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The influence of brightness, age and refractive errors on pupil size

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Abstract

Objectives: In this study, we aimed to investigate the influence of age, gender and refractive status on pupil size under different illuminance conditions in presbyopic healthy people.

Methods: A total of 75 volunteers (49 females and 26 males) were included in the study. The medical records of each participant was reviewed. Patients were divided into three groups according to their age and refractive errors. Pupil responses were evaluated with the automated pupillometry function of the Sirius Topographer. Relationship between pupil size and age, sex, laterality, dominant eye, refrative errors were analyzed by statistical analyses.

Results: In the early aged presbyopia group of patients the mean value of the hyperopic group was higher than the other two groups in photopic measurements. In scotopic condition, the mean value of the myopic group was found to be higher than the emmetropic and hyperopic groups. No difference was observed in the comparison of mesopic measurements in all three groups. In the patients with established presbyopia, myopic pupil diameter was higher compared to emmetropic and hyperopic pupils in all illuminances. There was a difference only in the scotopic condition when comparing the emmetropic and hyperopic groups. Pupil size did not change with age in all three conditions in emmetropic eyes. Pupil diameter decreased in all three conditions with age in hyperopics. Photopic and mesopic pupil size increased with age in myopics.

Conclusion: The results of this study support that the effects of patient age and refractive status on pupil diameter are important in optimal lens design.

Keywords: hyperopics; myopics; presbyopics; pupil size; sirius cornea topography

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Introduction

The pupil regulates the light entering the eye to reduce glare, to control retinal illumination, and to achieve adequate depth of field.[1] Scotopic vision is used at light brightness below 0.05 Lux, and pure photopic vision is used above 40 Lux. The vision between these two ranges is defined as mesopic vision.[2] Pupil diameter is an important element in the optical quality of the eye. Increase in pupil size increases high-order monochromatic aberrations, and this results in reduced image quality. In smaller pupil diameters, diffraction occurs; however, the depth of focus increases with a decrease in pupil size.[3]

Pupil diameter is a valuable parameter with important clinical implications. Its measurement can help detecting anomalies and knowledge of its normal range is essential for the optical industry.[4] It is considered the key factor for optimal optical quality in refractive surgery.[5] Several studies have evaluated the relationship between ablation site and pupil diameter with a focus on night vision problems after refractive surgery.[6,7] Scotopic and mesopic visions are the most important factors causing visual complaints after refractive laser surgery.[8] Pupil diameter also plays an important role in the design of bifocal or multifocal contact lenses, which are designed to get through optimal visual performance under various lighting conditions and at all viewing distances.[4,9] Pupil size is also an important consideration for intraocular multifocal or bifocal lenses. Because after successful intraocular placement of these lenses, optimal visual performance should be achieved at all viewing distances under varying brightness conditions.

Therefore, pupil diameter measurement has an important place for all ages and type of refractive errors.

This study aimed to determine the influence of age, gender and refractive status on pupil size under different illuminance conditions in presbyopic healthy people using the pupillometry software of Sirius Topographer.

Materials and Methods

This retrospective study was conducted at the ophthalmology department of a tertiary hospital in accordance with the ethical standards of the Declaration of Helsinki. The records of 75 patients who were admitted to the contact lens department of Beyoğlu Eye Training and Research Hospital, Istanbul were retrospectively analyzed through the hospital's electronic database.

The medical records of each participant were reviewed. A comprehensive ophthalmologic examination including funduscopic examination, slit lamp biomicroscopy and best corrected distance visual acuity (D-BCVA) testing were also performed. Pupil responses were evaluated with the automated pupillometry function of the Sirius Topographer (Costruzione Strumenti Oftalmici, Firenze, Italy) using Phoenix v2.1 software (Costruzione Strumenti Oftalmici, CSO, Firenze, Italy). All measurements were performed on the both eye of the subjects and performed by the same experienced clinician who was blinded to medical conditions of the patients.

Sirius Topographer is a placido-based videokeratoscope with two Scheimpflug cameras, one central and one rotating. The device allows both static and dynamic pupillometry, and uses different illumination levels to measure pupil size in scotopic (0.04 Lux) mesopic (4 Lux), and photopic (40 Lux) conditions. LED lighting was the only light source in the room, and the illumination conditions were tested and adjusted using a photometer. During the measurements, the subjects were advised to look straight ahead, not at the light source.

Emmetropia was defined as a mean spherical equivalent equal to and between +0.75 and -0.75 diopter (D). Moreover, myopia was defined as a spherical equivalent of -0.75 D or worse and hypermetropia was defined as a spherical equivalent of +0.75 D or worse. Patients were divided into groups according to age and refractive errors. Those aged between 43–52 were grouped as early presbiopia, and those aged between 52–62 were grouped as established presbiopia. Patients with any history of previous ocular or refractive surgery, ocular or systemic disease, or any history of ocular or systemic drugs which might affect the pupil size, were excluded from the study. Also, smokers and heavy alcohol drinkers (drinking five or more drinks on the same occasion on each of five or more days in the past 30 days) were excluded. Relationship between pupil size and age, sex, laterality, dominant eye, refractive errors were analyzed by statistical analysis.

The results for each parameter was displayed as mean±standard deviation (SD). For statistical analysis, the chi-square test was employed to compare the frequencies and percentages of the groups. The Kolmogorov–Smirnov test was applied to assess the normal distribution of data. To compare pupillometric measurements in each group, a paired sample t-test was performed. The Wilcoxon signed-rank test was used for variables that did not show normal distribution. The Statistical Package for the Social Sciences (SPSS) version 20 (IBM Inc., Chicago, IL, USA) was used for data analysis, for which values of $p<0.05$ were considered to be statistically significant.

Results

A total of 75 volunteers (49 females and 26 males) were included to the study. The mean age of the patients was 51.4±0.88 (range: 40–62 years). No statistically significant difference was observed in the comparison of the mean age of both genders ($p>0.05$).

The mean photopic, mesopic and scotopic pupil diameter values in the whole population was 4.20±0.88 mm (range: 2.14–6.67 mm). The mean photopic pupil diameter was 3.22±0.24 mm in males and 3.32±0.31 mm in females; the mesopic pupil diameter was 4.20±0.14 mm in males, 4.21±0.21 mm in females, and the scotopic pupil diameter was 5.13±0.24 mm in males and 5.12±0.22 mm in females. There was no statistically significant difference between the two genders for all three measurements ($p=0.482$, $p=0.751$ and $p=0.971$ respectively) (**Table 1**).

The mean photopic pupil diameter of the right eye was 3.29±0.19 mm, the mean mesopic pupil diameter was 4.18±0.21 mm, and the mean scotopic pupil diameter was 5.14±0.16 mm. In the left eye, mean photopic pupil diameter was 3.29±0.21 mm, mean mesopic pupil diameter was 4.23±0.18 mm, and mean scotopic pupil diameter was 5.10±0.14 mm. There was no statistically significant differences between the right and left eyes for all three measurements ($p=0.922$, 0.861 and $p=0.669$, respectively) (**Table 2**).

In the dominant and non-dominant eye measurements of our study population, the mean photopic pupil diameter of the dominant eye was 3.19±0.26 mm, the mean mesopic pupil diameter was 4.03±0.19 mm, and the mean scotopic pupil diameter was 5.01±0.24 mm. The mean photopic pupil diameter of the non-dominant eye was 3.22±0.16 mm, the mean mesopic pupil diameter was 4.09±0.21 mm, and the mean scotopic pupil diameter was 4.96±0.14 mm. There was no statistically

Table 1
The mean±SD photopic, mesopic and scotopic pupil diameter values in males and females.

Gender	Photopic	Mesopic	Scotopic
Male	3.22±0.24	4.20±0.14	5.13±0.24
Female	3.32±0.31	4.21±0.21	5.12±0.22

Table 2
The mean±SD photopic, mesopic and scotopic pupil diameter values on different sides.

Side	Photopic	Mesopic	Scotopic
Right	3.29±0.19	4.18±0.21	5.14±0.16
Left	3.29±0.21	4.23±0.18	5.10±0.14

Table 3
The mean±SD photopic, mesopic and scotopic pupil diameter values in the dominant and non-dominant eye.

Dominance	Photopic	Mesopic	Scotopic
Dominant	3.19±0.26	4.03±0.19	5.01±0.24
Non-dominant	3.22±0.16	4.09±0.21	4.96±0.14

significant differences between the right and left eyes for all three measurements (p=0.941, p=0.763 and p=0.682 respectively) (**Table 3**).

There were statistically significant differences in the photopic, mesopic and scotopic measurement comparisons of the patients within all groups (female, male, right, left, dominant, non-dominant) (p≤0.05in all).

In the group of patients aged 43–52 years (early presbyopia) the mean photopic pupil diameter was 3.15±0.22 mm, the mean mesopic pupil diameter was 4.16±0.18 mm, and the mean scotopic pupil diameter was 5.14±0.14 mm; and in the myopic patient group the mean photopic pupil diameter was 3.15±0.16 mm, the mean mesopic pupil diameter was 4.33±0.29 mm, and the mean scotopic pupil diameter was 5.49±0.18 mm; in the hyperopic patient group, the mean photopic pupil diameter was 3.40±0.20 mm, the mean mesopic pupil diameter was 4.31±0.09 mm, and the mean scotopic pupil diameter was 5.01±0.14 mm (**Table 4**). In photopic measurements, the mean value of the hyperopic group was statistically higher than the other two groups (p≤0.05). In scotopic measurements, the mean value of the myopic group was significantly higher than that of the emmetropic and hyperopic groups (p≤0.05). No statistically significant difference was observed in the comparison of mesopic measurements in all three groups (p>0.05).

In the patients with established presbyopia between the ages of 52 and 62, the mean photopic pupil diameter was 3.22±0.16 mm, the mean mesopic pupil diameter was 4.05±0.09 mm, and the mean scotopic pupil diameter was

Table 4
The mean±SD photopic, mesopic and scotopic pupil diameter values in early presbyopia group.

Early presbyopia (age: 43–52years)	Photopic	Mesopic	Scotopic
Emmetropia	3.15±0.22	4.16±0.18	5.14±0.14
Myopia mean:-3.00	3.15±0.16	4.33±0.29	5.49±0.18
Hypermetropia mean:+2.50	3.40±0.20	4.31±0.09	5.01±0.14

Table 5
The mean±SD photopic, mesopic and scotopic pupil diameter values in established presbyopia group.

Established presbyopia (age: 52–62 years)	Photopic	Mesopic	Scotopic
Emmetropia	3.22±0.16	4.05±0.09	5.09±0.22
Myopia mean:-3.25	3.92±0.26	4.56±0.19	5.42±0.14
Hypermetropia mean:+2.25	3.20±0.28	3.95±0.17	4.79±0.14

5.09±0.22 mm. In the myopic patient group, the mean photopic pupil diameter was 3.92±0.26 mm, the mean mesopic pupil diameter was 4.56±0.19 mm, and the mean scotopic pupil diameter was 5.42±0.14 mm; and in the hypermetropic patient group, the mean photopic pupil diameter was 3.20±0.28 mm, the mean mesopic pupil diameter was 3.95±0.17 mm, and the mean scotopic pupil diameter was 4.79±0.14 mm (**Table 5**). In all conditions, myopic pupil diameter was statistically significantly higher compared to emmetropic and hyperopic pupils ($p<0.05$). There was a statistically significant difference only in the scotopic condition when comparing the emmetropic and hyperopic groups ($p<0.05$).

Pupil size did not change with age in all three conditions in emmetropic eyes. Pupil diameter decreased in all three conditions with age in hyperopics. Photopic and mesopic pupil diameters increased with age in myopia (**Figure 1**).

Discussion

Pupil size has a great influence on visual function, and it is mainly dependent on adaptive luminance, which is modulated by other external factors.[3] Pupil diameter measurement has been the subject of many studies.[2,6] It is well known that pupil size decreases with increasing luminance. Factors investigated for possible relationships with pupil size are gender, iris color, age, refractive error etc.[4,10,11] In the literature, it was emphasized that there was no significant difference in pupil size between males and female;s and there was no correlation with iris color.[10] In our study, we did not find any difference in mean pupil diameters between males and females, in agreement with the literature. Also, we did not find any statistical difference in the comparison of the right and left eyes of the patients. In addition, no difference was observed in the comparison of the dominant eye and the non-dominant eye. It is shown that, the mean pupil

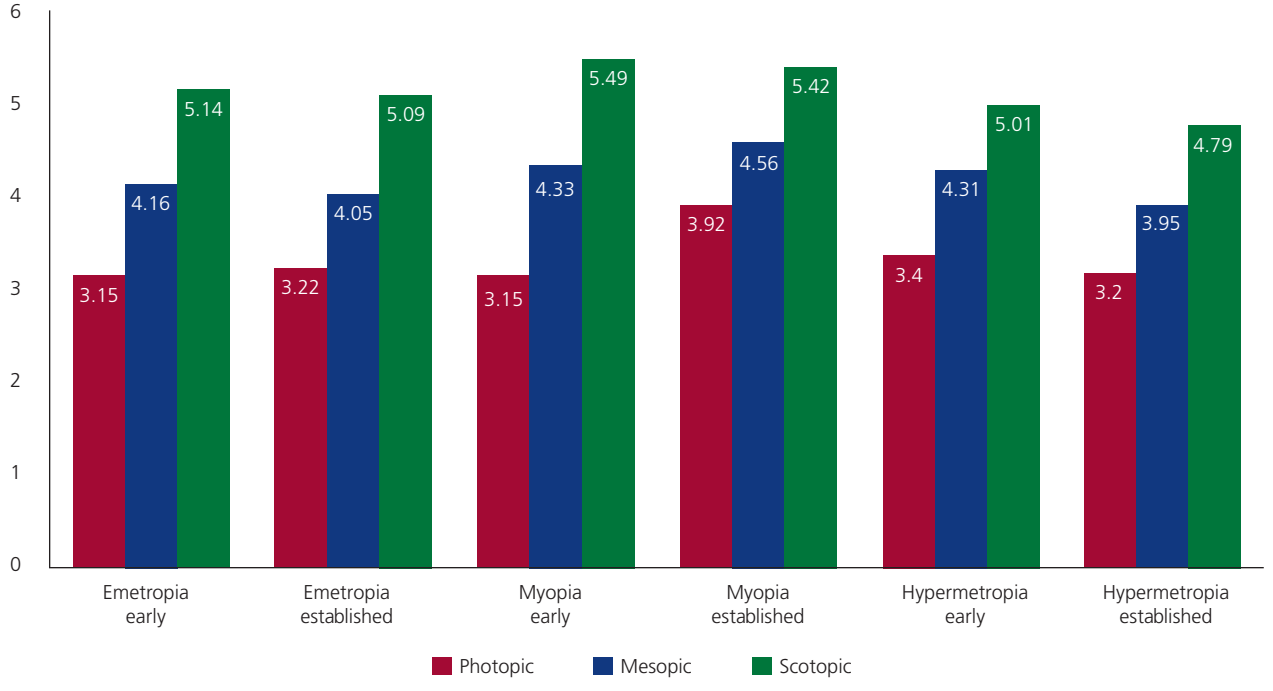

Figure 1. Change in pupil size with age in all three conditions.

diameter measurement data obtained were not related to gender, laterality or dominance.

In the human eye, the pupil diameter ranges from about 2 to 8 mm.[3] Pupil diameter has a great influence on the optical transfer function of the eye. It has a direct effect on retinal illumination, which affects the depth of field and contrast sensitivity.[1] In the first studies on pupil size, it was shown that the strongest determinant factor for the patient was age. Birren et al.[11] reported a nonlinear decrease in pupil size with age; however, the effect of changes in illumination level was not investigated in their study. Winn et al.[12] measured pupil size under different light levels in their study of 91 patients aged 17 to 83 years and found that for each brightness level, pupil width decreased linearly with age. And, they were the first team to take age into account when formulating it. Subsequent large population studies confirmed the inverse relationship between age and pupil size under various illumination levels.[10,13] However, in our study, pupil diameter did not change with age in all three conditions in emmetropic eyes. Pupil diameter decreased with age in hyperopia in all three conditions. While the photopic and mesopic pupil diameters increased with age in myopics, the scotopic diameter remained the same. We suspect that the different results were due to the comparison of subgroups formed according to the refractive errors of the patients in our study. It is also possible that the results were different because the age group was a presbyopic population. Guillon et al.[14] noted age progression as an important factor in decreasing pupil diameter. But overall, the difference was only significant between early presbyopia and established presbyopia patients. They noticed that the pupil size decreased significantly with increasing age, and the effect of age was more pronounced at low brightness.

Different results have been obtained in studies on the effect of refractive error on pupil diameter. Hirsch and Weymouth[15] conducted the first study investigating the relationship between refractive error and pupillary width, and reported that hyperopics had a smaller pupil diameter than myopics. Winn et al.[12] reported in their study that there was no significant relationship between refractive error and pupil size in the population consisting of myopia, emmetropia and hyperopia; however, the groups were not age matched in this study, with hyperopics being an average of 10 years older than myopics and emmetropics, so the age difference may therefore have been a confounding factor. Two studies which are involving a large number of refractive surgery candidates reported that preoperative refractive status is a determining factor in pupil size when measured under mesopic conditions, with smaller pupil sizes in hyperopics.[6,16] Yazdani et al.[17] reported that the pupil size was larger in myopics than in emmetropes in all light conditions. Truong et al.[18] emphasized that pupil sizes are affected only in high refractive errors. Cakmak et al.[5] found higher values in the myopic and astigmatic groups and lower values in the hypermetropic group in patients who had a mesopic pupil diameter before refractive surgery. In our study, the mean value of the hypermetropic group was higher in photopic measurements in early presbyopia patients compared to the other two groups. In scotopic measurements, the mean value of the myopic group was found to be significantly higher than the emmetropic and hyperopic groups. No difference was observed in the comparison of mesopic measurements in all three groups. In the established presbyopic group, myopic pupil diameter was found to be higher in all lighting conditions compared to emmetropic and hypermetropic pupils. There was a statistically significant difference only in the scotopic condition when comparing the emmetropic and hypermetropic groups. Guillon et al.[14] also noted in their study that when both age and refractive error were taken separately, the largest differences in pupil diameter between age groups and between refractive conditions were recorded at low luminance, and the differences diminished as luminosity increased. The smallest pupil diameter was measured in hyperopia and the largest in myopia. Although refractive error was not a significant factor only, the largest differences in pupil diameter occurred between low-brightness myopes and emmetropes.

There are some limitations in the study. Our study was conducted in the population over 40 years of age; different results may occur for younger individuals and children. There was no advanced myopia or hyperopia in our patient groups; results may vary in high myopia and hyperopia. The individuals we investigated were completely healthy; different results may be encountered in patients with systemic diseases such as diabetes and hypertension, in neuropsychiatric patient groups, or in those who use systemic medication. In addition, studies on pupil diameter can be performed in patients with various eye diseases such as dry eye, keratoconus, different types of glaucoma, strabismus, nystagmus and amblyopia, or in subjects with a history of eye surgery.

Conclusion

As the luminance is the most influential factor in determining pupil diameter, it is not suprising that the smallest pupil size was measured at high luminance levels. Larger values were obtained for myopia and younger individuals, and these differences were pronounced the most at low brightness levels. Multifocal contact lenses

and intraocular multifocal lenses are routinely used in myopia, presbyopia, and hyperopia and they must provide good visual performance in various brightness conditions. Because pupil size plays a crucial role in visual performance, the results of this study support that the effects of patient age and refractive status on pupil diameter are important in optimal lens design.

Conflict of Interest

Authors have no conflict of interest to declare.

Author Contributions

TY: project development, data analyses, manuscript writing; FÖ: project development, data collection, manuscript editing.

Ethics Approval

Approval for this study was obtained from a local ethics committee.

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