



Received: 07 November 2016  
Accepted: 01 June 2017  
First Published: 06 June 2017

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Udo Schumacher, University Medical  
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## OPHTHALMOLOGY | RESEARCH ARTICLE

# Effects of varying light conditions and refractive error on pupil size

Farah Maqsood<sup>1\*</sup>

**Abstract:** *Purpose:* To investigate the effects of small scale illumination levels and refractive error type on the pupil size measured with Visante Optical Coherence Tomography in healthy eyes. *Findings:* Pupil size increased with illumination decrements. Mean pupil size was 3.5 mm at 550 lux, 4.2 mm at 350 lux, 5.2 mm at 150 lux, 5.03 mm at 40 lux, and 5.4 mm at 2 lux. In multi-pairwise comparison of the five illumination levels, there were significant differences ( $p < 0.05$ ) down to 150 lux. Comparisons among 150, 40 and 2 lux show no differences ( $p > 0.05$ ). Refractive error ranged from spherical equivalent of +0.50 to -7.75D. Group of myopes had larger mean pupil size than emmetropes at all light levels but was not significant ( $p < 0.05$ ). Both refractive groups had some amount of increase in pupil size with illumination decrements. There were no hyperopes and presbyopes in the study. This study has demonstrated that ambient illumination levels from high to low cause increase in pupil size and refractive error does not appear to have an extra influence. At or below 150 lux, pupil was maximally dilated at about 5.2 mm. These findings may assist in further understanding pupillary light reflex.

**Subjects:** Physical Sciences; Health and Social Care; Medicine, Dentistry, Nursing & Allied Health

**Keywords:** visante optical coherence tomography; refractive error; pupil size; illumination

### ABOUT THE AUTHORS

Farah Maqsood is working as Assistant Professor at the Department of Optometry, College of Applied Medical Sciences, King Saud University, Saudi Arabia. She received a PhD degree in Physics from the Aligarh Muslim University, India. Her main fields of research areas include psychophysics, retinal imaging through the use of adaptive optics and light scattering techniques, fundamental visual processes, ophthalmic and physiological optics, novel applications of optics for visual science and role of different luminance in vision, Prismatic effect related.

### PUBLIC INTEREST STATEMENT

Vision is dependent on illumination. As light level increases, the pupil constricts in order to reduce the amount of light scatter and retinal illuminance, thereby increasing visual acuity. The aim of the present study is to investigate the effects of small scale illumination levels and refractive error type on the pupil size measured in healthy eyes. In refractive error, as the magnitude of spherical error increases, pupil size decreases. To examine the effect of light conditions in the presence of refractive error, subjects were grouped as myopes, and emmetropes. Pupil size measurements were performed with room lights at five different levels. Pupil size of each eye was measured three times and then mean calculated. This study examined that the pupil size decreases in linear manner with increasing illumination.

The pupil size data under various light levels obtained here may assist in understanding the pupillary light reflex and in diagnosing pupillary abnormalities.

## 1. Introduction

Vision is dependent on illumination. As light level increases, the pupil constricts in order to reduce the amount of light scatter and retinal illuminance, thereby increasing visual acuity. In the dark, the pupil dilates to allow more light in. Pupil size changes to light conditions have been associated with neurologic conditions, glaucoma, cataract, and used to evaluate the effect of medications and to reveal narcotic influence (Clark, 1989; Larson, 2008; Pärssinen et al., 2006; Pickworth, Welch, Henningfield, & Cone, 1989; Pilley & Thompson, 1975; Safran, Walser, Roth, & Gauthier, 1981; Smith & Dewhirst, 1986).

Normal pupil size tends to range between 2.0 and 8.0 mm depending on the light levels (Herrin, 1990; MacLachlan & Howland, 2002; Walker, Hall, & Hurst, 1990). Several researchers (Atchison et al., 2011; Bartleson, 1968; Kobashi, Kamiya, Shikawa, Goseki, & Shimizu, 2012; MacLachlan & Howland, 2002; Müller, Schnaidt, Buchwald, & Kampmeier, 2004; Perez-Carrasco, Sánchez-Ramos, Moral-Martinez, Puell-Marín, & Langa-Moraga, 2005; Winn, Whitaker, Elliott, & Phillips, 1994) have reported significant differences in pupil sizes between two lighting conditions, photopic (light), and scotopic (dark) and fairly recently have focused on a third lighting condition, mesopic (not quite dark). Human eye uses pure scotopic vision in the range below 0.05 lux, and pure photopic vision in the range above 49 lux (Cakmak, Cagil, Simavli, Duzen, & Simsek, 2010). Because of the large range of photopic vision, accurate pupil size must be determined with the level of illumination specified. This is especially crucial in refractive surgeries due to the role of pupil size in post-operative visual symptoms of glare and halo (Hashemian et al., 2012; Wang, Zhao, Jin, Niu, & Zuo, 2003). Extensive literature search show light levels have neither been investigated in smaller scale, nor have they been defined more accurately.

In refractive error, as the magnitude of spherical error increases, pupil size decreases (Cakmak et al., 2010). Smaller pupils have increased depth of focus, which in turn reduces the effect of refractive error on the blur of the retinal image (Hickenbotham, Tiruveedhula, & Roorda, 2012). There are few and conflicting reports on the effect of emmetropia, myopia and hyperopia on pupil size under various light levels (Bisneto, Temporini, Arieta, & Moreira, 2007; Cakmak et al., 2010; Carkeet, Luo, Tong, Saw, & Tan, 2002; Chaidaroon & Juwattanasomran, 2002; Collins, Wildsoet, & Atchison, 1995; He et al., 2002; Howland & Howland, 1977; Llorente, Barbero, Cano, Dorronsoro, & Marcos, 2004; Wei, Lim, Chan, & Tan, 2006). Further investigation into the refractive error aspect of pupillary light reflex is needed.

Several devices, such as corneal aberrometry topography (CAT), optical low coherence reflectometry (OLCR), Infrared Pupillometer, and Visante optical coherence tomography are available for the pupil size measurement. Visante™ OCT (ZEISS Visante OCT Model 1000, Carl Zeiss Meditec, Dublin, California, USA) is used in this study because it includes infrared measurement light with major advantages of speed of image acquisition, noncontact, high resolution, and ease of operation (Dacosta, Fernandes, Rajendran, & Janakiraman, 2008; Leung et al., 2008). Its tools enable planning and measurement of anterior chamber depth parameters, cornea and iris. Visante™ OCT use is mostly reported in studies involving disease conditions but only one study has reported its use for pupil size in healthy eyes (Dacosta et al., 2008).

The aim of this study is to investigate the effects of five light conditions and refractive error on pupil size measured with Visante™ OCT in healthy eyes.

## 2. Material and methods

Twenty-five healthy subjects (with healthy 49 eyes) were randomly recruited for pupil size imaging from the student population of the university. Exclusion criteria were abnormalities of pupil, refractive surgery or other eye surgery, glaucoma patients, history of trauma, anterior segment inflammation, and systemic diseases with ocular complications. One subject had only one eligible eye. All subjects had visual acuity corrected to 20/20 or better with spectacles or contact lens. Refractive error ranged from spherical equivalent of  $-6.75$  to  $+0.50$  D. To examine the effect of light conditions

in the presence of refractive error, subjects were grouped as myopes, (defined as  $\geq -0.50$  D spherical equivalent or as emmetropes (defined as  $-0.250$  D to  $+0.50$  D spherical equivalent). The number of emmetropic eyes (control) and myopic eyes was 29 and 20 respectively. There were no hyperopic or presbyopic subjects.

Visante™ OCT is designed for anterior segment imaging and measurement which acquires multiple A-scans and creates a two dimensional image from them. Pupil size was imaged with the “anterior segment single” protocol (scan length 16 mm; 256 A-scans) by a single examiner (Sayegh & Pineda, 2012). From images captured in the Anterior Segment mode, OCT can automatically measure the pupil size with the caliper measurement tool provided in the built-in analysis software. With the manipulation of calipers, the pupil size was determined by setting measuring points at the corresponding iris tips and measuring the space in between. Pupil size was calculated automatically by the internal software. Room illumination was measured with Digital Light Meter.

Pupil size measurements were performed with room lights at 2, 40, 150, 350 and 550 lux. All light levels were measured with the Visante™ OCT internal fixation light on. Two or three light levels per day were done per subject until all 5 levels were completed. Subjects were given a combined illumination adaptation and relaxation period of 30 min between light level changes. The experiment was performed in a white walled room with no windows that is usually used for eye examination. Lighting source was from ceiling mounted tungsten light with in-wall dimmer control that can render the room into total darkness or very brightly lit. One way to get an accurate meter reading of ambient light is to use an incident light meter, which is a handheld meter that reads the source of the light. In this study room illumination was measured with Reed LX-105 Digital Light Meter (model 407026) which has display of Lux (1 lux = 1 lumen/sq meter) in large LCD screen, this meter provides an accurate reading based on the light that hits it. Subjects were positioned with a head rest and chin in resting condition and asked to look inside the imaging aperture with no eye movement. To acquire images of the unaccommodated eye, the focus of an internal-fixation target was adjusted for the patient’s distance refractive correction. A real-time charge-coupled device displaying the position of the scan line and eye position was available to enable scan alignment. The scan line was manually adjusted to bisect the pupil. Measurement can be done in the dark without compromising the visibility of the scan location. Pupil size of each eye was measured three times and then mean calculated.

Statistical analyses were performed with InStat Software (Version 3; Graph Pad Software, San Diego, CA). Difference in pupil size measurements at various light levels with refractive groups were analyzed with Tukey-Kramer Multiple Comparisons Test. Significance level was set at 0.05.

### 3. Results

The mean age of all the 25 subjects; was  $22.54 \pm 4.65$  years (range 18 to 41 years). Mean, range and standard deviation (SD) of pupil size for total sample population is shown in Table 1. In Table 2, for the total population sample ( $n = 49$ ), multi comparison of light levels show significant difference in pupil size ( $p < 0.05$ ) in all light levels except between 150 lux vs. 40 lux, 150 lux vs. 2 lux and 40 lux vs. 2 lux.

Figure 1 shows the mean pupil sizes at the five different levels of illumination respectively for emmetrope and myope subjects. Pupil sizes were larger in myope but were not significant.

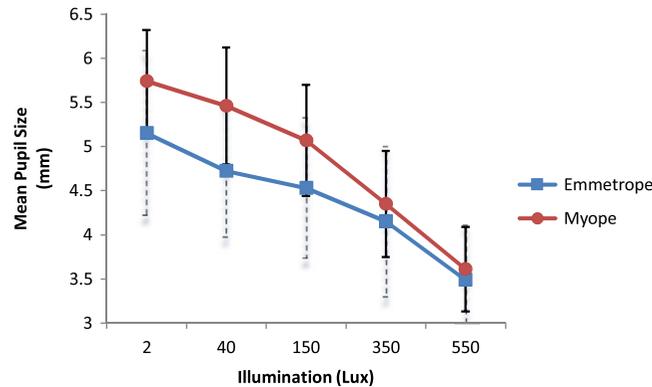
**Table 1. Mean pupil sizes (in mm) according to light levels for total sample population**

Sample size	2 lux	40 lux	150 lux	350 lux	550 lux
$n = 49$	Mean = 5.40	Mean = 5.03	Mean = 5.22	Mean = 4.24	Mean = 3.54
	Range: 2.91–7.0	Range: 3.15–7.0	Range: 2.62–6.31	Range: 2.7–6.06	Range: 2.50–4.72
	SD: 0.86	SD: 0.80	SD: 0.89	SD: 0.76	SD: 0.57

**Table 2. Multi-pairwise comparison of pupil size at five illumination levels in total sample subjects**

Comparison of pupil diameter	Mean difference (mm)	p value
550 lux vs. 350 lux	-0.69	$p < 0.001$
550 lux vs. 150 lux	-1.68	$p < 0.001$
550 lux vs. 40 lux	-1.48	$p < 0.001$
550 lux vs. 2 lux	-1.86	$p < 0.001$
350 lux vs. 150 lux	-0.98	$p < 0.001$
350 lux vs. 40 lux	-0.79	$p < 0.001$
350 lux vs. 2 lux	-1.16	$p < 0.001$
150 lux vs. 40 lux	0.19	$p > 0.05$
150 lux vs. 2 lux	-0.17	$p > 0.05$
40 lux vs. 2 lux	-0.37	$p > 0.05$

**Figure 1. Mean pupil size in emmetropes and myopes according to light levels.**



Tables 3 and 4 show pupil size is significantly different in all light levels in comparison to 550 lux for emmetropes and myopes.

There was no significant difference in all light levels between myopes and emmetropes as shown in Table 5.

**Table 3. Comparison of pupil size in myopes at five illumination levels with respect to 550 lux**

Comparison of myope pupil diameter	Mean difference (mm)	p value
550 lux vs. 350 lux	-0.74	$p < 0.05$
550 lux vs. 150 lux	-1.46	$p < 0.001$
550 lux vs. 40 lux	-1.85	$p < 0.001$
550 lux vs. 2 lux	-2.13	$p < 0.001$

**Table 4. Comparison of pupil size in emmetrope at five illumination levels with respect to 550 lux**

Comparison of emmetrope pupil diameter	Mean difference (mm)	p value
550 lux vs. 350 lux	-0.66	$p < 0.05$
550 lux vs. 150 lux	-1.04	$p < 0.001$
550 lux vs. 40 lux	-1.24	$p < 0.001$
550 lux vs. 2 lux	-1.66	$p < 0.001$

Note: There was no significant difference in all light levels between myopes and emmetropes as shown in Table 5.

**Table 5. Comparison of myope and emmetrope pupil sizes at five illumination levels**

Comparison of myope and emmetrope pupil diameter	Mean difference (mm)	p value
Emmetrope at 550 lux vs. myope at 550 lux	0.12	$p > 0.05$
Emmetrope at 350 lux vs. myope at 350 lux	0.20	$p > 0.05$
Emmetrope at 150 lux vs. myope at 150 lux	0.54	$p > 0.05$
Emmetrope at 40 lux vs. myope at 40 lux	0.58	$p > 0.05$
Emmetrope at 2 lux vs. myope at 2 lux	0.65	$p > 0.05$

#### 4. Discussion

This study investigated effect of five light levels (2, 40, 150, 350 and 550 lux) not previously examined and the result for the total population sample support previous studies suggesting that pupil size decreases in a linear manner with increasing illumination (Atchison et al., 2011; Bartleson, 1968; Kobashi et al., 2012; MacLachlan & Howland, 2002; Müller et al., 2004; Perez-Carrasco et al., 2005; Winn et al., 1994). In this study pupil size significantly increased from 550 to 150 lux, after which there was no appreciable increase (Table 1). This implies change in lower photopic levels do not generate appreciable change in pupil size (Table 2). This observation is also evidenced in a study by Dacosta et al. (2008) using Visante™ OCT under scotopic and photopic (at 310 lux) conditions, obtained photopic value of pupil diameter (mm)  $4.08 \pm 0.91$ , scotopic value of pupil diameter (mm)  $4.68 \pm 0.92$ , a mean difference in pupil size of about  $-0.60$  mm. In the present study, light level of 350 lux and the lowest illumination light level of 2 lux gave a mean pupil size difference of  $-1.16$  mm. The difference could be attributed to their larger sample size with inclusion of older subjects and hyperopes (smaller pupils) in their study.

It is unlikely the fixation light deep inside the Visante™ OCT contributed significant illumination of the pupil as a study showed that a windowless room with the door slightly opened by 1–2 inches to allow in some light from the hallway measured with infrared pupillometry registered a value of 0.5–0.6 lux (Oshry, 2011). Dacosta et al. (2008) study with Visante™ OCT for pupil size indicated in their method that “to obtain maximum pupil dilation in the dark, the subjects were instructed to continue fixing on the internal target until the room lights went off, and imaging was repeated”. The measurements (principally at low lux) in my study are therefore reliable as a measure of the “true” pupil diameter at the intended light levels.

For refractive error groups, as shown in Figure 1, my results do agree with the general clinical impression, myopes have larger pupils than emmetropes but which is also not supported by some studies (Bisneto et al., 2007; Cakmak et al., 2010; Carkeet et al., 2002; Chaidaroon & Juwattanasomran, 2002; Collins et al., 1995; Dacosta et al., 2008; He et al., 2002; Howland & Howland, 1977; Leung et al., 2008; Llorente et al., 2004; Wei et al., 2006). Within the myope group, pupils size show a mean difference of  $-2.13$  mm between 550 lux and 2 lux while within the emmetrope pupils size was  $-1.66$  mm between 550 and 2 lux (Tables 3 and 4) and was not significant in Table 5. It therefore appears that the larger myopic pupil dilates or constricts more than the relatively smaller emmetropic pupil to reach minimum and maximum pupil size threshold to light levels. The pupil size data under various light levels obtained in this study may assist in understanding the pupillary light reflex and in diagnosing pupillary abnormalities.

#### 5. Conclusion

The systemic changes were observed in pupil size with illumination and there is no appreciable pupil dilation below illumination level of 150 lux. Refractive error (emmetropia or myopia) does not have additional effect on pupil light reflex.

### Funding

The author received no direct funding for this research.

### Competing Interests

The author declare no competing interest.

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### Citation information

Cite this article as: Effects of varying light conditions and refractive error on pupil size, Farah Maqsood, *Cogent Medicine* (2017), 4: 1338824.

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