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Fluorescent Lighting's Impact on Academic Performance of High Schoolers

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ABSTRACT

Fluorescent Lighting maintains its prominence in schools, offices, and businesses across the country due to its cheapness and effectiveness, though its nature can lead to headaches, eye discomfort, or even inability to focus. While previous researchers have delved into how this lighting affects elementary-age students, college students, and adults outside of schools, high schoolers spend far more time under fluorescent lighting averaging 7 hours a day, 5 days a week, four weeks a month, and 10 months a year. Furthermore, this extended exposure can result in more severe effects of fluorescent lighting, leaving students at a disadvantage in the classroom. Utilizing an online IQ test and symptom pre/post-tests, high school students were examined under fluorescent lighting, natural lighting, and darkened lighting with their IQ score, time needed to complete the exam, and symptom prevalence measured. The average IQ score for fluorescent lighting was 123.4 whereas for the natural lighting trial, the average score was 130.4 and darkened lighting had an average score of 127.4, and 67% of scores under fluorescent lighting were 125.5 or below whereas natural lighting demonstrated 83% of scores being 125.5 or above (125.5 was the median number out of the entire data set). Similarly, 91% of participants under fluorescent lighting needed 11 minutes and 23 seconds or more to complete the test whereas 83% of participants under natural lighting needed 11'23" or less to complete the test (11' 23" was the median number out of all the data collected).

Introduction

Fluorescent lighting is, by far, the most common lighting source found in schools worldwide, often regarded for its energy efficiency and cheaper cost, especially when juxtaposed to other types of lighting such as LEDs (Duncan). These long tubes of illuminance are powered by a reaction between gasses and mercury vapor which produces an invisible UV light that illuminates phosphor powder, further coating the lighting tube, and creating what is seen as fluorescent lighting (Duncan). One of the more discussed and well-known characteristics of fluorescent lighting is its flickering, which can be traced back to the quick, but not constant blasts of light that derive from the aforementioned reaction. According to the Electromagnetic Field Portal, the frequency- demonstrated through cycles per minute- of average fluorescent lights ranges from 50-60Hz (EMF). With such a low frequency, the human eye often subconsciously picks up on the flickering until it reaches what is known as its critical flicker fusion frequency (CFF), or, as defined by the National Library of Medicine, the frequency at which flickering light can be perceived as continuous, which is believed to be anywhere from 50-90 Hz (Mankowska et al). This stems into eye strain and overall visual discomfort as the eye tries to recognize the flicker and often grows into the red eye and dry eye. It is even speculated that astigmatisms, nearsightedness, and retinal damage have their roots in fluorescent lighting sensitivity: a symptom of long-term exposure to fluorescent lighting. (Bullock). Furthermore, the National Headache Foundation illustrates that migraine triggers can consist of pulsing/flickering lights as well as bright lights, and considering the cool temperature, brightness, and flickering associated with fluorescent lighting, it truly is no surprise that many report fluorescent lighting provokes their headaches (National Headache Foundation).

The ever-present fluorescent lighting in schools and businesses that many spend the majority of their day within, such as high schoolers, can grow to be problematic. An average school day for high schoolers in District "X" lasts for 7 hours and will occur 5 days a week, for approximately 10 months of the year (excluding holiday breaks and weather closures). For about 12 years, this pattern continues and along with it, the risk of possible eye damage and headaches, often attributed to fluorescent lighting, grew with it. Headaches and visual discomfort can cost a student their optimal performance in the classroom by interfering with their ability to focus, ability to recall information accurately, and their speed when completing tasks due to their interactions with eye strain, headaches, and other symptoms.

Gap in the Research

Under the hypothesis that fluorescent lighting influences eyesight, frequency of headaches, comfort, ability to focus, and the ability to perform in the classroom, as well as knowing the frequency of exposure to this lighting, research was focused on the way fluorescent lighting, and its side effects, can influence the high schooler's performance academically. The gap in the research concerns an age group that has not been studied under fluorescent lighting. While "Illuminating the Effects of Dynamic Lighting on Student Learning" had a similar research goal, the study revolved around third graders. Similarly, "Modulation of Fluorescent Light: Flicker Rate and Light Source Effects" looked at the same concept, however undergrad students, 18-24, were studied. Assuming that the average highschooler spends roughly 6-8 hours a day, 5 days a week, and 180 days a year, in classrooms illuminated by fluorescent lighting, they are left susceptible to any and all "side effects" that may stem from the cheap and ever-present lighting in their classrooms. Especially understanding that long-term exposure to fluorescent lighting can intensify symptoms, high schoolers may demonstrate more drastic results. Significant findings may be brought to the attention of students and administrators and used as an argument to replace fluorescent lighting with less harmful lighting, once more considering the importance of high school performance to a student's long-term success. In the academic conversation, this research may also be used as a base for future research in the field to further explore the same age group under different lighting conditions, or even the same age group with different variables being studied.

Literature Review

Flickering, Frequency, and Headaches

Fluorescent lighting can often be characterized by its recognizable flickering, both subconsciously and actively recognized by those underneath its illuminance. The frequency of fluorescent lights ranges from 50-60Hz when dealing with a conventional ballast (tube), and changes to 45-60KHz for electrical ballasts, both of which can be recognized with the naked eye due to their lower scale frequency (EMF). Critical flicker/fusion frequency (CFF) is the frequency at which light waves transition from recognizable flicker to a continuous source of light and can differ between individuals, however, the average human can detect light flicker from 50-90Hz (NLM). In a study measuring the performance and physiological arousal of 37 participants, individuals under conventional fluorescent ballasts who possessed high CFF demonstrated significant increases in brain activity, an increase in their speed of completing the given task, and a decrease in accuracy in their results, which, according to Rikard Kuller, can be understood through the variation in lighting frequency triggering the nervous system to be on high alert (Kuller). In another study, 90 classrooms across 11 secondary schools and 6 local education authorities were studied. Variables included flicker, illuminance at desks, and luminance of whiteboards. It was determined from this study that 80% of the classrooms studied were lit with fluorescent lighting with a 100 Hz frequency that can cause headaches and impact visual ability (Journal of Environmental Psychology). This is in alignment with findings that the visual performance of 18-24-year-old University students studied under different lighting frequencies had drastically lowered under the low-frequency flicker than under the high-frequency flicker (Veitch). Finally, the rapid fluctuation of light from fluorescent lamps is known to affect the way our eyes move across text and interferes with the performance of visual tasks (Wilkins). Through all the aforementioned research, it can be understood that visual ability, visual and receptor accuracy, and academic accuracy are all compromised through the noticeable flicker from fluorescent lighting. With these possibilities in mind, the accuracy and ability of students under flickering lights is more than likely degraded, especially considering continuous and long-term exposure of high school students, calling the effect of fluorescent lighting's flicker on academic performance and focus into question, especially during such a critical time in students' academic lives. The flickering and discomfort that may bother the eye can lead to something more than just red eyes and eye damage: headaches. Fluorescent lighting's invisible pulsing can cause migraines, as the light, flickering and pulsing, and brightness can all be traced back to migraine triggers (National Headache Foundation). In a study of office workers, the average incidence of headaches and eyestrain was more than halved under high-frequency lighting (school fluorescent lighting is low-frequency) (Wilkins). Ultimately, the frequency of fluorescent lighting can be damaging due to its recognizable nature.

Visual Health

Not only can the frequency of fluorescent lighting grow to be damaging, but according to the US FDA, "All fluorescent lights emit some UV" and many fluorescent lights fall out of the safe range of UV radiation, with some exceeding the safe range of 2000 to 3500K and greater than 500 nanometers (AJPH). As Johns Hopkins Medicine explains, UV light ultimately deteriorates all eye structures and can lead to eye damage in the long run (Kuo). Furthermore, it has been noted that the longer one is exposed to fluorescent lighting, such as high school students, the more at risk they are for sore, watery, red, and burning eyes, as well as blurry and double vision and increased light sensitivity (Sargx). Some medical professionals have even begun to contemplate that retinal damage, myopia (nearsightedness), and astigmatisms can have their origins in fluorescent light sensitivity, especially due to blue light (Bullock). Going off of this, the UC Davis School of Health determines that continuous exposure to blue light over time can damage retinal cells and can ultimately cause vision problems (Barnett). With the majority of these damages to the eyes occurring through long-term exposure, one can only assume that high schoolers with constant exposure are most vulnerable to these risks. In addition to this, visual stress can become more impactful under fluorescent lighting (Leow). Visual Stress Syndrome (VSS) is a large contributor to the decline in literacy and numeracy of students: VSS can be a contributor to difficulties reading, writing, and focusing. It is thought that fluorescent lighting can create a heightened struggle with this visual stress, causing a much harder time for already struggling students (Leow). With the possibility of VSS on top of all of the already compromised vision, students' abilities to read, comprehend, and respond to classroom activities or assignments may be weakened, stripping students of their ability to perform at their best. Undoubtedly, the combination of both visual discomfort and deterioration that stem from fluorescent lighting poses harm to students and their abilities to perform at their best.

Performance Under Fluorescent Lighting

The combination of eye strain, visual discomfort, and headaches, combined with the demands of school can interfere with the performance of students in classrooms lit with fluorescent lighting. One study used 738 students in Delhi who were assessed through strategic sampling and questionnaire responses. It was found that lighting had a significant impact on students' focus and ability to perform. Classroom lighting between 250-500 lux was found to provide increased concentration in students and resulted in better scores and higher performance from students (Singh). Lux is a measurement of light intensity equivalent to one lumen/m^2, and as found, most of the lighting found in hallways and classrooms are T8s which emit 1,600 lumens. Ultimately, the strength and intensity of the fluorescent lighting may amplify its visual and mental influence, which is the least preferable in classrooms. Another study by the George Lucas Educational Foundation studied over 21,000 US elementary school students who were tracked throughout the year and determined that students with exposure to more sunlight during the school day demonstrated 26% higher reading test scores and 20% higher math test scores than students with less natural light exposure (Uncampher). With windows adorning many classrooms in schools, natural lighting is a cost-effective and beneficial alternative to the fluorescent lighting more commonly used. This correlation was also demonstrated in a study conducted by Mirjam Münch and her colleagues which studied participants aged 19-25 and exposed them to either daylight or artificial light for six hours a day for two days, and their melatonin and cortisol levels were used as a measure of sleepiness and cognitive performance. It was determined that those exposed to daylight were much more alert and therefore more productive than their counterparts (Münch). With high school often characterized as one of the most crucial times in the academic journey of students, the ability of fluorescent lights to interfere with student ability, performance, and comfort can grow problematic, especially considering the proven benefits of other, accessible lighting forms.

Method

Independent Variables

For this study, participants were asked to complete the same IQ test during the same time of the day for three trials within a week. The manipulated variable was the lighting source students completed the test under with either fluorescent lighting, natural lighting (from windows), or a darkened room being used to illuminate the room for students within each of the trials (the same room and room setup was used for each trial).

Dependent variables

For this experiment, the dependent variables were the IQ test score, the time needed to complete the IQ tests, and the self-reported symptoms of headache, eye strain, and/or inability/ability to focus.

1) IQ score: Given under all three types of lighting, IQ is used to measure the problem-solving abilities and reasoning of those who complete it. These skills are often used in the classroom, thus helping to determine the academic performance of test takers. These assessments were presented to the test taker without requiring prerequisite skills in math or English, making the study applicable to a bigger population.
2) IQ test time: While the timing of completion may be related to many factors, one big factor is the ability, or inability, to focus. This can derive from the inability of the eyes to focus, or overall mental focus deficiencies. By recording the time needed to complete the IQ test, the ability to focus can be measured (more time needed may imply less focus than a shorter completion time).
3) Symptoms: Students were administered a pre-test asking if they were experiencing any symptoms going into the trial using the Likert scale. This was used to ensure the effects of lighting were isolated from any unrelated symptoms. Following each trial's test, students were asked to complete a post-test. This was once again asking about their association with known symptoms of fluorescent lighting using the Likert scale. These were the same questions asked before to ensure the ability to identify true changes.

Instructional Materials

Students were administered an IQ test from IQTest.com on their school Chromebooks. This online test was developed by a group of PhDs and is a valid and reliable measure of student academic ability.

Control Group

The control group of this study was the trial completed under fluorescent lighting. Seeing as fluorescent lighting is most commonly worked under by students in district "x", they are more adapted to these conditions. The natural lighting and dimmed lighting results will be compared to one another but will primarily be juxtaposed with the fluorescent lighting results to determine if there are any significant differences between the more prevalent lighting in schools and alternative lighting methods.

Experimental Procedures

Participants/Sampling

The chosen participants were high school students from district "x", to best address the research question. The sample was gathered by Voluntary Response Sampling. Student TAGs (homerooms) were visited and presented with the study and students were able to choose whether to participate or not voluntarily. With approximately 25 students and each tag and 16 tags visited, a sample size of 400 was directly informed of the study, however, the ability to sign up for the study was opened up to the entire student population of about 1,400. Overall, 17 students signed up for participation and consented to the study. To avoid discrepancies due to the low sample size, students were asked to complete all three trials to be able to compare the individuals, while also allowing for the best representation of the high school population due to different academic abilities through high school "x". Of the 17 students who signed up, 11 participants showed up for the fluorescent lighting trial, 12 participants participated in the natural lighting study, and 8 students participated in the darkened lighting trial. There were no prerequisites required for this study.

Procedures and Data Collection

After gaining approval from the school's IRB board, Google forms with consent forms, pre-tests, and post-tests were made and also approved. Following this permission, the consent forms were posted on a site where students who were given information, and who were interested could choose to participate in numerous studies (Appendix 1). TAGs were visited where information about this study was described and participants and their parents' (if under 18) consent was gained and their contact information was recorded (Appendix 2-3). Once the dates and times for the study were determined, students were contacted with this information.

The first trial completed was the trial under the fluorescent lighting. Participants were given the link to a pre-test that worked to determine if they had any outside influenced symptoms that may interfere with their post-test answers, as well as used to provide answers to be compared to their post-test scores (Appendix 4). Each of the questions was answered using a Likert scale to best assess the intensity and behavior of a symptom without overwhelming the participant. One open-ended question followed the symptomatic questions to determine why a student felt that they could/could not focus, to qualitatively analyze the reasoning behind a participant's response. Once this survey was completed, students were given the link to the online IQ test (Appendix 5). Each participant was asked to complete this test and record their score (emailed to them by the website) as well as the time it took them to complete the test using the analytics provided through the website (Appendix 6). They were then asked to fill out the post-test questions (Appendix 7). These questions were the same as the pre-test, in the same order. This process was repeated for each of the other two trials.

Research Design

This study was based on an experimental, quantitative research design. Therefore, collecting the data of all three trials to be juxtaposed will reveal if scores rise, decrease, or stay level in each participant if the time needed to complete the test rises, decreases, or stays level, and if symptom occurrence or strength rises, decrease or stay level. This information can then be presented and analyzed through percentages and numbers to determine if fluorescent lighting presents higher reports of symptoms, lower scores, and more time required to complete the tests, especially when compared to the two other types of lighting.

Results

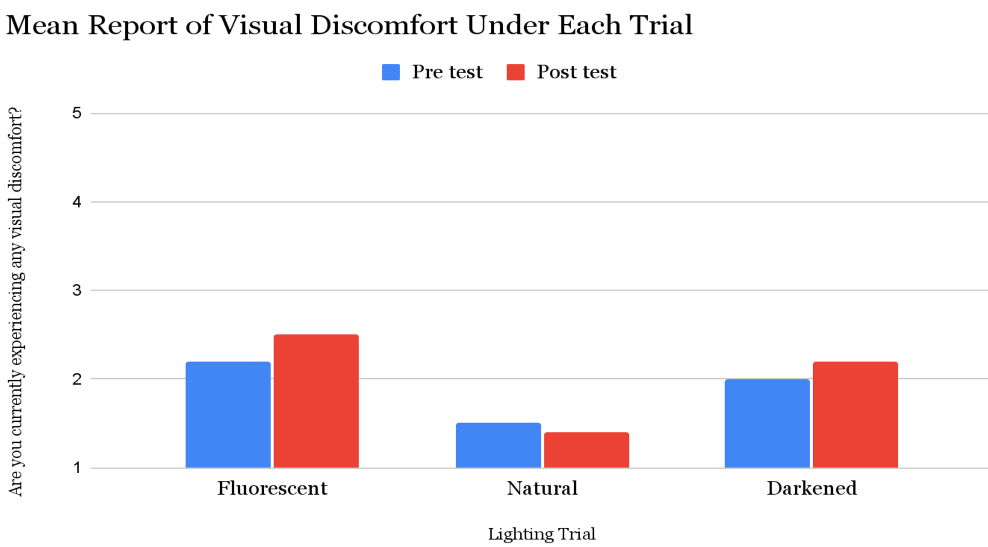

Figure 1: Average reports of visual discomfort before and after each trial on the Likert Scale.

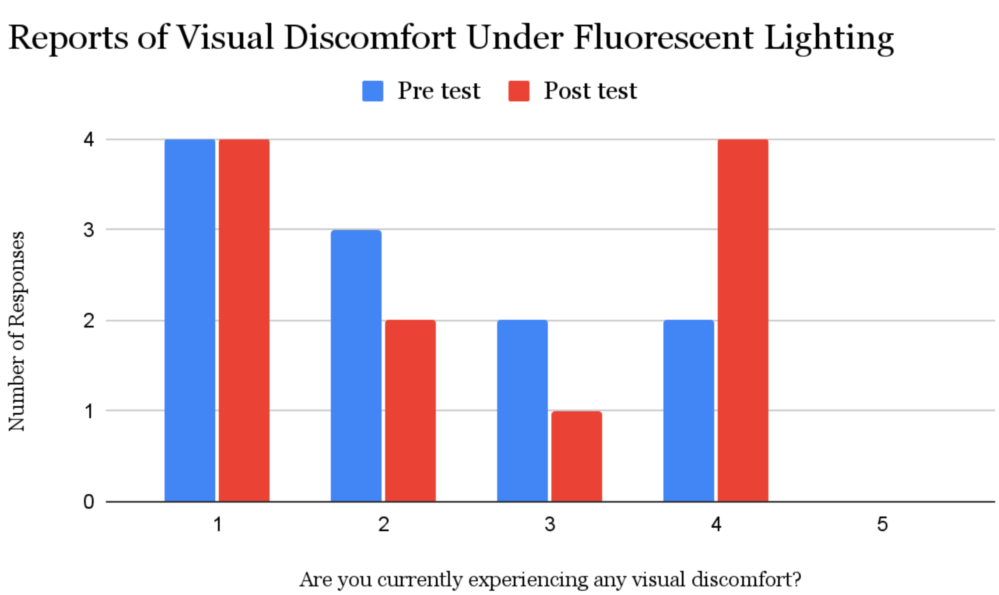

Figure 2: Reports of visual discomfort before and after fluorescent lighting trial on the Likert Scale.

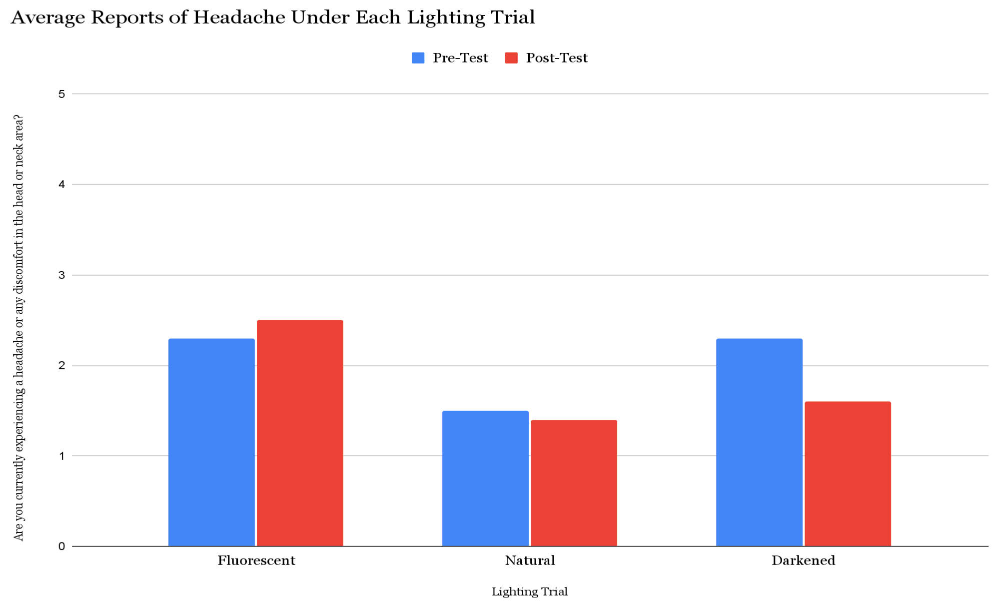

Figure 3: Average reports of headache before and after each trial on the Likert Scale.

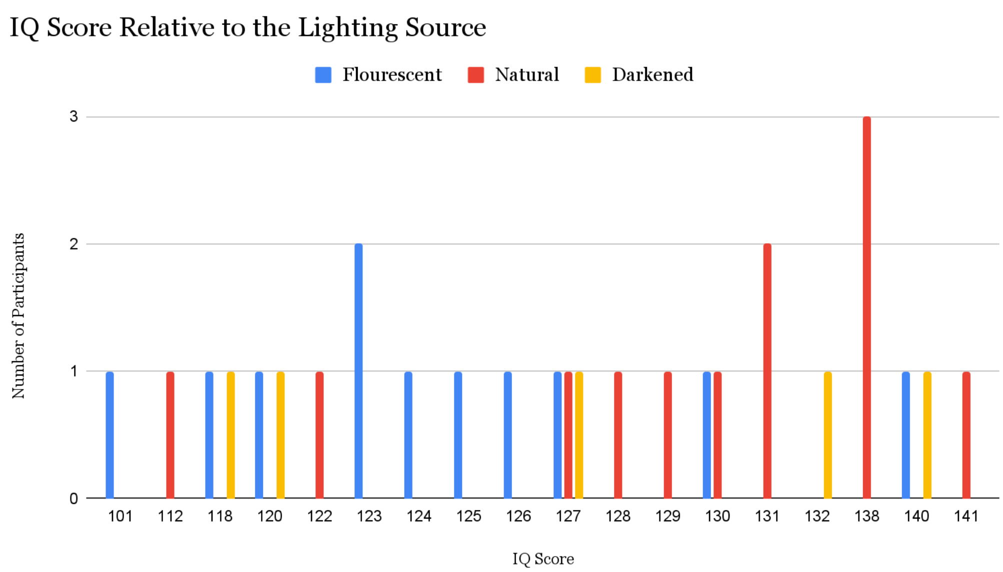

Figure 4: Reported IQ Scores relative to each trial.

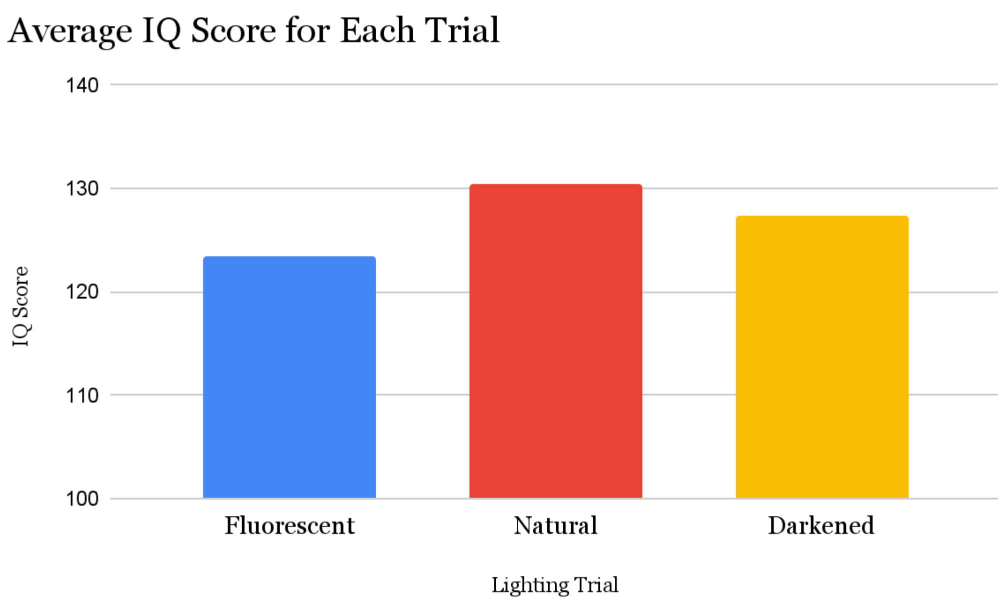

Figure 5: Mean IQ Score of each lighting trial.

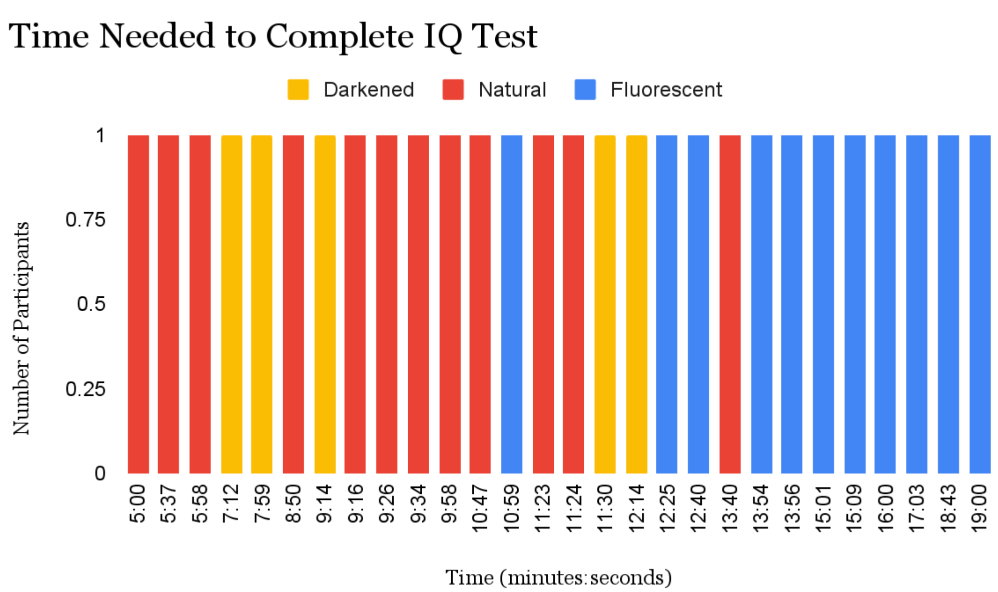

Figure 6: Time needed to complete the IQ test under each trial in minutes and seconds.

Discussion

Participants were asked five pre-test questions, followed by identical questions in the post-test to look for changes in symptoms such as headaches, eye strain, and ability to focus, similar to symptoms studied through self-reporting in Veicht's study of university students. While some of the questions demonstrated no changes or insignificant changes, reports of visual discomfort, especially under fluorescent lights showed change. Participants demonstrated a 0.3 increase in average visual discomfort under fluorescent lighting compared to a .1 decrease under natural lighting (Fig.

1). Specifically, there was a large jump from answers of minor discomfort in categories 2 and 3 to category 4 with more serious discomfort specifically under fluorescent lighting (Fig. 2). This can be attributed to the subconscious recognition of flickering as well as the lighting intensity commonly associated with the fluorescent light as seen through Veitch's study which found that the visual performance of those studied was drastically lowered in the low-frequency flicker than during the high-frequency flicker. Similarly, the Journal of Environmental Psychology's study found that of the 80% of classrooms lit with fluorescent lighting, 84% of classrooms had lighting that exceeded the recommended amount for visual comfort.

Similarly, reports of headaches under the lighting trials demonstrated more significant results. Under fluorescent lighting, there was an average increase of .2, compared to a .1 decrease under natural light and a .7 decrease under darkened lighting (Fig 3). Once again, the flickering of fluorescent lighting, often subconsciously recognized by the eye, can be translated into headaches from visual stress and discomfort as outlined by the National Headache Foundation's development that fluorescent lighting's invisible pulsing can cause migraines. The natural lighting trial showed little change in disagreement with the Society of Light and Lighting's findings that the average incidence of headaches and eyestrain was more than halved under high-frequency lighting and that headaches tended to decrease with increasing natural light. The darkened lighting trial showed a significant decrease in headaches. An open-ended question following the question of the ability to focus under darkened lighting was answered by Participant 1 with a score of 5 and a response of "The darkness was actually quite soothing". This may be linked to the lack of light intensity and frequency processing done by the eye.

Where results become most intriguing pertains to the IQ test scores as well as the time needed to complete the tests. In terms of scores, the average score for fluorescent lighting was 123.4 whereas for the natural lighting trial, the average score was 130.4 and darkened lighting had an average score of 127.4 (Fig 5). Figure 4 clearly shows the skewed results of the IQ Scores with 67% of scores under fluorescent lighting being 125.5 or below whereas natural lighting demonstrated 83% of scores being 125.5 or above (125.5 was the median number out of the entire data set). The George Lucas Foundation and Singh are both in accordance with studies determining higher scores in participants with more exposure to natural lighting versus those exposed to more fluorescent lighting. In terms of timing, 91% of participants under fluorescent lighting needed 11 minutes and 23 seconds or more to complete the test whereas 83% of participants under natural lighting needed 11'23" or less to complete the test (11' 23" was the median number out of all the data collected) (Fig 6). In both the scores and the timing needed for the tests, darkened lighting demonstrated no significant results. Overall, this study concluded that students under fluorescent lighting took more time and did worse compared to the natural lighting students who demonstrated much higher scores and took far less time, directly aligning with Kuller's findings of a decrease in accuracy found to be attributed to sensitivity to flickering under fluorescent lighting whether participants recognized it or not. This may be attributed to unconscious recognition of flicker and discomfort, headaches, and skewed focus under the fluorescent lighting.

The data collected supports the hypothesis that fluorescent lighting disrupts the academic performance of students at high school "x" as seen through the lower test scores and higher incidences of distracting symptoms under the fluorescent-lit trials. With 67% of the IQ scores collected under fluorescent lighting dragging below the median score through all three trials, as 91% of fluorescent lighting participants needing more than the median collected time to complete the test it is evident that fluorescent lighting can decrease accuracy while also deterring optimal focus of participants seen through the higher timing required for participants. Symptoms like headaches and visual discomfort also saw a rise in incidence under the fluorescence that was opposed or unseen under natural lighting and/or darkened lighting.

Conclusion

Overall, the presence of fluorescent lighting greatly limits the full potential of academic performance in students in high school "x". Students who tested under fluorescent lighting demonstrated longer times needed to complete their IQ tests and ultimately came out with lower scores juxtaposed to the other lighting trials, in agreement with the George

Lucas Foundation's findings of higher scores under natural light than fluorescent as well as Singh's findings of better ability to focus under natural lighting. In school settings, the ultimate goal is ultimately high accuracy and good results in a timely manner which was seen as completely rejected under fluorescent lighting. Ultimately, this ever-present lighting in schools can ruin the potential of high performance in classrooms, and act as an obstacle to optimal levels of focus in the classroom. Symptoms of headaches and visual discomfort also yielded significant results with fluorescent lighting demonstrating the highest increases in frequency and intensity of these symptoms in alignment with the National Headache Foundation's conclusion that the invisible yet subconsciously recognized flicker of fluorescent lighting may act as a migraine trigger as well as the Journal of Environmental Psychology's findings that the majority of classrooms lit with fluorescent lighting with frequencies that can limit visual ability and generate headaches. Visual discomfort and headaches could not only distract students but are also capable of taking away optimal conditions for academic performance, as outlined by the American Academy of Neurology's discussion that poor school performance is in alignment with factors such as having migraines, the frequency of migraines, the length of these migraines, more intense migraines, and having associated nausea with migraines.

Fluorescent lighting, despite its convenience and cheapness, poses harm to students and their academic abilities in the classroom. These factors far outweigh the financial benefits they pose and should be enough reason for schools to consider removing and replacing the lighting sources used in their classrooms. While natural lighting demonstrated lower times needed and much higher scores than the other trials, it is not always accessible year-round or accessible in classrooms with limited windows. In the case of this inaccessibility, LEDs are an alternative source that can be implemented at a much cheaper cost overall than fluorescent ballasts. With this in mind, more research should be done concerning academic performance under LED lighting to ensure safety and efficiency. Without this change, students' classroom experiences and their academic products will continue to be compromised.

The research ultimately addresses the overlooked demographic of high schoolers, a group underway with critical academic development and testing, while also proving, once more, the significance of fluorescent lighting's impact on students through both their academic performance as well as their susceptibility to symptoms when compared to their results of the same variables under natural lighting. Proof of visual discomfort and incense of headaches have been shown through this study, while adding the considerable factor that the participants were high school students who are susceptible to these phenomena for about 7 hours a day, 180 days a year, for 12 years consistently.

Limitations

Due to the fact that students were given the information of the study and were able to decide if they wanted to participate may reveal that those who did participate feel more strongly about the subject of inquiry and may be more subjective to the Hawthorne effect, which can be a limitation of its own due to intentional alteration of behavior due to personal awareness of observation. Another limitation of this study is the number of participants; human participants may choose whether or not to participate in a study, and therefore the number of participants who may have been willing to participate or comfortable completing the study may be lower than what was wanted or what have been needed to draw conclusive results. Going off of this, the symptoms questioned required self-reporting, so factors like visual discomfort may not have been measured to their full potential due to reliance on the human eye, also drawing into the limitation of little access to advanced technology. Further research into visual discomfort and the impact of fluorescence on the eyes of high schoolers, may be completed using more complex technology that can measure variables that self-reporting cannot. Timing was another limitation. This study was completed within three days over a five-day period. The closeness of these trials may have drawn mental remembrance of certain questions or processes used and could have a slight impact on scores or times (participants were unable to see the order of questions, what questions they got right, or what questions they got wrong).

Future Directions

As mentioned above, more technology implementation, and the studying of various alternative lighting methods, such as LEDs will allow for the solidification of recognized patterns that cannot always be self-reported, and further research into what can and should replace fluorescent lights throughout high schools and offices around the world. Focus on other variables growing in popularity across these settings, like computers, may also allow for a better understanding of how the combination of computer screens and lighting impacts individuals, or how the two variables interact with each other as a whole. Long-term research following students throughout a longer period of time with continued exposure, much like the George Lucas Educational Foundation, may allow for more data collection concerning test scores and overall school behavior to further research how high school students are afflicted by lighting type and exposure.

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