• **Clinical Research** •

Effect of changing mesopic and photopic light conditions on visual functions

Fatemeh Mosayebi[1], Seyyed Mehdi Tabatabaee[2], Haleh Kangari[1], Saeed Rahmani[1]

[1]Department of Optometry, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran 19839-63113, Iran
[2]Department of Biostatistics, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran 19839-63113, Iran
Correspondence to: Saeed Rahmani. Department of Optometry, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran 19839-63113, Iran. medicalopto@yahoo.com

Abstract
● **AIM:** To determine the effects of change in light conditions on refractive error and visual functions including visual acuity, stereopsis and contrast sensitivity.
● **METHODS:** This cross-sectional study was conducted in the optometry clinic of the Shahid Beheshti School of Rehabilitation on 48 students in 2021-2022. All of them had eye health and normal visual function and could have refractive errors or not. Light intensity of 4 lx was considered equivalent to photopic light condition and light intensity of 1 lx was considered to be equivalent to mesopic light condition. The amount of refractive error was checked by auto refractometer and its changes in mesopic light condition were subjectively measured. Also, visual acuity, stereopsis and contrast sensitivity (in five spatial frequencies of 1.5, 3, 6, 12, and 18 cycles per degree), were measured first in photopic light condition and then in mesopic light condition, by Snellen control vision chart, stereo butterfly test and the M&S technology monitor test respectively.
● **RESULTS:** In the 48 student subjects with an average age of 22.69±3.56y, mean of refractive error as sphere equivalent, visual acuity and stereopsis were -1.25±1.74 diopters, 0 logMAR, 44.37±13.03 seconds of arc, respectively in photopic light condition while in mesopic light was equal to -1.56±1.75 diopters, 0.12±0.09 logMAR and 50.62±33.35 seconds of arc, respectively. The mean of contrast sensitivity measured at spatial frequencies of 1.5, 3, 6, 12, and 18 cycles per degree in photopic condition was equal to 2.38±0.04, 2.37±0.07, 2.04±0.21, 1.27±0.32, 0.82±0.27 logarithm of contrast sensitivity, respectively and in mesopic lighting condition was equal to 2.34±0.12, 2.30±0.16, 1.84±0.28, 1.02±0.28, 0.63±0.24 logarithm of contrast sensitivity, respectively. Statistical analysis showed a significant difference between the two lighting conditions in all evaluated variables [refractive error ($P<0.001$), visual acuity ($P<0.001$), stereopsis ($P=0.008$) and contrast sensitivity ($P<0.001$)].
● **CONCLUSION:** The refractive error of the student subjects in mesopic light condition change towards myopia, and its amount is clinically significant. Also, the examination and comparison of the factors of visual acuity, stereopsis and contrast sensitivity in these two lighting conditions show that the decrease in brightness level to the mesopic level causes a decrease in the aforementioned visual functions.
● **KEYWORDS:** mesopic light condition; photopic light condition; visual performance; visual acuity; stereopsis; contrast sensitivity; visual functions

INTRODUCTION

The visual system is exposed to different degrees of light during daily activities[1], so knowing its effect on visual performance is essential. The most important feature of the visual system is the ability to function effectively in a wide range of environmental light intensity changes, which include photopic, mesopic and scotopic with light intensities of high (about 10 to 10^8 cd/m^2), medium (about 0.001 to 10 cd/m^2), and low light (about 10^{-6} to 10^{-3} cd/m^2), respectively[2]. Good vision requires sufficient lighting, and its lack or excess can cause various discomforts such as eye fatigue, headache, vision loss, glare, physical fatigue, and mental problems[3]. The visual system reacts to changes in the intensity of light entering the eye by the different functions of two types of retinal photoreceptors, including rod cells for lower light intensities and cone cells for higher light intensities[2].

The highest sensitivity in the visible light spectrum and in cone photoreceptors in photopic light conditions is at the wavelength of 555 nm and in the scotopic light conditions in rod photoreceptors is at the wavelength of 504 nm and in light intensity lower than photopic, there is more sensitivity to light rays in front of the retina[4], as a result, in mesopic and scotopic light conditions and with the change of pupil diameter, high-order eye errors such as spherical and chromatic aberrations as well as accommodative error affect the quality of the retinal image and night myopia occurs[2,5-6]. Night myopia refers to the change in refractive error towards myopia in mesopic and scotopic light conditions; the amount of night myopia varies among people and in different studies and on average -1.50 diopters is mentioned in scotopic light conditions, but the myopia occurring in mesopic light conditions is usually less than this amount[5-6]. The most obvious complaint of this type of myopia is reduced vision while driving at night[7].

Many of the activities performed during the night hours are in mesopic light conditions, and most of the indoor and environmental lighting settings are at a level that prevents the creation of absolute scotopic light conditions: As a result, the lighting of most streets at night is not less than 1 cd/m$^{2[5]}$. Professions related to transportation by air, sea, rail and especially road can also be affected by these light conditions. For example, the number of accidents leading to death at night has been reported to be three to four times higher than during the day[8], in addition, the severity of accidents at night is at least twice as high as during the day[9-10].

Mesopic light conditions and resulting night myopia, in addition to visual acuity, can affect other visual functions[11-12]. Examining contrast sensitivity in these lighting conditions, in addition to being able to identify minor damages that are not revealed in 100% contrast, can be a way of investigating vision problems at night and reveal other important details of visual performance[11,13-14]. For example, in some countries such as Germany, checking visual acuity and contrast sensitivity in mesopic light conditions is necessary to get a certificate[15].

Stereopsis is related to depth perception and distance of objects and plays an important role in many daily activities[16-17]. Sufficient stereo acuity is necessary for complex visual activities, especially those that require precise eye-hand coordination. Also, the value of examining stereopsis is to evaluate the overall performance of both sensory and motor aspects of the visual system, which defects can cause complaints such as eye fatigue, headache, and diplopia[18].

Therefore, due to the importance of the effect of different lighting conditions on visual performance, in this study, the effects of changing lighting conditions on refractive error and visual functions such as visual acuity, contrast sensitivity, and stereopsis have been investigated.

SUBJECTS AND METHODS

Ethical Approval This research was approved by Ethics Committee of Shahid Beheshti University of Medical Sciences (IR.SBMU.RETECH.REC.1400.712). A written informed consent was obtained from all participants.

This cross-sectional study was conducted in optometry clinic of the Shahid Beheshti School of Rehabilitation on 48 students in 2021-2022.

The inclusion criteria were the healthy eye without nystagmus and central fixation disorder, amblyopia, deviation, refractive surgery, using drugs or alcohol and using of eye drops or contact lenses.

Visual functions were examined under photopic light conditions with a light intensity of 4 lx[19] measured by a lux meter (Leybold, Germany). At this degree of light, all light sources in the examination room were on. First, the refractive errors of the subjects were determined by Topcon auto refractometer (RM8900, Tokyo, Japan) objectively and then the individual was checked subjectively and monocularly. At the same time, the visual acuity of the subjects with the best optical correction at a distance of 6 meters was evaluated monocularly using the control vision chart (Snellen chart-6000, Abtahi Teb, Iran) and was calculated and recorded based on the logMAR system.

Stereo Butterfly stereopsis test was used to measure stereopsis at a distance of 40 cm, and polarized glasses were worn for each subject on optical correction (in case of having refractive error). Then, based on the last diagnostic pattern in the booklet, the stereopsis was recorded in second of arc. The patterns include three rows of circles and three rows of animals on the first page and a butterfly on the second page. The rows of circles have a stereopsis level of 800 to 40 seconds of arc respectively from top to bottom, which we used for the measurement.

To measure the contrast sensitivity, a computer test (M&S Technologies) was used with a sinusoidal pattern at a distance of 4 meters. Contrast sensitivity was measured for spatial frequencies of 1.5, 3, 6, 12, and 18 cycles per degree. First, the appropriate optical correction was placed in front of the subject's eyes and we started to ask from the spatial frequency of 1.5 cycles per degree. The display pattern in each spatial frequency is from high contrast percentage (the highest percentage is 100%) to decreasing contrast percentage (the lowest percentage is 0.4%). At each stage, the subject must recognize the direction of the lines, which can be oblique, horizontal, and vertical. The contrast sensitivity of the last pattern detected by the individual was calculated and recorded separately for each spatial frequency in terms of logarithm of contrast sensitivity.

After this stage, each subject was placed in mesopic

light conditions with a light intensity of 1 lx[19] for 10min (the minimum time needed to start the activity of rod photoreceptors) with the aim of getting dark adapted, and then each of the steps were performed in the photopic stage were repeated in these light conditions. At this level of light, only one small lamp was on in the examination room and there was no other light source. In the phase of determining the refractive error, the amount of changes towards myopia was recorded by subjective examination. To evaluate the contrast sensitivity, in order to simulate the mesopic lighting conditions, we also reduced the brightness of the display, which reached 0.8 lx, and this brightness was also measured by lux meter. At the end of the project, the average values were calculated and the data were compared in two different light conditions, mesopic and photopic.

To analyze the data, first the normality of the variables was evaluated using the Shapiro-Wilk test; then, due to the non-normal distribution of the studied sample ($P<0.001$) in all variables, we used the Wilcoxon rank test to compare their averages in the two light conditions. The significance level in the tests was considered $P<0.05$ and SPSS software (version 16) was used for data analysis.

RESULTS

Among 48 subjects who were studied, 20 were men (41.7%) and 28 were women (58.3%). The average age of these people was 22.69±3.56y, and their age range was 19 to 37.

To investigate the changes in refractive error (in the form of spherical equivalent) and visual acuity in photopic and mesopic light conditions that were evaluated monocularly, only the data of the right eye were used. As presented in Table 1, the mean of refractive error in the form of sphere equivalent and in photopic lighting conditions was -1.25±1.74 diopters and in mesopic lighting conditions was -1.56±1.75 diopters and the mean of refractive error changes in mesopic lighting conditions was -0.31±0.16 diopters.

The results of visual acuity examination in two lighting conditions are as follows. The amount of visual acuity measured in photopic lighting conditions was reported as 0 logMAR (10/10 decimal acuity) in all subjects. Also, the mean of visual acuity in mesopic lighting conditions was 0.12±0.09 logMAR, which was equal to the same amount of visual acuity reduction in mesopic lighting conditions (Table 1).

The results of the stereopsis examination in these two lighting conditions are as follows. The mean of stereopsis measured in photopic lighting conditions was 44.37±13.03 seconds of arc and its mean in mesopic lighting conditions was 50.62±33.35 seconds of arc, and the mean of stereopsis reduction in mesopic lighting conditions was 6.25±24.2 seconds of arc (Table 1).

According to Figure 1, the mean of contrast sensitivity measured in spatial frequencies of 1.5, 3, 6, 12, and 18 cycles
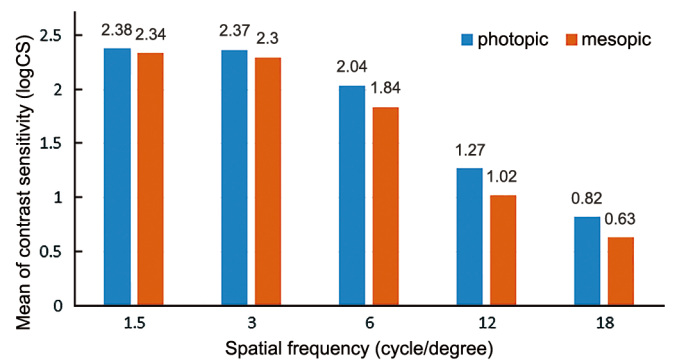

Figure 1 Changes of contrast sensitivity (CS) in 5 level spatial frequencies in photopic and mesopic light conditions.

Table 1 Examined variables of the samples

Variable	Light condition	Mean±SD	P
Equivalent sphere of refractive error, diopter	Photopic	-1.25±1.74	<0.001
	Mesopic	-1.56±1.75	
Visual acuity, logMAR	Photopic	0	<0.001
	Mesopic	0.12±0.09	
Stereopsis, second of arc	Photopic	44.37±13.03	0.008
	Mesopic	50.62±33.35	

per degree in photopic lighting conditions was 2.38±0.04, 2.37±0.07, 2.04±0.21, 1.27±0.32, and 0.82±0.27 logarithm of contrast sensitivity and in mesopic lighting conditions was 2.34±0.12, 2.30±0.16, 1.84±0.28, 1.02±0.28, and 0.63±0.24 logarithm of contrast sensitivity, respectively. The mean of decrease in contrast sensitivity in mesopic lighting conditions in spatial frequencies measured was 0.04±0.11, 0.07±0.15, 0.2±0.23, 0.25±0.2 and 0.19±0.18 logarithm of contrast sensitivity respectively. Changes in contrast sensitivity in two lighting conditions, photopic and mesopic, and simultaneously with the change in spatial frequency, can be seen in Figure 1. Statistical analysis by Wilcoxon test showed a significant difference between the two lighting conditions in all evaluated variables refractive error ($P<0.001$), visual acuity ($P<0.001$), stereopsis ($P=0.008$) and contrast sensitivity ($P<0.001$).

DISCUSSION

According to this study, in the comparison of the refractive error in the form of sphere equivalent and with subjective examination in subjects under photopic and mesopic lighting conditions, the mean changes were -0.31 diopters and this amount was considered as night myopia. Except for five people whose refractive error was the same in two lighting conditions, in the rest of the people changes towards myopia occurred. As a result, in mesopic light conditions, there is a different amount of refractive error changes among different people, which is mainly towards myopia. Also, this change was statistically significant, and it is also a clinically significant amount that needs to be considered in optometric examinations and prescription.

Compared to other studies, in the study of Artal *et al*[5], the amount of changes towards myopia that was measured

subjectively, in the mesopic light intensity, contrary to the results of this study, was an insignificant amount. Also, the light intensity varied from the maximum brightness of 20 to 22×10^6 cd/m^2. Using an adaptive optics visual analyzer is a strength of the study, but few subjects were investigated.

In the study of Iizuka et al[20], refraction was checked subjectively at a light intensity of 10 cd/m^2 (under twilight conditions), and its average was reported as approximately -0.17 diopters. Contrary to the present study and due to the fact that in the study of Artal et al[5] and Iizuka et al[20], a higher light intensity was considered as mesopic light intensity, naturally, the refractive error changes did not show a significant amount. Although investigation of different light conditions on visual performances is a strength of the study but, inability to reproduce actual changes in sunset luminance over time is considered as a limitation for the study.

In a study of Chirre et al[21], this amount was also subjectively checked in seven different light intensities and its amount in the light intensity similar to the present study, was reported less than -0.25 diopters (-0.23 and -0.60 diopters on average under binocular and monocular vision, respectively). In comparison to present study, there was a difference in the method of measuring refractive error (use of adapted vision device). Only 10 subjects were participated, but monocular and binocular evaluation in different light intensities is considered as a strength of the study.

In the comparison of visual acuity in subjects under photopic and mesopic lighting conditions, the mean of changes in visual acuity was found to be 0.12±0.09 logMAR. Also, comparing this variable in these two lighting conditions showed a statistically significant difference. This amount of reduced vision in mesopic light conditions for people with full visual acuity is equal to almost one line of the vision chart, which is also significant clinically. Generally, in three subjects, the visual acuity did not show any difference in two lighting conditions, as a result, a decrease in visual acuity in mesopic lighting conditions was seen in most subjects, but there were still some people who did not experience this decrease in vision. Also, in the process of examining the amount of refractive error changes, despite the maximum correction, some subjects still did not achieve full vision and it can be concluded that the cause of reduced vision can be reasons other than the effects of night myopia.

In the study of Hiraoka et al[11], visual acuity was checked in mesopic lighting conditions with the background light intensity set in the device (0.1±0.01 cd/m^2) was 0.39±0.12 logMAR and the amount of changes compared to photopic light conditions was almost 0.5 logMAR. In this study, unlike the present study, a lower light intensity was considered for mesopic conditions, as a result, the amount of visual acuity reduction was greater

than the results of the present study. In the study, they focused on visual acuity and other visual functions have not been evaluated.

In the study of Arumi et al[22], the level of visual acuity was examined monocularly, which at light intensity of 1 cd/m^2 (mesopic equivalent) reached from 6/6 to 6/9 Snellen (0.18 logMAR). In this study, an open-view auto refractometer was used, and neutral density (ND) filters (ND filters with different densities to reduce light intensity) were used to control the light intensity of the monitor and unlike the current study, the number of people was much less (six subjects) and the method of light control was also different and as a result, the visual acuity showed a greater decrease. However, in the study, only six subjects have been evaluated, but night driving is important and can be considered as a strength of the study.

In the study of Lin et al[23], the visual acuity of the subjects was measured monocularly and with open-view auto refractometer by a monitor vision test, which were respectively on average 0.27 logMAR, 0.16 logMAR and 0.05 logMAR in light intensities of 0.38, 0.75 and 3 cd/m^2. The light intensity of 3 cd/m^2 was obtained by reducing the light of the monitor, and to achieve the light intensity of 0.75 and 0.38 cd/m^2, an ND filter was used on the monitor screen. Unlike the current study, in this study, a monitor chart was used and the way of light control was the same as in the Arumi et al[22] study, also the amount of changes in visual acuity in the light conditions similar to the current study showed a greater decrease in vision, but the same as in the Arumi et al[22] study, had very little difference with the results of the current study. Evaluation of the effect of several factors on mesopic light condition is well investigated in the study.

In the study of Iizuka et al[20], changes in visual acuity were investigated by a monitor chart with adjustable light, where the light intensity of 300 cd/m^2 was considered for photopic light conditions and 10 cd/m^2 for mesopic light conditions, and the visual acuity was on average, -0.2 and -0.11 logMAR, respectively. In the study, the changes in visual acuity were checked by a monitor chart, but according to the light intensity considered as mesopic, which was close to the photopic light intensity, a decrease in visual acuity was seen, but it was still reported as better than full vision.

In the comparison of stereopsis in people under photopic and mesopic lighting conditions, the average stereopsis showed a decrease of approximately 6 seconds of arc. Also, from 48 subjects examined, only eight subjects showed this reduction, but the amount of changes was statistically significant in mesopic lighting conditions.

In the study of Reynaud et al[24], it was concluded that by changing the average brightness (with an ND filter on one eye), the stereopsis decreases, but by reducing the brightness

in both eyes to the same amount, there was a slight reduction in stereopsis. In the study, unlike the present study, wheatstone device was used to separate the images of the two eyes and a monitor at a distance of 54 cm was used to show the dimensional images. The detailed examination of stereopsis is one of the advantages of this study, but it would have been better more observers were participated.

In the study of Mehta et al[18], using a filter with a density of 0.3 changed the average stereopsis from 42.7 to 67.3 seconds of arc, and by placing filters with a higher density up to the full scotopic level, the stereopsis decreased to 598 seconds of arc. The similarity between the method of this study and the current study was the use of the Titmus stereo test (there are similar tests on the first page of both notebooks) and the difference is the reduction of the light intensity by the filter, which does not recreate the conditions of natural light reduction in the environment. One of the strengths of the study is use of neutral filters on stereopsis levels, although the conditions are not natural.

In the present study, unlike the two mentioned studies, the investigation of the level of stereopsis was carried out along with reducing the light intensity naturally to the mesopic level and without using ND filters and as a result, the amount of reduction in stereopsis was lower than mentioned studies.

In the comparison of contrast sensitivity in mesopic lighting conditions compared to photopic, in all measured spatial frequencies, a decrease in contrast sensitivity was seen in mesopic light intensity. Also, the largest changes in the spatial frequency of 12 cycles per degree and the smallest changes in the spatial frequency of 1.5 cycles per degree occurred, and the amount of changes in all measured spatial frequencies showed a statistically significant difference. As a result, with an increase in spatial frequency, a further decrease in contrast sensitivity performance occurred in mesopic lighting conditions.

In the study of Healy et al[13], the comparison between contrast sensitivity (binocularly and at a distance of 8 feet) in two different light conditions, as in the present study, showed a decrease in contrast sensitivity in mesopic lighting conditions, also in their study the greatest changes in contrast sensitivity was at the spatial frequency of 12 cycles per degree, furthermore, in Healy et al's[13] study, the amount of change in the measured spatial frequencies was greater than the changes in the present study. Another difference between Healy et al's[13] study and the current study was the use of the CSV1000E test to check the contrast sensitivity and how to adjust the lighting conditions (use of an ND filter with a density of 1.5 on the monitor). The study exclusively designed to investigate the effect of light conditions on contrast sensitivity, while in this study another visual function have been evaluated.

In the study of Haughom and Strand[14], as in the present study, contrast sensitivity (binocularly) decreased in mesopic light conditions, with the difference that the amount of changes in the desired spatial frequencies was greater than in the present study and also the most changes in contrast sensitivity were seen in the spatial frequency of 12 and 18 cycles per degree. A large sample size (197 subjects) is considered as a strength of the study and Optec 6500/FACT device was used to check contrast sensitivity and the amount of light conditions 85 cd/m^2 for photopic and 3 cd/m^2 for mesopic condition considered for the investigations.

In conclusion, the refractive error of the studied subjects changed to myopia in mesopic light conditions, and its amount was clinically significant. Also, the examination and comparison of the factors of visual acuity, stereopsis and contrast sensitivity in these two lighting conditions, showed that the decrease in brightness levels to the mesopic level causes a decrease in the aforementioned visual functions. It is suggested that the investigated vision factors be compared in other light conditions such as scotopic light intensity.

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