JOURNAL OF
EMERGING INVESTIGATORS

Article

Eye color, visual acuity and photophobia: How eye color affects light sensitivity

Sophia N. Spencer[1], Rebecca R. Young[2]
[1] Brentwood School, Los Angeles, California
[2] Duke Clinical Research Institute, Duke University, Durham, North Carolina

SUMMARY

Photophobia is eye discomfort in bright light environments and is linked to migraines, which millions of people experience each year, leading to severe to pain and lack of productivity. However, it is unknown if photophobia is related to vision and eye color. This study aimed to measure the impact of eye color and visual acuity on light sensitivity. We hypothesized that people with blue eyes would have more photophobia compared to people with green or brown eyes, that people with worse light vision would have worse photophobia compared to individuals with strong visual acuity, and that photophobia would be prevalent in an elementary school population. This cross-sectional study evaluated participants in an elementary school population including students, teachers, and administrators, ranging in age from 6–72 years old. We assessed visual acuity using a Rosenbaum Vision Chart and assessed photophobia using a modified three question UPSIS-17 Photophobia Symptom Impact Scale. In the primary analysis, we found no significant association between eye color and photophobia (W=0.65, *p*=0.724). Additionally, we found no correlation between light and dark vision and photophobia scores (Spearman's Rho=0.08, *p*=0.467), (Rho=0.11, *p*=0.319). In conclusion, we observed no substantial difference in vision by eye color. Remarkably, participants who reported high levels of photophobia did not have decreased light vision. There was no association between eye color and photophobia, however photophobia was prevalent in elementary school students.

INTRODUCTION

Migraines are a serious health problem that affect many people of different ages, with a prevalence of 6% in males and 18% in females (1,2). People who experience migraines frequently need to miss several days of work, and this loss of work due to migraines is estimated to cost the US economy 13 billion dollars a year (3). The cause of migraines is not well understood, but there is a known link between photophobia and migraine: 80% of migraine patients report photophobia, defined as discomfort in bright lights, during a migraine (1). In fact, photophobia is so common during migraines that it can be used as a diagnosis criterion (1). By better understanding the cause of photophobia there might be a way to develop more effective treatments for migraines.

Photophobia is the sensory state in which bright light conditions cause discomfort, which is believed to have evolved from the danger of directly looking into the sun (1). There are many nerves in the eye that contribute to photophobia (1). These nerves can relay pain signals to the brain (1). One common consequence of photophobia is a signal from the trigeminal nerves (located in the conjunctiva, cornea, sclera, uvea and iris) to blink (4). Rods convert photons to chemical signals through the retina, and then the chemicals signals are transmitted to the brain cells, which can also lead to photophobia (4). Rods are highly sensitive to light (4). The pathway that relates light photons to photophobia symptoms is called the retino-thalamo-cortical pathway (5). The nerve cells in the retina relate to the thalamic trigeminovascular neurons, which can cause migraines (5). Light sensitivity causes headaches that get worse, as well as a change in perception of light, words, and smells (6). If someone is experiencing a migraine, they may find blue light, like the light emitted from electronics, to be especially painful (7). Symptoms such as light-headedness, dizziness, nausea, vomiting, and salivation can co-occur with photophobia during a migraine (5).

Photophobia can be challenging to prevent, as avoiding bright light is not always feasible (4). There have been no major clinical trials to fully treat photophobia (8). Sunglasses are the best photophobia prevention, but using sunglasses in most instances can reduce tolerance to bright lights, which can be harmful (4). Treating dry eyes can treat photophobia, and if migraine prevention medication is used, photophobia is less likely to happen (4). There is a large amount of variation in photophobia severity in healthy adults, where age and photophobia severity were not found to be correlated (8). Severity is often assessed using the verified Utah Photophobia Symptom Impact Scale (UPSIS-17), which is composed of 17 Likert questions (9). Furthermore, it is unknown whether photophobia leads to reduced vision, and if vision is better in bright light or dark settings. Some people report having higher vision in bright light conditions and others report having better vision in dark conditions (9). Interestingly, blind people can still experience photophobia (10). Photophobia is also rarely studied in students, despite reports that it can be experienced by youth (4). It is therefore possible that bright classrooms could make learning uncomfortable for students with photophobia (7).

While there are many possible avenues for studying photophobia, this study focuses on the effects of eye color on vision and photophobia. Eye color is unique to each individual person, genetically determined from the gene *OCA2* (9, 11). The colored part of the eye is called the iris, which helps to control the size of the pupil (12, 13). Melanin is a molecule that creates pigments in many parts of the body, including the eyes, and is correlated with eye color (12). Typically, the more melanin a person has, the darker their eye color, though this is not true for everyone (14). Most

https://doi.org/10.59720/25-270

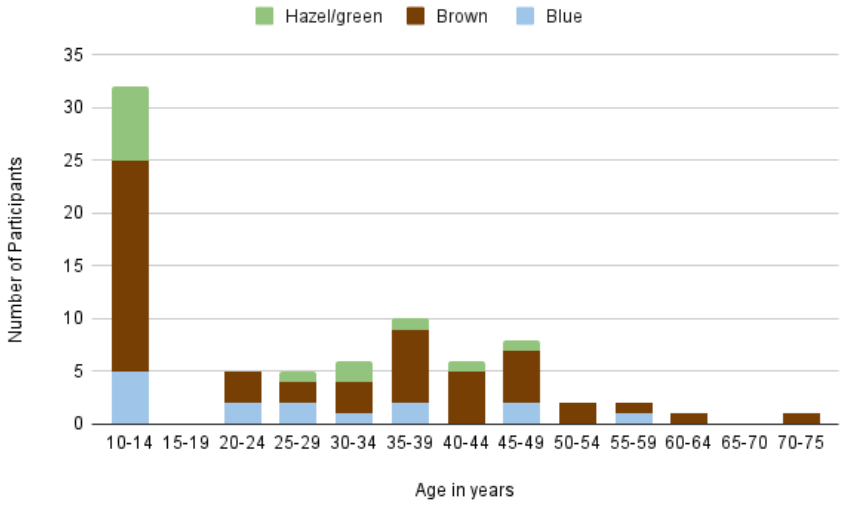

Figure 1: Distribution of eye color by age range of study participants. A stacked histogram shows the distribution of the age of study participants in 5-year intervals. Eye color (green/hazel, brown, and blue) is shown by the color of the bar. Age was not equally distributed among the study participants. Due to recruiting restraints, most subjects were 10–14. No study participants were between 15–19 or 65-70.

people have melanin in the back of the iris, but people with lighter eye colors like blue have little to no melanin in the front of their iris (12). People with green or hazel eyes have an intermediate amount of melanin in front of their irises, and people with dark brown eyes have the most melanin in their irises (12). The association between eye color and vision is not well understood. Melanin-concentrating hormone is a neuropeptide involved in the deposition of melanin molecules into the iris (6). This hormone is also hypothesized to be involved in the biochemical pathways relating to photophobia (15).

Our primary hypothesis was that eye color would impact photophobia. Specifically, we hypothesized that people with more melanin in their eyes experienced less photophobia due to the ability of melanin to absorb photons. A secondary hypothesis was that people with photophobia saw better in the dark and worse in the light, due to photophobia discomfort, compared to people without photophobia. The prevalence of photophobia in school-aged students is unknown (7). Therefore, the effect of photophobia contributing to vision disturbances in this age group has not been well studied. We did not observe any difference in visual acuity by eye color, either in light or dark environments. Interestingly, on average, people who reported having photophobia did not have worse vision in the light. However, this study did show prevalent photophobia in elementary-school aged children. This study helps to bring awareness of photophobia to many age groups with a possibility to make accommodations to help those who have photophobia be more comfortable.

RESULTS

To test the association between photophobia, vision, and eye color, we administered a series of assessments to 78 students and staff at an elementary school. We tested visual acuity using the logarithm of the minimal angle of resolution (logMAR) scale in both bright (logMARLight) and dim (logMARDark) conditions. We also administered a variation of the UPSIS-17 scale to quantify photophobia with possible values of 0 (no photophobia) to 15 (extreme photophobia). Finally, we asked questions about eye-color and difficulty with vision.

First, we analyzed the participant age distribution and eye color distribution (**Figure 1**). No participants were between the ages of 15–19 or 65–70. Forty-one percent of the population were between the ages of 10–14 years old and 59% of the study population were school staff members between the ages of 20-75. Green/hazel, blue, and brown eyes were found in 16.67%, 19.2% and 64.1% of the population, respectively. We saw a bimodal distribution, where there were many students of a similar age, and school staff had a wider range of ages.

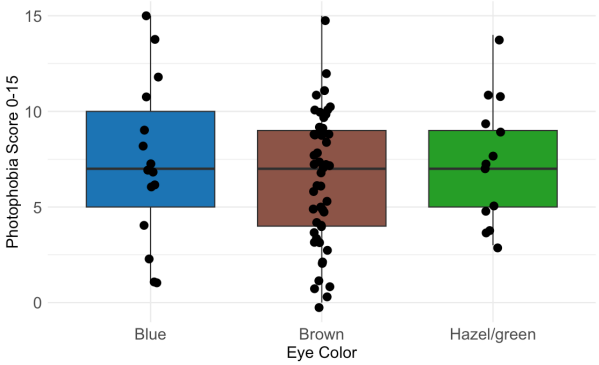

Figure 2: There is no significant association between eye color and reported photophobia. The distribution of photophobia questionnaire results is shown for each eye color (blue, brown, and hazel/green). Photophobia Questionnaire by eye color showed no significant difference by a Wilcoxon Sum Rank Test (p=0.7244, W=0.65).

https://doi.org/10.59720/25-270

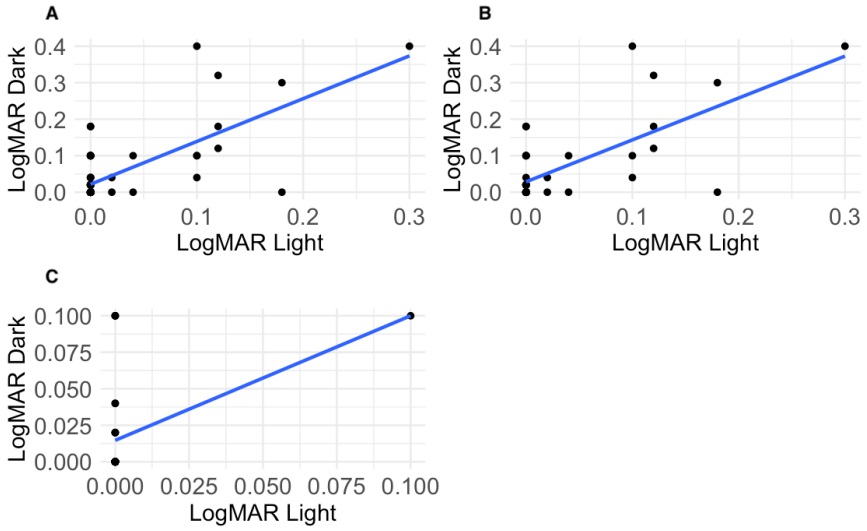

Figure 3: Correlation between light and dark visual acuity across the entire study population (A), in staff only (B), and in students only (C). A) A scatter plot recorded a significant correlation between logMARLight and logMARDark between all human subjects (Rho=0.47, p<0.01) and B) only staff (Spearman's Rho=0.49, p<0.001). C) There was no significant correlation between logMARLight and logMARDark between the students (Spearman's Rho=0.34, p=0.057), by a Spearman's Rho correlation test. The blue line represents the line of best fit.

We analyzed the distribution of photophobia by eye-color using a Wilcoxon Rank Sum test (**Figure 2**). We found no significant difference in reported photophobia by eye color (W=0.65, p=0.724). Therefore, our primary hypothesis that photophobia differs by eye color was not supported.

Next, we use Spearman's Rho tests to assess the correlation between visual acuity in light and dark settings. There was a strong correlation between visual acuity in the light and visual acuity in the dark for all participants, (Rho=0.47, p<0.01) (**Figure 3**). We found a strong correlation between logMARLight and logMARDark in the staff subset of the school population (Rho=0.49, p<0.01). Among students, who were 39.7% of the population, there was a strong correlation between logMARLight and logMARDark, (Rho=0.34, p=0.057). Many students (96.8%) had perfect vision in the light and 71% of students had perfect vision in the dark. Among the staff, 70.2% had perfect vision in the light and 46.8% had perfect vision in the dark. Two test subjects had better dark vision than light vision, whereas 15 test subjects saw better in the light and 61 saw the same in the

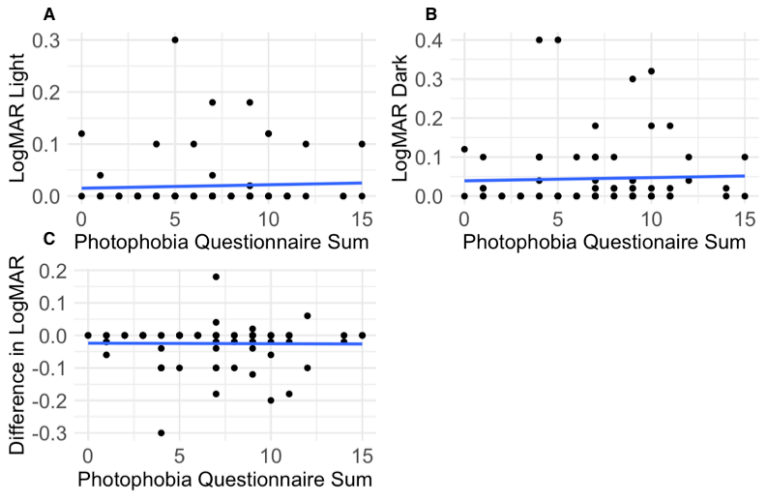

Figure 4: There is no significant correlation between photophobia and any of the following: light vision, dark vision, and difference between light and dark vision. A) A scatter plot shows no significant correlation between Photophobia Questionnaire Sum and logMARLight (Rho=0.08, p=0.467), B) logMARDark (Rho=0.11, p=0.319) and C) Difference in logMAR (Rho=-0.05, p=0.644). The blue line represents the line of best fit.

https://doi.org/10.59720/25-270

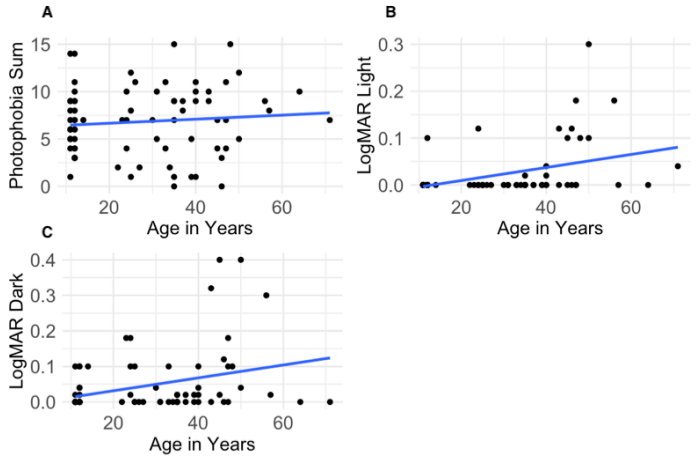

Figure 5: Visual acuity is correlated with age in light and dark environments. There is no correlation between age and photophobia. A) A scatter plot shows no significant correlation between age in years and the photophobia questionnaire sum (Rho=0.12, *p*=0.312). There is a significant correlation between age in years and B) logMARLight (Rho=0.45, *p*<0.01) and C) logMARDark (Rho=0.35, *p*<0.01). The blue line represents the line of best fit for each plot.

light and the dark. Most people in this study (89.7%) reported more difficulty seeing in dim light environments compared to bright light (10.3%). This result was consistent throughout all eye colors. Overall, there was a strong correlation between light and dark visual acuity; however, many participants had perfect vision in both environments, which caused clustered data points.

We hypothesized that people with photophobia would have worse visual acuity in light conditions than in dark light conditions. However, there was no correlation between the degree of reported photophobia and logMARLight (Rho=0.08, *p*=0.467), logMARDark (Rho=0.11, *p*=0.319) and the difference, within one person, between their logMARLight and logMARDark (Rho=-0.05, *p*=0.644) **(Figure 4).** There was a large range of results from the photophobia questionnaire (**Figure 2**). However, we found that 29 participants (37.2%) reported some limitations for reading in bright light environments. This result shows that photophobia was present in our study and reported by people of all ages.

As vision can change dramatically with age, we were

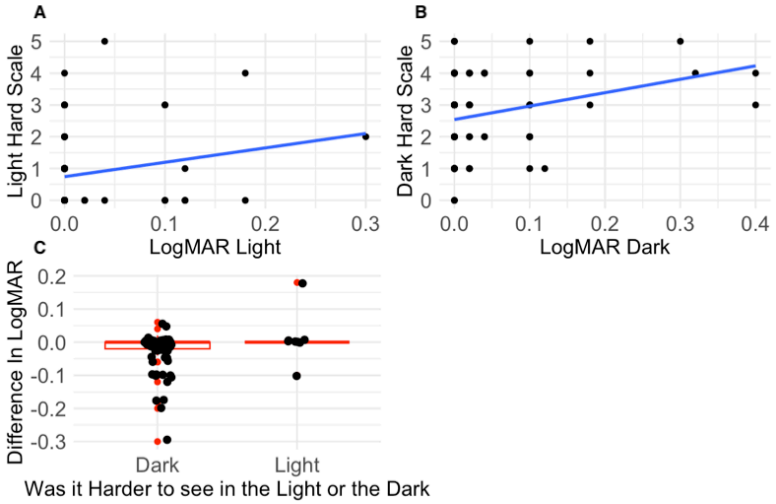

Figure 6: Correlation between reported difficulties seeing in the dark or light, and actual visual acuity in the dark or light. A) A scatter plot shows no significant correlation between logMARLight and participant-reported visual acuity in the light (A, Rho=0.06, *p*=0.557). B) There is a significant correlation between logMARDark and participant-reported visual acuity in the dark (Rho=0.26, *p*=0.022). C) A box and whisker plot shows no significant association between whether the participant reported seeing as more difficult in the light vs the dark and the Difference in logMAR (W=197, *p*=0.133). The blue line represents the line of best fit.

https://doi.org/10.59720/25-270

interested if our results were true when we looked at the subset of students and adults separately (16). A Spearman's Rho test found no correlation between age in years and logMARLight (Rho=0.45, p=0.312). However, there was a significant correlation between logMARDark, and age in years (Rho=0.35, p<0.01) **(Figure 5).**

The test subjects reported how difficult they felt it was to see in the light and the dark on a scale from 0--5, 0 being not difficult and 5 being challenging. Participants who reported difficulty seeing in the dark had worse dark vision, but the opposite with light vision was not true (**Figure 6**). A Spearman's Rho test found no correlation between logMARLight and the reported difficulty seeing in the light (Rho=0.06, p=0.557). There was a significant correlation between logMARDark and the reported difficulty seeing in the dark (Rho=0.26, p=0.022). There was no significant association between increased reports of difficulty seeing in the light more than dark vs. logMAR (W=197, p=0.133) **(Figure 6).**

DISCUSSION

We did not detect any differences between vision and photophobia by eye color in our study. Additionally, the relationship between vision and photophobia was similar between eye colors. Light and dark vision were very strongly correlated. Since light and dark vision are recorded in the same person, we would expect to see a high level of correlation between these two. The strong correlation that was observed provides reassurance that the vision test was accurate. Light sensitivity causes eye strain and eye discomfort. Therefore, it is plausible to believe that high photophobia would be highly correlated with lower vision in a light environment. However, we did not detect any correlation between photophobia and light vision.

Many people experience a decline in vision as they age (16). Ideally the statistical models would control for age. However, due to small sample size, we used non-parametric unadjusted analysis. We performed a sensitivity analysis where all tests were conducted in students only and staff only. In both sub-populations, we found no correlation between photophobia and vision. Due to logistical constraints, all participants needed to have access to the approved experimental facility. Therefore, the age distribution of this study did not match the larger population; most participants were between 10–14 years old. Vision and photophobia both change with age (4), meaning that age is a confounding factor in this experiment and should be studied further. Due to scheduling limitations, potential test subjects under the age of 10 were not able to participate.

There are several methodological improvements that could have been made. The most impactful improvement would be a larger sample size. In addition, this study did not account for people who wear contact lenses or glasses. We tested corrected vision instead of uncorrected vision. Contact-wearers were not asked to remove their contacts, as there was no appropriate handwashing sink in the experimental area. Future studies should include elementary school children and participants who are over the age of 60. Further, different characteristics of light could be analyzed. Dark vision should be tested without external light, including the pen light which was used to help see the Rosenbaum Pocket Vision chart. It is possible that the brightness in the study was not bright enough to induce photophobia. In the future we would consider conducting this study with brighter lights. The Rosenbaum Pocket Vision chart has high contrast—it is possible that a lower contrast vision screen would lead to different results. This study did meet the enrollment target, but there was not enough statistical power to discern differences in photophobia between eye colors. The majority of people in this study had brown eyes (64.1%), which resulted in less statistical power. This study did not determine a cause of photophobia. Future studies could examine associations between anatomical features of the eye and photophobia. Future studies should be conducted with an older population.

Our research builds upon the work on a cross-sectional study performed in classrooms in Malaysia that tested reading speed of students with low vision in a variety of lighting conditions (7). This study reported that students with lower vision were able to read faster in bright light environments (7). Lux is the quantity of light that falls on a surface, and the authors recommend that the optimal lux level in a classroom is between 276.67–701.59 lux; however, that study did not consider students with photophobia (7). Our result confirms that most people have better vision in bright light environments compared to dim environments. This should be considered when determining light brightness in public spaces. Therefore, when deciding the optimal amount of light in a public space like a classroom, we suggest that it is important to balance both the needs of people with low vision and the people with photophobia. Future work should further study the optimal amount of light in a classroom environment. Another factor to consider is the temperature color of the lighting. Future studies should be conducted to understand which wavelengths of light is best for people who experience photophobia.

Photophobia can occur at all ages, including in children. However, there is little awareness of the causes and consequences of photophobia in youth (17). This study contributes to the field by showing photophobia could be present in participants aged 10-14 years. Awareness of the frequency of photophobia in school aged children could help to minimize discomfort while learning in different levels of brightness.

MATERIALS AND METHODS

General Overview

This study was conducted in 78 participants in the Mirman School community. A human consent form was sent out to each of the test subjects, which were signed before testing began. An email was sent to all students in 5th through 8th grade requesting participation, and staff at the school were personally contacted.

Before Contact with Test Subjects

This study was conducted at the start of the COVID-19 pandemic. Therefore, strict sanitation protocols were followed. At the start of each participant's designated testing window, all instruments were sterilized with 99.99% alcohol disinfecting wipes. When resetting the procedure, all windows/blinds were opened, and lights were turned on in the room to mimic light sensitivity testing in the bright conditions.

https://doi.org/10.59720/25-270

Informed Consent Procedures

A consent form was required for all participants. If a participant was under age 18 years, their parent/legal guardian was required to co-sign the consent form. The consent form allowed participants to withdraw from the study at any point. The consent form described the purpose of the study, as well as a brief description of the procedures.

This study was conducted under the regulations of the Los Angeles County Science and Engineering Fair Science Review Committee (LACSEF SRC). Prior to the start of the study, approval was obtained from the LACSEF SRC. An advisory committee consisting of two scientists and an ophthalmologist was formed to oversee the study and ensure participant safety.

Visual Acuity Testing in the Light and Dark

The study lead student-author conducted the vision testing under instruction from an ophthalmologist. The method was tested on volunteers before official testing began. Prior to starting the light sensitivity analysis, each of the test subjects were asked their name, age, and grade (if the participant was a student). Their eye color was analyzed by the tester. Each subject's name was kept confidential to protect participants' privacy. After the first set of demographic questions were asked, the test subjects were handed a Rosenbaum Vision Pocket Screener (PRECISION VISION SKU2745), which was held 14 inches away from shoulder level. Next, a Primacare Medical Diagnostic penlight was reflected on the pocket screener. The test subject was then asked to read line by line until 3 or more letters were missing or they reached the end of the chart. Vision results were analyzed by using logMAR value. LogMAR was calculated as described in a prior study (18). Briefly, logMAR (logarithm of the minimum angle of resolution) is calculated by converting visual acuity into the logarithm of the angle (in minutes of arc) that a person can resolve, where each line on a standardized chart represents a 0.1 log unit change. It is determined by assigning a base value to the smallest line read and adjusting by 0.02 for each letter correctly or incorrectly identified, allowing for a precise and continuous measure of visual acuity. The logMAR test is the same procedure in both light and dark environments. The only difference is the amount of light in the room. During a sample experiment, the light intensity was 497 lux in the bright conditions and 55 lux in the dark conditions. logMARDark is used to study lower acuity compared to logMARLight. After the test subjects had read the smallest viewable row, the smallest line they could read with 2 or fewer mistakes was recorded. The test subjects were then asked how difficult they felt it was to see in the light on a scale from 0–5, 0 being not hard to see at all and 5 being hard to see. The same process was repeated in a dark setting where the blinds and windows were closed, and all of the lights were turned off. The dark light intensity was 55 lux. A medical penlight was not used for testing in the darker environment. The subject's vision was then recorded from the pocket screener and the same difficulty question was asked for the dark.

Photophobia Questionnaire

After testing was done in both testing conditions, the test subjects were asked three questions from the UPSIS-17 Photophobia Symptom Impact Scale. The questions were based on a subject's discomfort in brighter environments, which could potentially be due to photophobia. The questions determined how severe one's light sensitivity is. Again, the questions were based on a scale from 0–5, where 0 is experiencing no light sensitivity at all and 5 is experiencing a lot of light sensitivity.

Statistical Analysis

All data were analyzed using the R statistical coding software, which was used to create all figures and tables. This study recorded a sample size of 78 participants, which limited the analyst to use nonparametric statistical tests. A Kruskal-Wallis test was used to test the association between one categorical (e.g., eye color) and one numerical variable (e.g., photophobia scale), where the numerical variable is the outcome. A Wilcoxon Sum Rank test is similar to a Kruskal-Wallis test but is used when there are only two groups in the categorical variable. A Spearman's Rho test was used to test the correlation between two continuous variables (example: logMARLight and logMARDark). To maximize statistical power, continuous variables were used instead of categorical variables, such as the Photophobia Questionnaire Score, logMAR and Age in Years. The function Ggplot2 was used to create all the figures (19).

ACKNOWLEDGEMENTS

The authors would like to thank Brentwood School and especially the BCIL center (Belldegrun Center for Innovative Leadership) for all of their support and mentorship through this scientific process. From the BCIL, we acknowledge Dr. Katie Gerrans, Darlene Fukuji, and Theavy So for being outstanding mentors. We would also like to thank the judges at LACSEF (Los Angeles County Science and Engineering Fair) for their constructive feedback.

Received: May 29, 2025
Accepted: February 14, 2026
Published: May 20, 2026

REFERENCES

1. Wilkins, A. J., et al. "Photophobia in Migraine: A Symptom Cluster?" *Cephalalgia*, vol. 41, no. 11–12, 2021, pp. 1240-1248. https://doi.org/10.1177/03331024211014633.
2. Allais, G., et al. "Gender-related Differences in Migraine." *Neurological Sciences*, vol. 41, no. Suppl 2, 26 Aug. 2020, pp. 429–436. https://doi.org/10.1007/s10072-020-04643-8.
3. Hu, X. H., et al. "Burden of Migraine in the United States: Disability and Economic Costs." *Archives of Internal Medicine*, vol. 159, no. 8, 26 Apr. 1999, pp. 813–818. https://doi.org/10.1001/archinte.159.8.813.
4. Digre, K. B., and K. C. Brennan. "Shedding Light on Photophobia." *Journal of Neuro-Ophthalmology*, vol. 32, no. 1, Mar. 2012, pp. 68–81. https://doi.org/10.1097/WNO.0b013e3182474548.
5. Burstein, R., et al. «Neurobiology of Photophobia.» *Journal of Neuro-Ophthalmology*, vol. 39, no. 1, 2019, pp. 94–102. https://doi.org/10.1097/wno.0000000000000766.
6. Amiri, P., et al. "Migraine: A Review on Its History,

https://doi.org/10.59720/25-270

Global Epidemiology, Risk Factors, and Comorbidities." *Frontiers in Neurology*, vol. 12, 23 Feb. 2022. https://doi.org/10.3389/fneur.2021.800605.
7. Yong, P. T., et al. "Does the Optimal Level of Illumination Improve Both Visual Functions and Visual Comfort in Schoolchildren with Low Vision?" *PLoS One*, vol. 19, no. 9, 19 Sep. 2024. https://doi.org/10.1371/journal.pone.0310592.
8. Verriotto, J. D. "New Methods of Quantification of Visual Photosensitivity Threshold and Symptoms." *Translational Vision Science & Technology*, vol. 6, no. 4, Jul. 2017, p. 18. https://doi.org/10.1167/tvst.6.4.18.
9. Cortez, M. M. "Validation of a Photophobia Symptom Impact Scale." *Cephalalgia*, vol. 39, no. 11, Oct. 2019, pp. 1445–1454. https:// doi/10.1177/0333102419845641.
10. Amini, A., et al. "Photophobia in a Blind Patient: An Alternate Visual Pathway. Case Report." *Journal of Neurosurgery*, vol. 105, no. 5, Nov. 2006, pp. 765–768, https://doi.org/10.3171/jns.2006.105.5.765.
11. Roy, E. "Blue-eyed Humans Have a Single Common Ancestor." *NewsBreak*, 24 Feb. 2023, https://www.sciencedaily.com/releases/2008/01/080130170343.htm. Accessed 26 Feb. 2023.
12. Mackey, D. A. "What Color Are Your Eyes? Teaching the Genetics of Eye Color & Color Vision." *Eye*, vol. 36, no. 4, Apr. 2022, pp. 704–715. https://doi.org/10.1038/s41433-021-01749-x.
13. Nischler, C., et al. "Iris Color and Visual Functions." *Graefe's Archive for Clinical and Experimental Ophthalmology*, vol. 251, no. 1, Jan. 2013, pp. 195-202. https://doi.org/10.1007/s00417-012-2006-8.
14. Ashraf, Gizem, and Rahul Chakrabarti. "Paediatric Photophobia: The Pressure of a Timely Diagnosis." *Australian Journal of General Practice*, vol. 50, no. 10, Oct. 2021. https://doi.org/10.31128/AJGP-09-20-5649.
15. Sturm, R. A., and M. Larsson. "Genetics of Human Iris Colour and Patterns." *Pigment Cell & Melanoma Research*, vol. 22, Aug. 2009, pp. 544–562. https://doi.org/10.1111/j.1755-148X.2009.00606.x.
16. Akpek, E. K., et al. "Overview of Age-related Ocular Conditions." *The American Journal of Managed Care*, vol. 19, no. 5 Suppl., May 2013, pp. S67–75, https://ajmc.com/view/ace011_13may_agingeye_akpek.
17. Staff. "Pay More Attention to Photophobia, Study Argues." *Review of Optometry*, 20 Apr. 2022, https://reviewofoptometry.com/article/pay-more-attention-to-photophobia-study-argues.
18. Holladay, J. T. "Proper Method for Calculating Average Visual Acuity." *HicSoap*, 1997, https://hicsoap.com/__static/97f48a5a0aaf79194b295070d91fe2b6/62propermethodforcalculating_in-3426.pdf.
19. Wickham, H. "ggplot2: Elegant Graphics for Data Analysis." Springer-Verlag New York, 2016, https://ggplot2.tidyverse.org.