

In this study, we found no significant difference in esophoria and exophoria at both near and far distances across the three conditions. However, distance phorias seemed to be more affected than near phorias. Clinically, even slight changes in phoria may be noticeable and cause symptoms for some individuals.

Due to the challenges of measuring phoria under glare conditions, there's a lack of research on the effect of sunglasses on phoria. The most standard tests, like the cover test and Maddox rod test, are not suitable for use with sunglasses, as they require specific lighting conditions[29].

In conclusion, the findings of this study revealed no statistically significant differences in the visual functions examined, including visual acuity, contrast sensitivity, phoria, and stereopsis under controlled glare when comparing the use of polarized sunglasses to conditions with and without non-polarized lenses.

ACKNOWLEDGEMENTS

Conflicts of Interest: Ebrahimi F, None; **Kangari H,** None; **Akbarzadeh-Bagheban A,** None; **Rahmani S,** None.

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