Article ▸ Pupil Diameter and Illuminance Measurements in Day and Night Baseball Game Scenarios

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ABSTRACT

Purpose: To measure the amount of day game (natural) and night game (artificial) illuminance at home plate at the lateral canthi and to determine if day game pupil diameter can be simulated by artificial light levels at night.

Methods: Twenty-two subjects stood at home plate, wore a baseball cap, and looked at a distance target (60.5 feet away) while five photos were taken during each scenario. Illuminance was then measured three times at home plate and at each lateral canthi. Three day game and night three game images, of the same eye, were filtered to enhance pupillary margins. Diameters were measured using Adobe Photoshop CS4. A paired sample t-test was used to compare day-night pupil diameters and illuminance.

Results: Mean day game pupil diameter and standard deviation was 2.58 ± 0.45 mm. Night game diameter mean ± SD was 6.45 ± 1.11 mm. The mean ± SD diameter increase was 3.87 ± 1.14 mm (P<0.001, r=0.120). Average day game illuminance (foot-candles) measurements were: Home plate = 3907.62, OD = 4505.87, OS = 4096.77. Average night game illuminance measurements were: Home plate = 12.11, OD = 5.60, OS = 5.23. Day game illuminance measurements between home plate and each canthus were not found to be statistically significant (POD=0.344, POS=0.751), but were for night game measurements (POD=<0.001, POS=<0.001).

Conclusion: Significantly less light is available to the eye during artificially lighted night game scenarios than during naturally lighted day game scenarios. The magnitude of this difference depends on where illuminance is measured. Subjects experienced a change in pupil diameter at night consistent with earlier studies.

Keywords: baseball, illuminance, pupil diameter, visual task analysis

Introduction

Several previous efforts have been completed to profile the visual make-up of baseball players.[1-3] The intent of many of these studies is to investigate the link between certain visual skills and success in baseball performance,[4,5] whether or not performance improves by changing the visual aspects of the game or player,[6-10] or simply what occurs physiologically when a batter is facing a ball they intend to hit.[11-16]

Stopping to consider the visual demands placed on a batter while hitting, it is easy to conclude that hitting a baseball is a unique and challenging task requiring investigation. Batters are given less than a second to view and then analyze facets of the pitcher's delivery (arm slot, speed, the grip on the ball, etc.) and the ball itself (spin pattern, trajectory, speed). Correct analysis can help the batter identify the type of pitch thrown, predict the ball's approach, and anticipate the time at which it will cross the plate. In addition, batters are doing this across dynamic environments.

Noise levels rise and fall, teams travel to different stadiums, pitchers are replaced and lighting levels go from high noon to dusk and finally to the artificially lighted environment of a night game. All levels of baseball competition have different lighting standards. Studies have attempted to analyze the differences in offensive statistics between night and day game scenarios for professional baseball players.[17] Table 1 shows changes in illumination based on level of competition or the presence television broadcast equipment.

As light levels increase or decrease over the course of a game, the iris' pupil diameter responds. It attempts to maximize the amount of light entering the eye through dilation, while limiting the deleterious optical effects of higher order aberrations through pupil constriction.

Table 1. General Lighting Guidelines.[18]

Level of Competition	Horizontal Illumination in Foot-Candles (fc)	
	Infield	Outfield
International/Olympics	150	100
Minor Leagues – AAA & AA	100	70
Minor League – A & Rookie	70	50
College – Non-Televised	70	50
College – Televised	100	70
Recreational	30	20

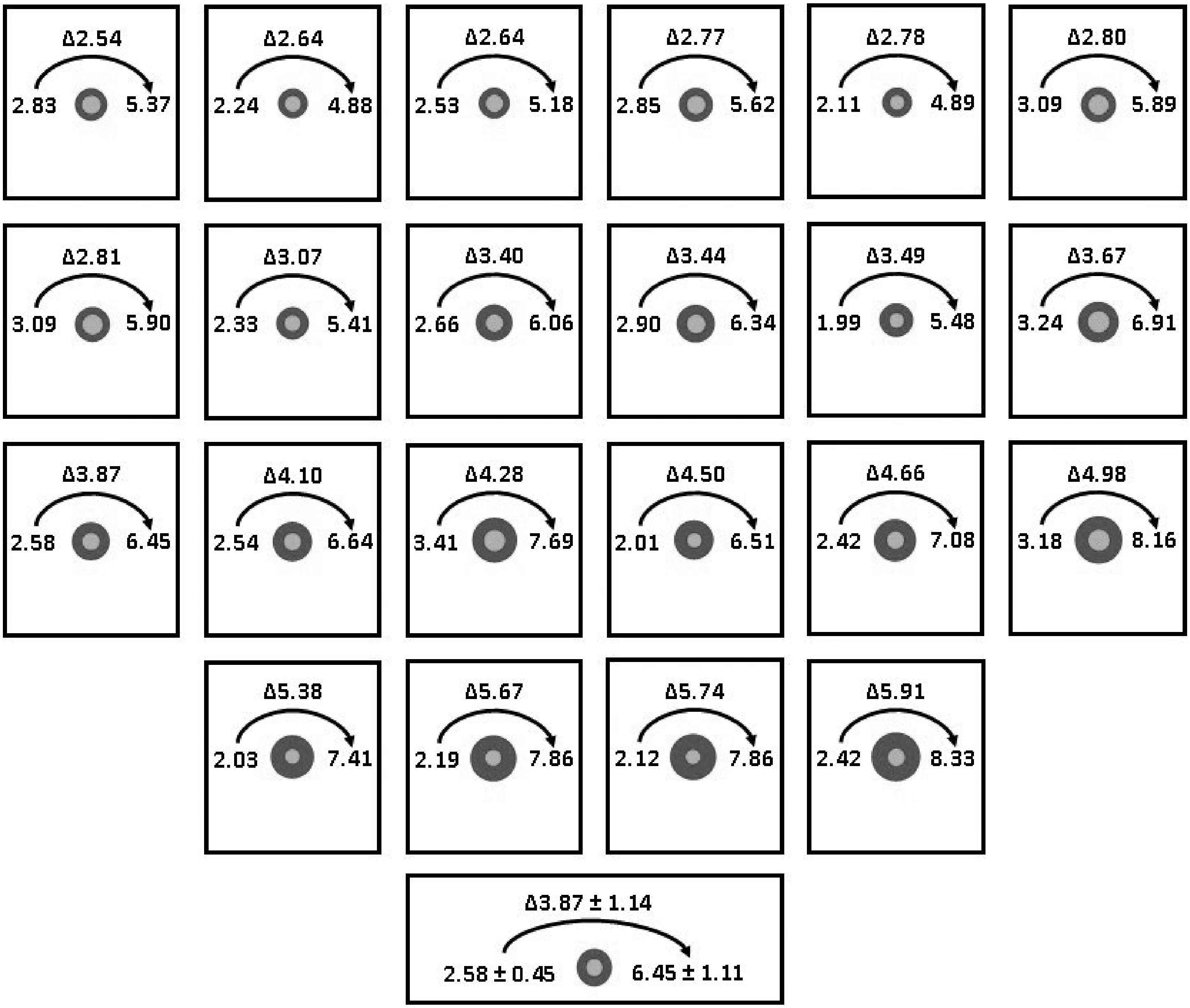

Figure 1. *Day game and night game pupil measurements. Ordered by magnitude of change for all 22 subjects. The bottom box shows the averages of all measures.*

Given that ambient illuminance effects pupil size directly, which in turn influences retinal image quality, this study sought to investigate if the artificial lighting available on a baseball field during a night game would produce similar pupil diameters as those observed in day game scenarios. There are no existing studies discussing the effect of pupil size or illuminance variations on baseball performance.

Methods

Twenty-two subjects, 16 males and 6 females, were recruited from Midwestern University Glendale Arizona campus. Subjects were between the ages of 18 and 35. All were capable of 20/20 (6/6) vision or better (with or without correction) in each eye at distance on the Snellen visual acuity chart. Subjects were excluded if they were taking any medications known to alter pupillary response (anti-psychotics, anti-allergy, anti-anxiety/anti-depressants, recreational drugs, painkillers, cardiovascular medications, asthma inhalers). No subjects were pregnant at the time of the study. Methods and procedures used in recruitment of subjects and performance of this study adhered to the tenets of the Declaration of Helsinki. The Midwestern University-Glendale institutional Review Board approved these methods and procedures. Subjects gave written informed consent prior to participation and after the nature and possible consequences of the study were explained.

Subjects were asked to come to a little league baseball field for a night game (630PM to 930 PM) and day game (6 AM to 12 PM) session of photos. Pictures were taken with each subject standing at home plate, wearing a baseball cap, and fixating vision upon a distance target on the pitcher's mound (60.5 Feet away) while facing the pitcher's mound. Five photos were taken of each eye from a distance of 15 inches while the subject was in primary gaze. In order to avoid varying photo distance, which would lead to measurement error, a piece of

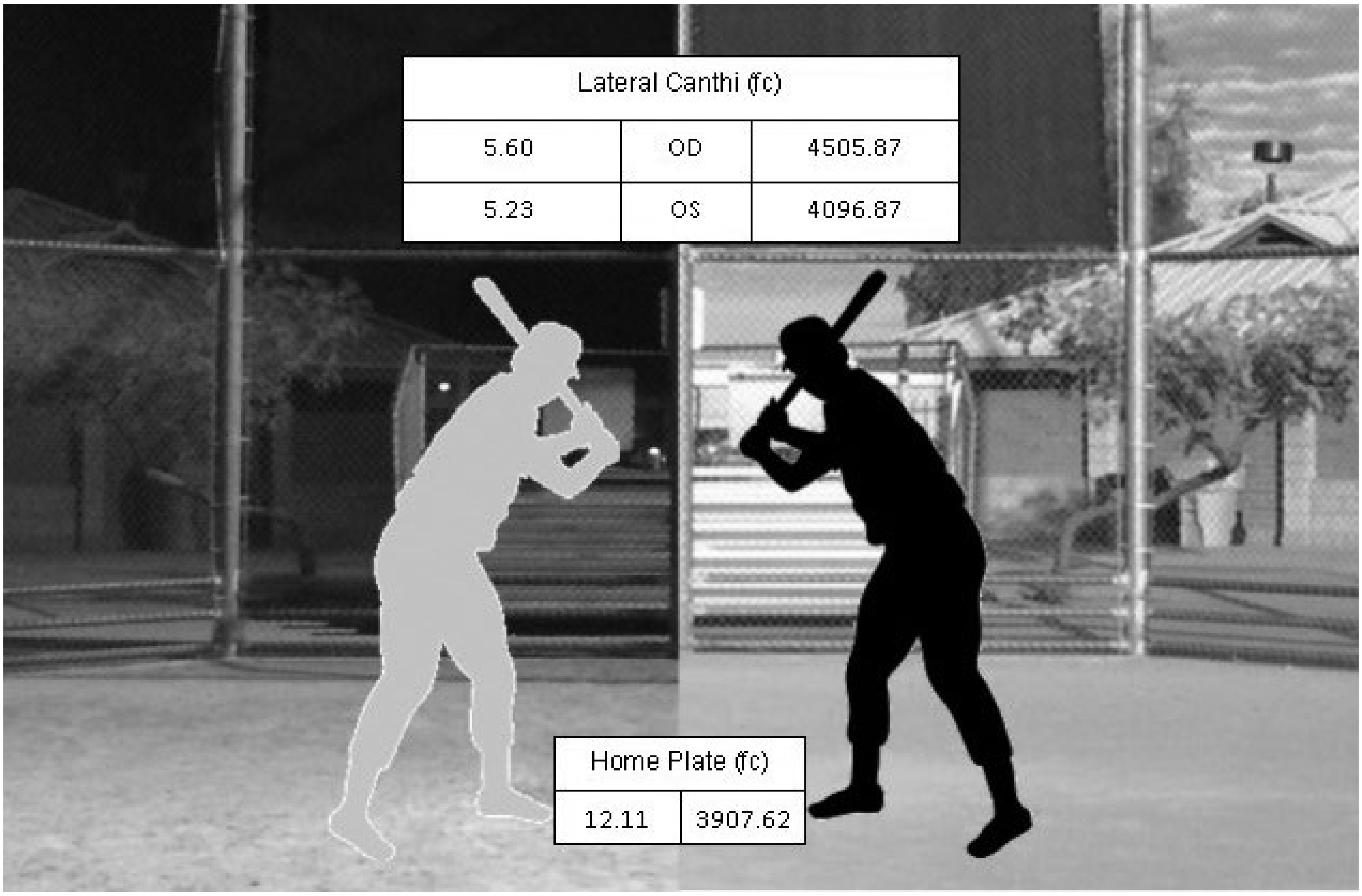

Figure 2. *Day game and night game average illuminance measurements.*

thread with a white button was fixed to the camera. Subjects placed the button at the lateral canthus of the eye that was being photographed. This method provided a known standard in size to which the pupil would be compared and a true pupil diameter could be calculated from the photographs. After photographs were taken and while the baseball cap was still on, three illuminance measurements were taken at each lateral canthus. Three additional illuminance measurements were taken at home plate after the subject had stepped away. Illuminance was measured using a Sekonic i-346 Illuminometer (Sekonic Corporation, Japan). This device simply measures all available ambient light and calibrated by the manufacturer prior to shipping. Researchers were careful to avoid obstructing the optical pathway to the light sensor when measuring illuminance at home plate and positioned the sensor under the cap at each lateral canthi to ensure that it rested in the shade of the cap's brim. In order to eliminate the effect on pupillary response from flash and the flashes effect on lateral canthi illuminance measurements, flash was not used during night time photography.

To enhance the pupillary margins in the digital images, photos were filtered with an Apple "Tonal" filter using iPhoto (Apple Inc., Cupertino, CA) software. Using a method of pupillary measurement similar to one previously published,[19] the pupil diameters were measured. One eye, from each subject, was measured in three night photos and three-day photos. Eyes were selected by the quality of the night images, giving the best chance of accurate measurement (11 OD and 10 OS). Using Adobe Photoshop CS4 (Adobe Systems Incorporated, San Jose, CA) the horizontal diameters of the button and pupil were measured. This measurement was then used to calculate the true pupil diameter using the formula:

$$\text{True Pupil Diameter} = \frac{\text{Photoshop Measured Pupil Diameter X 11.8mm}}{\text{Photoshop Measured Button Diameter}}$$

Three day game true pupil diameters were then averaged to provide true day game pupil average. The same was done with the three night game true pupil diameters. The difference between the true day game pupil average and the true night game pupil average was then calculated for each subject. Three illuminance measures at home plate and each lateral canthi were averaged together to obtain night and day illuminance measurements for home plate and each lateral canthi.

Using a paired t-test, we determined if a statistically significant difference exists between day game true pupil diameter averages and night game true pupil diameter averages. We also measured for statistically significant difference between illuminance measurements at home plate and each lateral canthi during day and night game scenarios.

Results

The average day game true pupil average was measured and calculated to be 2.58±0.45mm. The average night game true pupil average was 6.45±1.11mm. The average change in these was 3.87±1.14 mm ($P<0.001$, $r=0.120$). As expected, pupil diameters of all subjects increased in night game scenarios (Figure 1).

Average day game illuminance measurements were higher at the lateral canthi (OD = 4505.87 fc, OS = 4096.87 fc) than at home plate (3907.62 fc). The differences in day game illuminance averages, between the lateral canthi and home plate were not found to be statistically significant (POD=0.344, POS=0.751). Night game illuminance was 40.3% less than the recommended 30fc, but were higher at home plate (12.11 fc) than at the lateral canthi (OD = 5.60 fc, OS = 5.23 fc). This difference between home plate and lateral canthi was found to be statistically significant (POD=<0.001, POS=<0.001). Figure 2 provides these measured averages.

Discussion

It is difficult from publically available information to determine how lighting standards were created, and how or where to measure illumination. This study showed that measurements between home plate and the lateral canthi were significantly different in the night game scenario. Factors such as angle and position of the artificial lights, and position of the baseball cap or batting helmet will affect the level of light available to the eye. The amount of light available to the retina is even less than ambient availability due to the absorptive properties of ocular tissues and fluids. There have not been studies investigating whether or not illuminance variation at night can explain performance differences between one stadium and another. A study such as this could also influence standardization and compliance to recommended lighting standards.

This study reminds the reader of the remarkable adaptability of the human visual system across illuminances. Measured illuminance observed between day game and night game scenarios showed a tremendous drop in light levels. On average, subjects experienced a 99.88% reduction in illuminance at the lateral canthi from day game scenarios to night game sessions. Given the different lighting recommendations observed between Little League (Recreational) and other ball fields, we should be cautious in translating the raw findings in this study to the professional level until a similar study is performed on those athletes in their major league surroundings.

A previously published study measured the "presence, type and size" of higher order aberrations (HOA) in professional baseball players and compared their measurements to those found in non-baseball players.[3] Subjects participating in this study were required to have a natural pupil dilation of at least 4 mm when taking HOA measurements. The authors found that there was no clinically significant difference between the two groups and concluded that lower order aberrations like defocus and astigmatism limit a baseball player's vision. With the understanding that HOA's degrade vision as the pupil diameter increases, it would be interesting if a similar result would be found when HOA's could be measured in an environment mimicking the ambient light levels of those found on the professional field at night. Large pupil diameters or a large change in pupil diameter in professional athletes could affect their athletic performance at night as visual acuity, dynamic visual acuity, contrast sensitivity, vergence and/or accommodative facility are impacted by this anatomical alteration. Could a large pupil diameter or a large change in pupil diameter at night possibly explain why some MLB players perform better at night while others perform better during the day?[19]

The average diameters (Day = 2.58±0.45mm, Night = 6.45±1.11mm) from this study are very similar to those found by Twa et al. when measuring pupil diameter with digital photography.[19] They found a measured a 2.76±0.46mm diameter in a "bright" (1000 lux) setting and a 6.33±1.17mm pupil in a dark (<0.63 lux) setting. It should be noted that our night game canthal illuminance measures on average (OD = 60.23 lux, OS = 56.30 lux) fell between Twa's dim (5 lux) and bright settings. This variance could be attributed to our uncontrolled, outdoor environment. Still, both studies illustrate a day to night (or bright to dark) change in pupil diameter in the 3.57-3.87mm range. These averages lie within an accepted range of 2-4 mm.[20] It is interesting to note that of the 22 eyes measured, nine (41%) fell beyond this range, illustrating that not everyone experiences an identical day to night pupil dilation.

This variability may not play into clinical relevance or impact the visual experience for the majority of patients. However, it may impact an athlete's ability to perform a visually demanding task in very stressful settings by capping vergence and/or accommodative facility. As other studies have attempted to investigate the relationship between visual skills on on-field performance, a study investigating whether a large pupil diameter or a large day-to-night change in pupil diameter has a greater impact on performance should be performed.

Future studies attempting to discover correlations between visual factors and baseball performance should consider using more modern analytics in their investigations. Though batting average is a statistic that has been used for over 100 years, it is an imprecise number that eliminates well-struck balls that end up as "outs" and punishes a player for not swinging at a ball outside of the strike zone. Instead of the more interdependent performance metrics such as batting average and slugging percentage, investigators should eliminate as much noise from the data by using behavior metrics. Novel, creative and more descriptive baseball statistics such as Swing%, Z-Swing%, O-Swing%[21] or Z-Maps[22] can isolate visual successes by examining behavior rather than production at the plate.

Of course, studies determining which pupillary feature (size or change in size) affects performance should not be limited to baseball statistics. The impact of these on a subjects' visual acuity, contrast sensitivity or any other visual abilities on day to day life, is worthy of investigation.

Conclusion

The increase in pupil diameter observed across our sample could have been anticipated when simply considering pupil change that occurs when moving from light to dark. All pupils responded in the expected fashion of dilating under conditions where less light is available. This study assessed if night game lighting produce similar pupil sizes at home plate as day game lighting conditions. The results of this study show that night game true pupil measurements were significantly larger than their day game counterpart.

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