The Effects of Lighting Design on Mood, Attention, and Stress

A Thesis

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List of Abbreviation

CPT	Continuous Performance Task
CCPT	Conjunctive Continuous Performance Task
POMS-SF	Profile of Mood States-Short Form
SAD	Seasonal Affective Disorder
SPAQ	Seasonal Pattern Assessment Questionnaire
SPD	Spectral Power Distribution
TMD	Total Mood Disturbance

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Abstract

Previous studies have indicated that lighting design has an impact on mood, attention, and stress. This thesis sought to compare three lighting conditions, one bright, white light designed to treat Seasonal Affective Disorder (SAD), one dim, 450nm blue light, also potentially affective for treating SAD, and a dim, warm light (Control), to see what their effects would be on these constructs. It was hypothesized that the bright SAD lamp would negatively affect attention and heighten stress compared to the control and blue light conditions. It was also hypothesized that the SAD and blue light conditions would decrease negative mood compared to the control condition. Participants from Reed College (N=11) participated in three separate sessions, (one for each lighting condition) over a span of three weeks, one session per week. Participants answered the Profile of Mood States-Short Form (POMS-SF), to measure emotion, the Conjunctive Continuous Performance Task (CCPT) to measure sustained attention, and changes in heart rate were assessed to measure stress reduction. Results showed no statistically significant changes across lighting conditions but did show a numeric trend as predicted in some aspects of the CCPT. This pattern of results could be explained by various methodological limitations, or a genuine lack of effects of these lighting conditions on mood, attention, and stress.

Introduction

1.1 The Built Environment

In the modern era, humans spend much of their time in built environments. From schools and office buildings to restaurants and concert venues, it is inarguable that architecture has a profound effect on daily life. Understanding the intricate ways in which the built environment affects human behavior, particularly in terms of cognition and emotion, can lead to the creation of functionally optimal spaces (Banaei, Hatami, Yazdanfar, & Gramann, 2017).

Modifying even the minutia of our built environment, such as the paint color of a wall, appears to impact the overall perception of the space. For example, a previous study showed that variation in interior colors in a store affected participants’ perception of the store as being either “high luxury” or “low luxury,” as well as influencing overall store preference (Cho & Lee, 2017). In a school context, one study found that wall color had an effect on students’ reading and writing progress, but not their math progress, implying potentially complex relationships between interior design and execution of cognitive skills (Barrett, Davies, Zhang, & Barrett, 2016). There seems to be a delicate balance between colors that feel inviting, and colors that are distracting. This balance ultimately affects what type of environment is optimal for a specific activity. For instance, there is evidence that preschoolers in an environment with lots of bright colors have a more difficult time focusing on tasks (Stern-Ellran, Zilcha-Mano, Sebba, & Binnun, 2016). This is presumably because they have not yet learned how to filter out extraneous information from their environments and, therefore, they focus their attention on design components of the classrooms themselves rather than the learning materials. However, one can imagine that being surrounded by stark, blank walls would also make children feel trapped, uncomfortable, bored, or uninspired. The way the environment affects brain activity, cognition, and behavior is nuanced and complex. Thus, when creating spaces, one must consider not only the function of the space, but also the specific group occupying the space, along with the way that the space is intended to make the occupant feel.

Environments judged as “warm” through their color scheme and interior decoration have been shown to make people feel more secure (Kombeiz, Steidle, & Dietl, 2017). In one study, warm spaces made participants feel calmer, and many reported that they felt a sense of familiarity while in them (Zanjani, Hilscher, & Cubchik, 2016). Creating spaces that make people feel more secure and relaxed is important not only in home design, but also when constructing buildings such as hospitals because it has been shown that built environments can have restorative effects (Peterson, Sandin, & Liljas, 2016). Improved restoration and increases in comfort can also be achieved through customization, especially in locations such as residential hospices where patients have limited control of the surrounding space that they occupy (Niedzielski, Rodin, Emmerson, Rutgers, & Sellen, 2016). Having a sense of agency and the ability to create a routine can improve one’s mood and extend the stay of the patient.

There has also been recent neuroscientific evidence showing how different forms in one’s built environment can alter one’s perception and emotion. It has been shown that curved forms, as opposed to rectilinear forms, are both preferred and show an increase of activity in the anterior cingulate cortex of the brain compared to rectilinear forms (Banaei, Hatami, Yazdanfar, & Gramann, 2017). This shows that there is a measurable change in brain activity with regards to the perception of a space. The anterior cingulate is known to be associated with attentional control of cognitive and emotional processing (Bush, Luu, & Posner, 2000). However, there seems to be a limit, as too many curved forms have been shown to increase stress (Banaei, Hatami, Yazdanfar, & Gramann, 2017). Recent experiments aimed at investigating influences of the built environment on brain activity have employed modern virtual reality (VR) technology, like the Oculus Rift (Vecchiato et al., 2015; Banaei, Hatami, Yazdanfar, & Gramann, 2017). These studies are using VR to their advantage, bringing environments to the lab instead of bringing subjects and brain imaging devices to the environment (which is technically challenging). As a result, a number of variables in the built environment can be carefully controlled and manipulated while precise measurements of ongoing brain activity are made. Using the combined powers of both VR and brain recording technologies, researchers are now able to correlate patterns of brain activity with certain architectural features and begin to understand some of the complex relationships between the brain and the built environment.

1.2 Lighting

One of the simplest ways to influence cognition and emotion through the built environment is to manipulate interior lighting. Lighting specifications, such as color temperature and illuminance, have been shown to influence a multitude of human behaviors (Hedge, 2000). One particularly unexpected finding has been the influence of lighting on collaboration in social settings. A recent study found that rooms with dim, warm light were more likely to foster social collaboration than rooms with bright, cool light in them (Kombeiz, Steidle, & Dietl, 2017). This suggests that meeting rooms with bright, white light may inadvertently disrupt team work. Similarly, the previously mentioned study on classroom environment showed a positive correlation between natural light without glare and students' writing progress (Barrett, Davies, Zhang, & Barrett, 2016). Another study, using VR technology, found a positive correlation between office workers who chose to have more sunlight than artificial light in a virtual office environment and their reading speed and comprehension (Heydarian, Pantazis, Carnerio, Gerber, & Becerik-Gerber, 2016). These findings further support the idea that lighting can influence various aspects of human behavior, from cognitive abilities to social interactions. Clearly, lighting design has much broader implications than just style, as these studies suggest that interior lighting can influence psychological factors such as attentional and emotional processing.

1.3 Light Therapy

1.3.1 Specifications of Lightbulbs

This study will be focusing on how lighting influences attentional and emotional processing. As such, there are various specifications for lights that are relevant to the current study. *Lux* is the intensity of illumination at a given location. *Lumens* refers to the amount of light radiated from a light source. These two concepts are related but are not interchangeable because lux varies depending on the distance from the light source as well as the angle of the beam of light, while lumens does not.

Color temperature is a measure that helps indicate the color of the light. Color temperature is measured in Kelvins. Typical household lightbulbs may vary from 2000°K to 6500°K. Most 2000°K lights are warm in tone and are categorized by their yellow glow. 3100°K lights are "cool whites," a cool-toned, slightly blue white lights, and 4600°K and above are considered "daylight" style lights. These daylight lightbulbs that are still primarily white but with even more blue in their tone, making them a more accurate imitation of actual sunlight on a sunny day.

Color wavelength is another measure to indicate the color of a light. Different light sources have differing wavelength combinations of light, measured in nanometers. Spikes of energy at different wavelengths change the overall appearance of the color of a light, as well as the color rendering index of the objects it illuminates. Spectral power distributions (SPD) of various wavelengths, ultimately determine the color of the light. However, wavelength and color temperature are different entities. Lights vary in the intensity where specific nanometers peak, ultimately combining into something that converts into a color that can be measured in Kelvins. To preview, one of the lights used in the current experiment for the blue condition was 470nm, thus it had no other wavelengths compromising the color. As a result, the blue light was a concentrated form, atypical for most household lightbulbs.

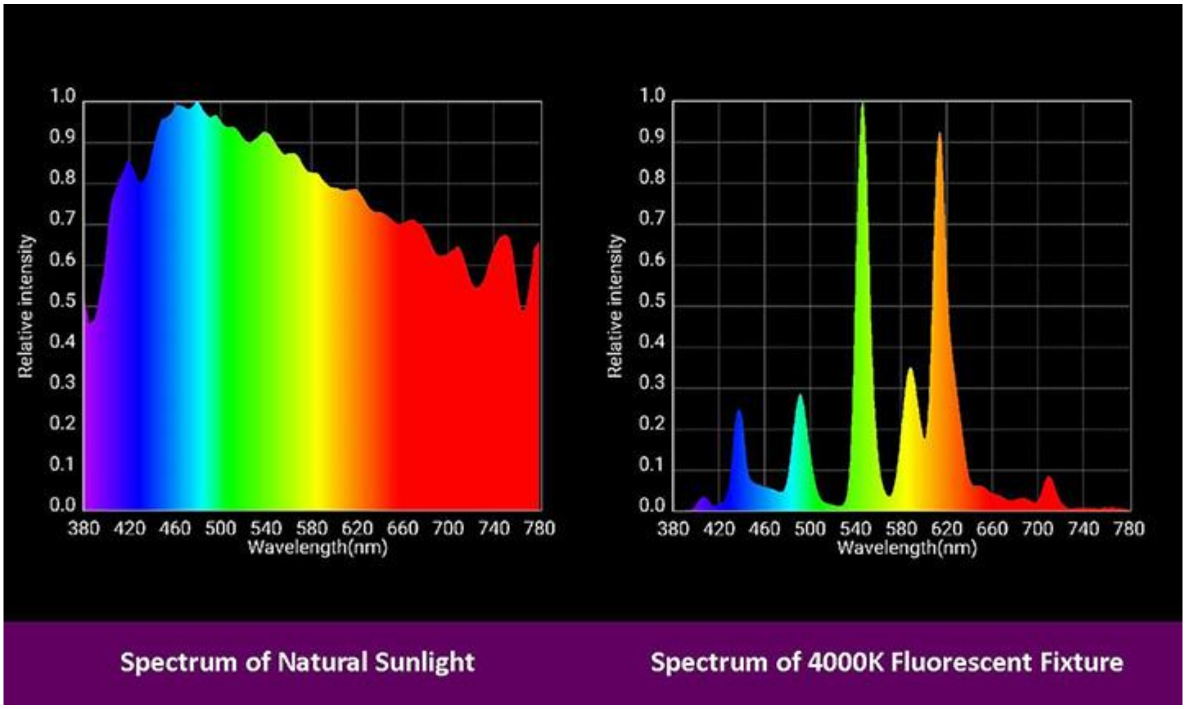

Figure 1: Spectral Power Distributions of Two Lights
(SPD Samples, 2018) This figure highlights the difference between natural sunlight and a 4000K fluorescent light. The intensity of different wavelengths of light is shown to be variable depending on the specific type of light source.

Lights considered *full spectrum* are closer to 5600°K, but there is no official standard for what is considered full spectrum. Full spectrum bulbs use a higher color temperature in order to more accurately imitate sunlight, which can get up to 10,000°K on a very sunny day and hovers around 4000°K for regular, direct sunlight.

1.3.2 Seasonal Affective Disorder

A specific sub-category of lights is often used to treat a relatively common condition known as Seasonal Affective Disorder (SAD). SAD refers to a reoccurring state of depression brought on by a shift in the seasons, particularly during the gray winter months of the year (Melrose, 2015). Symptoms include increased sadness, sleepiness, and appetite, as well as a lack of energy, and potentially an increase in suicidal thoughts. It is theorized that SAD occurs because the days in the winter months have a shorter photoperiod (period of daylight hours) than in the summer, shifting circadian rhythms (Boyce & Hopwood, 2013). It has also been theorized that one possible reason for why photoperiod and SAD are linked is because of the connection between sunlight and serotonin. People prone to SAD are more likely to have a serotonin transporter, SERT, that decreases the amount of available serotonin. Sunlight keeps levels of SERT lower, which means in seasons with shorter photoperiods (or in times where there is more cloud cover) SERT levels will be higher (McMahon et al., 2016). It is also possible, although not proven, that people with SAD overproduce melatonin, a neurotransmitter involved in regulated circadian rhythms, and that during the shorter photoperiod they are more likely to overproduce melatonin, causing them to become more lethargic and sleepy (Melrose, 2015). Over 90% of physicians say that they recommend SAD lamps, lights created specifically to imitate sunlight, for treating SAD (Winkler-Pjrek et al., 2017). These lamps have been considered the standard treatment of the disorder since the 1990s (Anderson et al., 2016). Investigating SAD in a place like Portland, Oregon, famous for its rain and dreary days, seems appropriate.

Unfortunately, SAD is often targeted by marketers who take advantage of there being no actual criteria for what counts as a SAD lamp. SAD is often confused and misaligned with vitamin D deficiencies, and while the two can certainly coexist there is no evidence that the relationship is more than a correlation that comes from a lack of sun exposure. Although there is evidence that Vitamin D deficiencies have been correlated with depressive symptoms in young women, there is no evidence that Vitamin D has a causal effect on depression, seasonal or not (Kerr et al., 2015).

Although this thesis will primarily focus on the use of light therapy in relation to SAD, light therapy is also being used to treat other illnesses, including adult attention deficit disorder, and Parkinson's disease (Terman, 2007). Light therapy is also being considered for treatment of comorbid major depression and type 2 diabetes because past research has shown insulin sensitivity to be affected by circadian rhythms (Brouwer et al., 2015). The number of applications of light therapy implies that there may be more mechanical actions happening behind the scenes that need to be investigated further. Lighting design has many potentially advantageous applications that should be thoroughly investigated and assessed.

1.3.3 Light Therapy Lamps

The lamps normally used to treat SAD vary in their color temperature and illuminance, but they are often full spectrum and produce 10,000 lux when 20 cm away from the eye. Specifications on individual products vary considerably because no exact definition of what constitutes a "SAD lamp" exists. Thus, misleading marketing can obscure what, exactly, the mechanisms are behind these products and what specifications are most relevant for therapeutically decreasing SAD.

Studies have found that blue lights at 17,000°K with only 750 lux can be just as affective at treating SAD as 10,000 lux, 5000°K lights (Meesters, Dekker, Schlangen, Bos, & Ruiter, 2011; Meesters, Winthorst, Duiizer, & Hommes, 2016). Intrinsically photoreceptive retinal ganglion cells in the eye have been shown to react to 470-490 nm of blue light wavelengths, impacting circadian rhythms. Unlike rods or cones, photoreceptive ganglion cells are non-image forming; these cells simply react to the presence of light (Meesters, Dekker, Schlangen, Bos, & Ruiter, 2011). These photoreceptive ganglion cells send signals to the superchiasmatic nucleus of the hypothalamus and impact the secretion of melatonin, thus affecting circadian rhythms. Blue light adversely influences sleep at night, specifically, when one should be resting, even though there is evidence that exposure to blue light during the day does not affect circadian rhythms (Duffy & Czeisler, 2009; Hatori et al., 2017). This is why it has recently become common to recommend turning off computers and cell phones, both emitters of blue light, at night in order to get better sleep (Heo et al., 2017).

Trials using lights with 470-490 nm wavelengths have been shown to improve the effects of SAD. Interestingly, there is no evidence of blue-enriched light actually treating SAD significantly better than white light, although blue light has been shown to be superior to red light (Anderson et al., 2016; Gordijn, 't Mannetje, & Meesters, 2012; Meesters, Dekker, Schlangen, Bos, & Ruiter, 2011; Meesters, Winthorst, Duijzer, & Hommes, 2016). Therefore, it seems that the impact of light on chronobiology (in this case, specifically circadian rhythms) is a specific and important factor to consider in the treatment of SAD, since other types of light have not been shown to have the same effect.

Despite all of the advantages, traditional 10,000 lux SAD lamps are not exclusively beneficial. There is evidence that the light that they emit is too bright to the point of distraction and discomfort (Anderson et al., 2016). In these cases, the light is actually detrimental. When lights are too bright they begin to show negative influences on certain cognitive functions, such as delayed reaction times in attention tasks (Min, Jung, Kim, & Park, 2013). A different experiment found that the level of physiological agitation (i.e., increased heart rate and skin conductance) can be manipulated through the brightness of a light (Sugimoto and Hataoka, 1986). Another study showed that a higher color temperature led to less favorable mood ratings (Smolders & de Kort, 2017). This would imply that the current use of SAD lamps that imitate sunlight as closely as possible instead of using a dimmer light, may actually end up making people feel less positive, a hypothesis in opposition to the "therapeutic" ideal of a light therapy lamp.

1.4 The Current Study

1.4.1 Rationale

Although a fair amount of research has been devoted to comparing white light versus blue light in terms of using light therapy to decrease SAD, there are few studies that also include a third, control condition. As a result, it remains difficult to determine the magnitude of effects of SAD lights relative to light that we are normally exposed to on a daily basis. In addition, it has been shown that the effects of SAD lamps are not always beneficial or therapeutic, especially since some of their shortcomings seem to be rectified by using a lower-intensity blue light instead. Therefore, it important to expand research in this area. Finally, while previous studies have either focused on how these lights might help treat SAD, or how they influence one specific aspect of cognition, no previous study has explored the effects of such lights on a broad range of basic psychological processes.

The current study involved manipulations of interior lighting in order to study how lighting can influence emotion, cognition, and basic physiology. Three different lighting conditions were tested in a within-subjects design: light therapy (10,000 lux, full-spectrum, white light), blue light (40 lux, 450 nm light), and a control light (40 lux, warm incandescent light). In each lighting condition, emotional state was assessed via the Profile of Mood States-Short Form (POMS-SF). To measure a key aspect of cognitive functioning, subjects' ability to sustain attention on a task was measured with a Conjunctive Continuous Performance Task (CCPT). Intermittent measurements of heart rate were taken to assess the impact of the lighting condition on an aspect of basic physiology, known to be related to stress (Thayer, Åhs, Fredrikson, Sollers, & Wager, 2012).

The Seasonal Pattern Assessment Questionnaire (SPAQ) was also administered as an exploratory co-variate, in case subjects' reactions to the different lighting conditions varied as a function of having SAD. All measures are relayed in more detail in section 2.2.

1.4.2 Hypotheses

Based on previous studies we predicted that scores on the POMS-SF would be lower in the light therapy and blue light conditions compared to the control condition since there is evidence that both bright white light and blue light are effective for treating SAD. Lower scores on the POMS-SF indicate a lower Total Mood Disturbance, and, thereby, a better mood. For the CCPT, we expected that error rates would increase, and reaction times would take longer in the light therapy condition compared to the blue light and control conditions, because of the bright SAD lamps' potential to distract and irritate participants. Similarly, heart rate was expected to increase in the light therapy condition relative to the two other conditions because of the potential for bright lights to increase arousal and physiological stress.

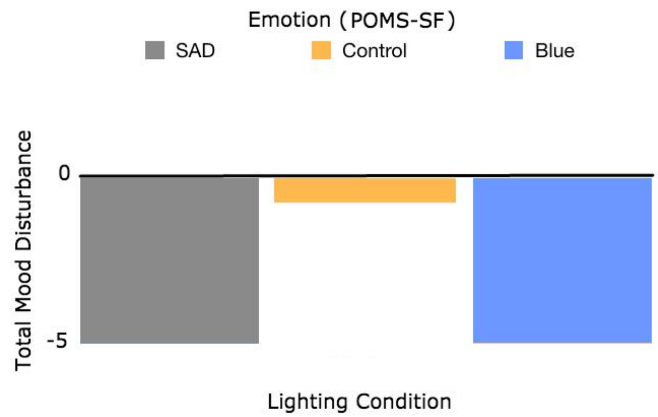

Figure 2: Predicted Results of the Effects of Light Condition on Total Mood Disturbance from the POMS-SF

This figure shows the pattern of results we expect to find between lighting conditions on the Profile of Mood States Short Form (POMS-SF). The lighting conditions include one bright, white light (SAD), one dim, warm light (Control), and one dim, blue light (Blue). The SAD condition and Blue condition are both expected to positively affect mood between the beginning and end of the light session, creating a negative Total Mood Disturbance Score, whereas the Control is hypothesized to have no effect.

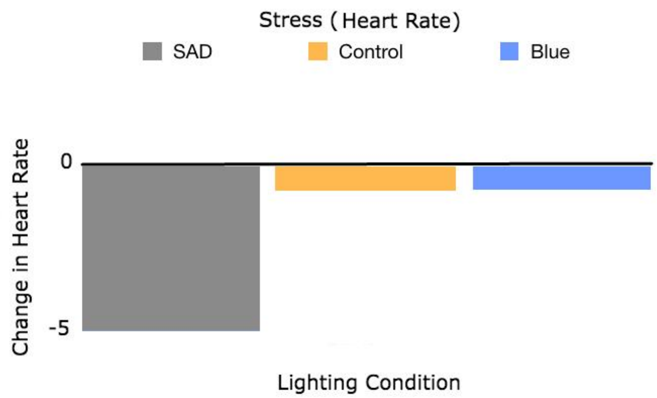

Figure 3: Predicted Results of the Effects of Light Condition on Change in Heart Rate
The figure shows the expected pattern of results of lighting conditions on change in heart rate from the beginning to the end of the lighting session. The lighting conditions include one bright, white light (SAD), one dim, warm light (Control), and one dim, blue light (Blue). The SAD condition is hypothesized to show a larger change in heart rate than both the Blue and Control conditions, indicating more physiological stress. The Blue and Control conditions are not expected to show any statistically significant differences.

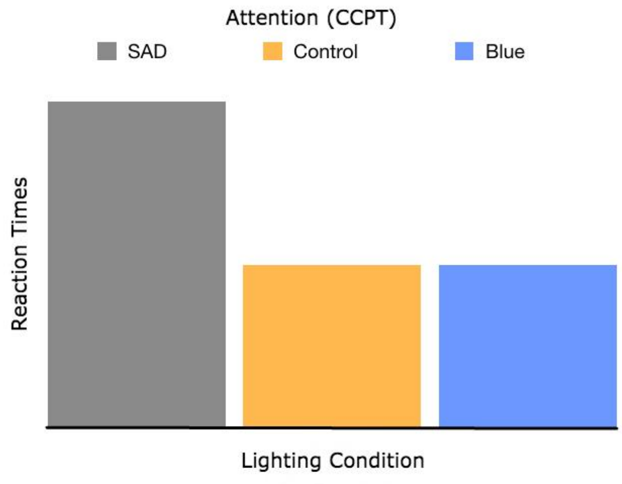

Figure 4: Predicted Results of the Effects of Light Condition on Reaction Times in the CCPT

The figure above shows the hypothesized pattern of results of reaction times from the Conjunctive Continuous Performance Task by lighting condition. The lighting conditions include one bright, white light (SAD), one dim, warm light (Control), and one dim, blue light (Blue). The SAD condition is hypothesized to result in slower reaction times than both the Blue and Control conditions. The Blue and Control conditions are not expected to show any statistically significant differences.

Methods

2.1 Participants

Participants were twelve 19-22-year-old students from Reed College who were recruited using social media posts and word of mouth (6 female, 2 non-binary, 2 non-binary women, 2 male). One subject only completed one session and, as a result, was excluded from analysis. As a result, the final data set included eleven participants. Participants were compensated for their time with “lottery tickets” that gave them the chance to win $50. Those who had color deficiencies were excluded from the experiment because color discrimination was essential for the sustained attention task. Participants were advised that if they had a light sensitivity that they may find the sessions uncomfortable and should consider withdrawing from the study. Although 63% of the participants reported feeling at least some change between seasons, only 27% of the participants met the minimum requirements for possible SAD according to the SPAQ.

2.2 Measures

2.2.1 Profile of Mood States-Short Form

The Profile of Mood States-Short Form (POMS-SF[1]) was used to assess emotional state both pre- and post-session (Shacham, 1983). The POMS-SF contains five subscales: Depression-Dejection, Confusion, Tension, Anger, Fatigue, and Vigor. Total mood disturbance is found by adding the scores of the sub scales and subtracting the Vigor score. The measure uses a five-point Likert scale and a list of 37 adjectives that participants mark on a scale from “not at all” to “extremely.” The POMS-SF was originally derived from the POMS for cancer patients who may have found it difficult to complete the full, 65 adjective version of the POMS. This briefer scale has been shown to

[1] Available in the Appendix

be just as psychologically valid as the original and even has better psychometric properties on a few of the sub-scales (Curran, Andrykowski, & Studts, 1995).

2.2.2 Seasonal Pattern Assessment Questionnaire

A shortened version of the Seasonal Pattern Assessment Questionnaire (SPAQ) was used to assess if participants had symptoms of Seasonal Affective Disorder (SAD) and was administered before the participants' first session. The shortened measure uses two questions to assess a person's Global Seasonality Score and identify possible SAD or sub-threshold SAD. Although on the original measure there are more questions, only the two questions we employed are actually used to calculate the Global Seasonality Score. The measure is imperfect, known for over diagnosis, but was used as a rough estimate of susceptibility to SAD.

2.2.3 Heart Rate

Participants' heart rate was taken as a measure of physiological arousal. Heart rate was checked three times; once pre-session, once during exposure to the light (detailed more in section 2.3), and once after exposure to the light, but before subjects began the attention task. Heart rate was assessed over two-minute periods and the average of each time period was taken. Pre-session heart rate was taken after the administration of the POMS-SF in order to ensure that participants' heart rate was not elevated from prior activities. The heart rate measuring device was an Air Wireless Pulse Oximeter (iHealth).

2.2.4 Sustained Attention Task

A visual Conjunctive Continuous Performance Task (CCPT) was used to measure participants' ability to sustain attention. This task is similar to the Continuous Performance Task (CPT). The CPT is a simple task in which participants respond to a single letter or number stimulus (such as the letter "X," or the number "1") by pressing a button while ignoring all other stimuli (the other 25 letters of the alphabet, or the digits 2-10, respectively) when they appear on the screen (Riccio, Reynolds, Lowe, & Moore, 2002). Stimuli appear one at a time for 100 msec, with 1900 msec between each stimulus, for a total duration of about 10 minutes. The task is not challenging, but is purposefully unstimulating in order to measure participants' ability to focus and sustain attention (Riccio, Reynolds, Lowe, & Moore, 2002)

The CCPT is a modified version of this original task in which respondents must attend to the conjunction of two visual qualities, color and shape. It has been argued that the CPT's use of single letters or numbers is not as efficient for measuring attention because it is possible that these very familiar, overlearned, stimuli are processed effortlessly and subconsciously (Shalev, Ben-Simon, Mevorach, Cohen, & Tsal, 2011). The CCPT is designed to correct for this potential flaw by having the task stay simple while adding a conjunction component to the stimuli, which, presumably, requires focused attention to visually bind the features together (Shalev, Ben-Simon, Mevorach, Cohen, & Tsal, 2011). The "conjunction" is the addition of another feature to which the participant must attend. In this case changing the CPT from a single feature stimuli (numbers) into a more varied stimulus (varying shapes, as well as colors). The version of the CCPT used here included four distinct shapes and four distinct colors which were combined for a total of 16 possible stimuli. The target, a red square, appeared 30% of the time, non-red squares (blue, green and yellow squares) appeared 17.5% of the time, red non-squares (red circles, triangles, and stars) appeared 17.5% of the time, and non-targets with none of the target features (blue/yellow/green circle/triangle/star) appeared the other 35% of the time. Stimuli were presented for 100ms with a randomized blank period of either 1000ms, 1500ms, 2000ms, or 2500ms in between the presentation of each stimulus (visualized in Figure 5). The task lasted approximately 10 minutes.

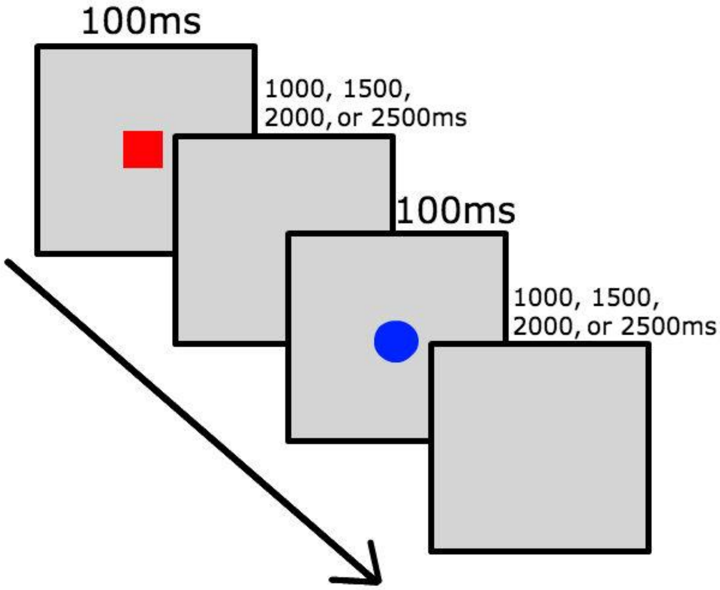

Figure 5: Example of the Stimuli Used in the CCPT
This figure shows both an example of the stimuli used in the Conjunctive Continuous Performance Task as well as the milliseconds over time in which stimuli were presented and the varying amount of time (1000, 1500, 2000, 2500ms) that took place between the presentation of the next stimuli. The task was to press a response key whenever a red square was presented and to withhold responses for all other stimuli (including squares of other colors and other red shapes).

2.3 Procedure

The within-subjects experimental design included a total of three lighting conditions: a *light therapy* condition with a 10,000 lux, 6500°K light, a *blue light* condition with a 50 lux 450 nm light, and a *control* condition with a 50 lux 3500°K standard office light. Previous literature has shown that effects of light therapy are measurable in less than one hour of administration (Virk, Reeves, Roseenthal, Sher, & Postolache, 2009). As a result, participants spent a total of 45 minutes in each lighting condition. Each condition was separated by one week (each participant completed three separate sessions), and the order of lighting conditions was counterbalanced across participants. Data collection took place over a three-week period in Portland, OR from late-February to mid-March. Participants were scheduled at various times throughout the day and into the evening, but each came in at the same time each week. Participants completed the shortened SPAQ before their first session. POMS-SF and baseline heart rate were taken before each session. Heart rate was taken again 25 minutes into each session. The POMS-SF was administered again at the end of the session. After the POMS-SF was completed and heart rate was taken a final time, participants started the CCPT. The CCPT lasted approximately 10 minutes. Each session lasted a total of about 1 hour.

2.4 Data Analysis

To assess the impact of the lighting manipulation on self-reported emotional states, scores on the POMS-SF were compared across the three lighting conditions via a one-way, repeated measures ANOVA. Differences in the physiological arousal as a function of lighting condition was assessed by converting the three heart rate measures into two composite scores (taking the difference between mid-session heart rate and pre-session heart rate as well as the difference between post-session heart rate and pre-session heart rate) and then entering these scores into a one-way, repeated measures ANOVA. In order to determine whether the different lighting conditions affected participants' ability to sustain attention, four separate measures derived from the CCPT were compared across lighting conditions with one-way, repeated measures ANVOA: reaction times, miss rates for conjunction targets (omission errors), false alarm rates for non-targets that shared one feature with the target (feature commission errors), and errors rates for non-targets without any target features (non-feature commission errors). If there were significant differences across conditions in the ANOVAs, pairwise comparisons (t-tests) were used to determine the exact pattern of differences.

Results

3.1 Emotion: POMS-SF

The analysis of the POMS-SF data included the Total Mood Disturbance score, as well as the scores of two specific subscales that seemed appropriate to investigate based on the content of this thesis: Depression-Dejection, and Fatigue. Total Mood Disturbance is calculated by adding all of the subscales and then subtracting the Vigor subscale. Higher mood disturbance scores indicate a worse mood, whereas lower mood scores indicate a better mood. Difference scores in the analysis were achieved by subtracting the scores taken post-light session from the initial, pre-light session scores. As a result, negative difference values indicate that mood improved during the session.

We decided to look specifically at the subscales of Fatigue and Depression-Dejection because symptoms of SAD often fall into one of these two categories. It seemed worth investigating in case relevant data was lost in the larger combined dataset of Total Mood Disturbance. As with Total Mood Disturbance, negative values indicate an increase in good mood.

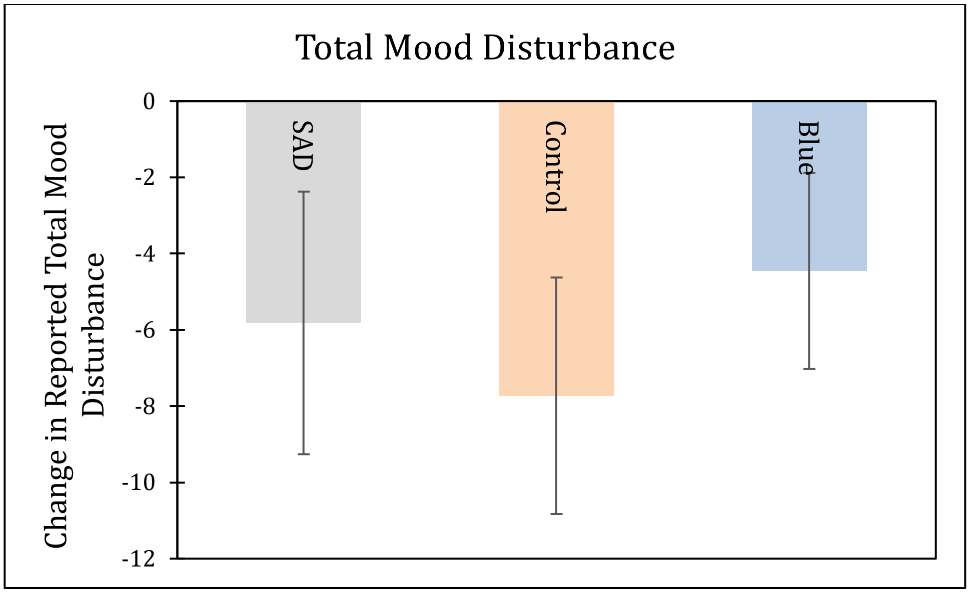

Figure 6: Total Mood Disturbance by Light Condition

This graph shows the change in reported Total Mood Disturbance (TMD) on the Profile of Mood States Short Form (POMS-SF) across three lighting conditions. Total mood disturbance was calculated by adding the subscales of the POMS-SF and then subtracting the vigor subscale. The difference scores shown here were obtained by taking the TMD from the POMS-SF administered after the end of the lighting session and subtracting it from the POMS-SF given before the lighting session. Negative scores indicate a more positive reported mood. The lighting conditions included one bright, white light (SAD), one dim, warm light (Control), and one dim, blue light (Blue). The error bars reflect the standard error of the mean.

A one-way ANOVA indicated that Total Mood Disturbance was not significantly different across light condition, $F(2, 10) = 0.55$, $p = .58$. Total Mood Disturbance showed no significant variation between the three light conditions, but after all three lighting conditions, participants were more likely to indicate a better mood than when they initially started the session (means: SAD = -5.81; Control = -7.73; Blue = -4.45). The largest increase in positive mood in the control condition is possibly due to the less abrasive nature of the light. Both dim and a normative color, the control condition was also the most familiar to participants.

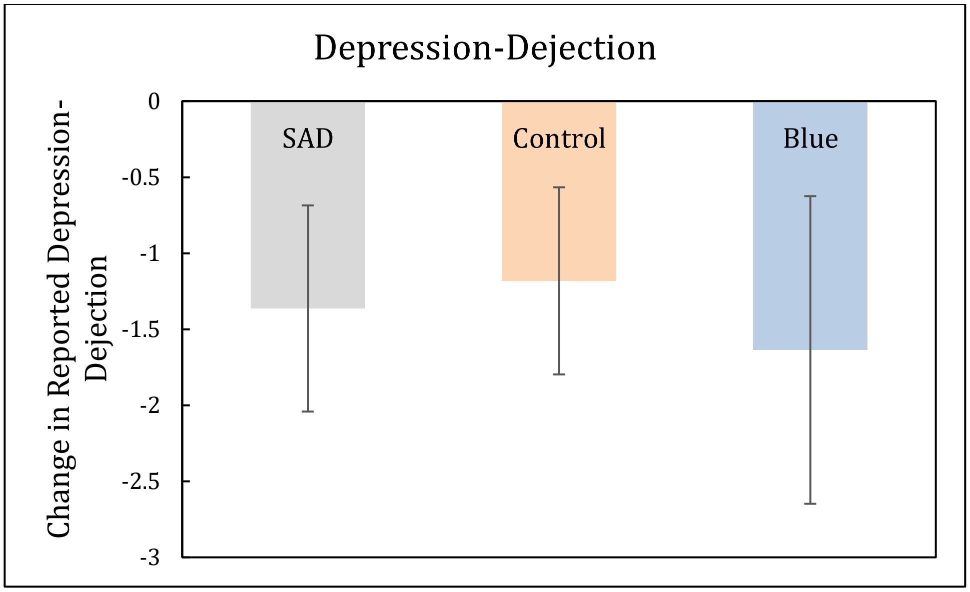

Figure 7: Depression-Dejection POMS Subscale by Light Condition

This graph shows the change in reported Depression-Dejection on the Profile of Mood States Short Form (POMS-SF) across three lighting conditions. The difference scores shown here were obtained by subtracting the post-light session Depression-Dejection POMS score from the pre-session score. Negative scores indicate a lower reported feeling of Depression-Dejection. The lighting conditions included one bright, white light (SAD), one dim, warm light (Control), and one dim, blue light (Blue). The error bars reflect the standard error of the mean.

A one-way ANOVA indicated that Depression-Dejection was not significantly different across light condition, $F(2,10) = 0.089$, $p = .92$. As shown in Figure 7, the numeric pattern of the data indicates that the control condition was slightly less effective at reducing reported depressive mood than the SAD or blue light conditions, as one would expect if the SAD and blue light conditions were effectively reducing the symptomology of SAD (means: SAD = -1.36; Control = -1.18; Blue =-1.63).

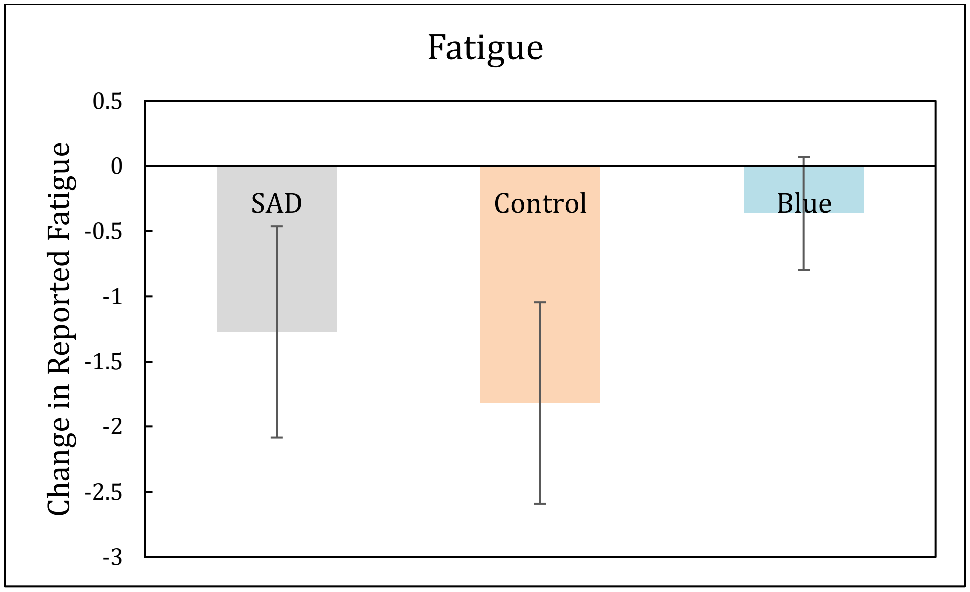

Figure 8: Fatigue POMS Subscale by Light Condition
This graph shows the change in reported Fatigue on the Profile of Mood States Short Form (POMS-SF) across three lighting conditions. The difference scores shown here were obtained by subtracting the post-light session Fatigue POMS score from the pre-session score. Negative scores indicate less reported Fatigue. The lighting conditions included one bright, white light (SAD), one dim, warm light (Control), and one dim, blue light (Blue). The error bars reflect the standard error of the mean.

A one-way ANOVA indicated that Fatigue was not significantly different across light condition, $F(2,10) = 1.14$, $p= .34$. The Fatigue subscale unexpectedly showed the blue light condition as the least effective at reducing Fatigue in participants (means: SAD = -1.27; Control = -1.81; Blue =-0.36). This is interesting because, in theory, the blue light should have reduced the production of melatonin and actually reduced feelings of fatigue; although the differences were not statistically significantly different.

3.2 Physiology: Heart Rate

The difference in heart rate between time 3, the post-session time, and time 1, the pre-session time, was taken as well as the difference between time 2, the mid-session time, and time 1 to assess change over time as a result of the session. It is important to note that time 2 heart rates were often lower than time 1 and time 3 measurements, which were taken while the researcher was physically present. Due to technical errors, one participant's data was excluded; for this reason, the *n* of this data set is 10. Technical errors also caused one participant's initial time during the control session to not be taken. A substitute heart rate was created using the average of the participant's initial heart rate from the other light sessions.

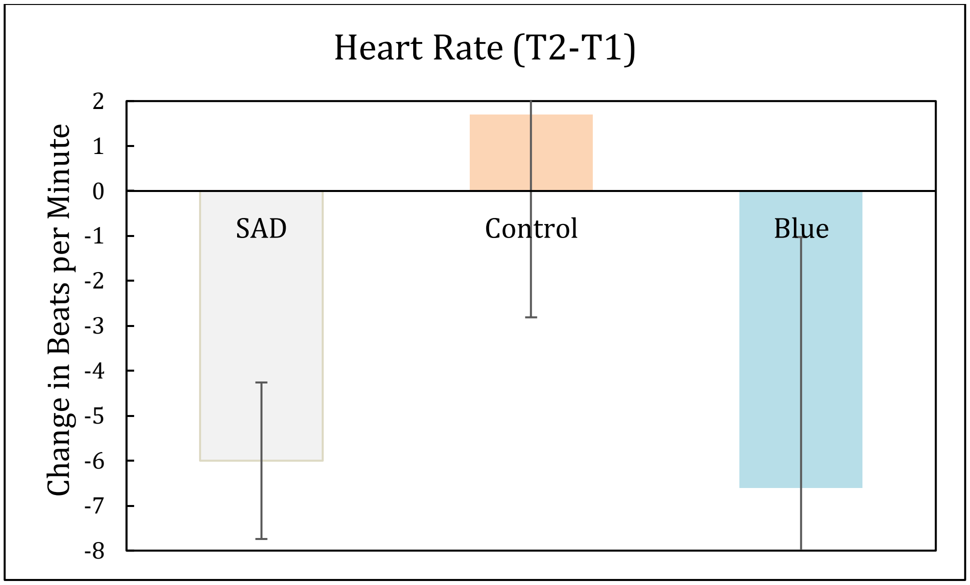

Figure 9: Change in Heart Rate from Time One to Time Two by Light Condition
This figure shows the change in heart rate from the start of the experiment before light exposure, to 25 minutes into light exposure across the three different lighting conditions. Heart rate was taken over a two-minute period and the average of the two-minute period was used for the measurement. The heart rate measurement taken 25 minutes into the light session was subtracted from the initial heart rate to show the change over time. A negative score indicates that heart rate went down over time. The lighting conditions included one bright, white light (SAD), one dim, warm light (Control), and one dim, blue light (Blue). The error bars reflect the standard error of the mean.

A one-way ANOVA indicated that change in heart rate from pre-session to mid-session was not significantly different across light condition, $F(2,9) = 1.49$, $p= .25$. Interestingly, the numeric pattern shows a similar difference score for both the SAD light condition as well as the blue light condition, but a wildly different, positive score for the control light condition (means: SAD = -6; Control = 1.7; Blue = -6.6). Heart rate at time two was typically lower than values at time one or time three (possibly due to the presence of the researcher at both time one and time three), but the average heart rate difference score in the control condition indicates the opposite pattern, as if the participants' in the control condition were more likely to experience an elevated heart rate over time. However, due to the large variability in the data, seen in the standard errors bars in Figure 9, it is hard to say if this effect would be replicable or relevant.

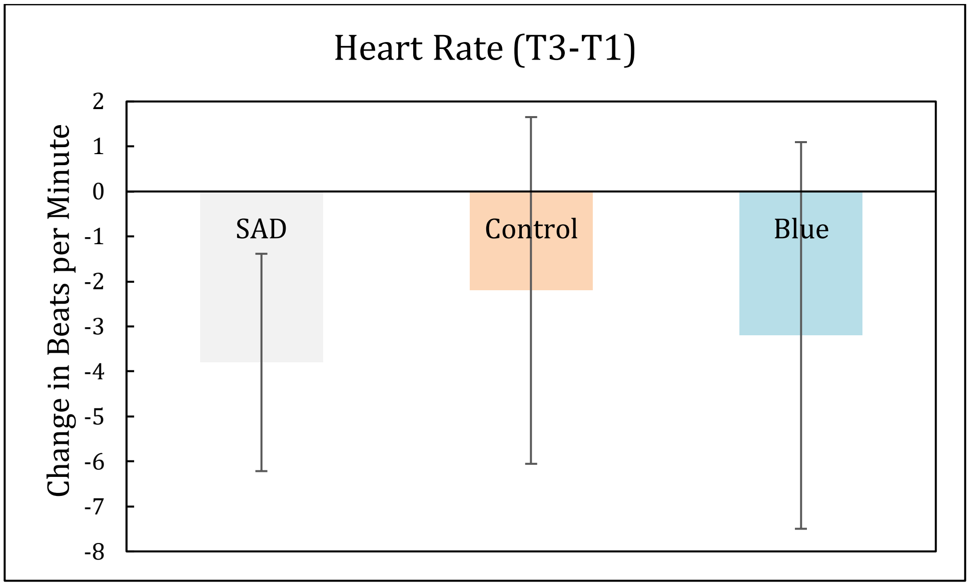

Figure 10: Change in Heart Rate from Time One to Time Three by Light Condition
This figure shows the change in heart rate from the start of the experiment before light exposure, to the end of the light exposure, 45 minutes later across three different lighting conditions. Heart rate was taken over a two-minute period and the average of the two-minute period was used for the measurement. The heart rate measurement taken after the light session was subtracted from the initial heart rate to show the change over time. A negative score indicates that heart rate went down over time. The lighting conditions included one bright, white light (SAD), one dim, warm light (Control), and one dim, blue light (Blue). The error bars reflect the standard error of the mean.

A one-way ANOVA indicated that change in heat rate pre-session to post-session was not significantly different across light condition, $F(2,10) = 0.044$, $p = .96$. The difference scores between the initial heart rate measurement and the final heart rate measurement show a similar, although less dramatic, numerical pattern to the initial time and time two difference scores with the SAD and blue conditions resembling one another more closely than the higher control score (means: SAD = -3.8; Control = -2.2; Blue = -3.2). Again, this pattern implies a link between a slightly elevated heart rate and the control condition as compared to the SAD and blue light conditions. Statistical tests and standard error indicate that this pattern is not statistically significant, but it is interesting to note.

3.3 Cognition: Sustained Attention (CCPT)

Four measures from the sustained attention task were taken to measure participants' ability to concentrate. This included average reaction time during the task, the standard deviations of those response times, the percent of omission errors (when the participant did not respond to the target stimulus), and the percent of commission errors (when the participant responded to a non-target stimulus). Significant changes in these measurements between conditions would indicate that lighting condition had a significant impact on participants' ability to concentrate and focus attention.

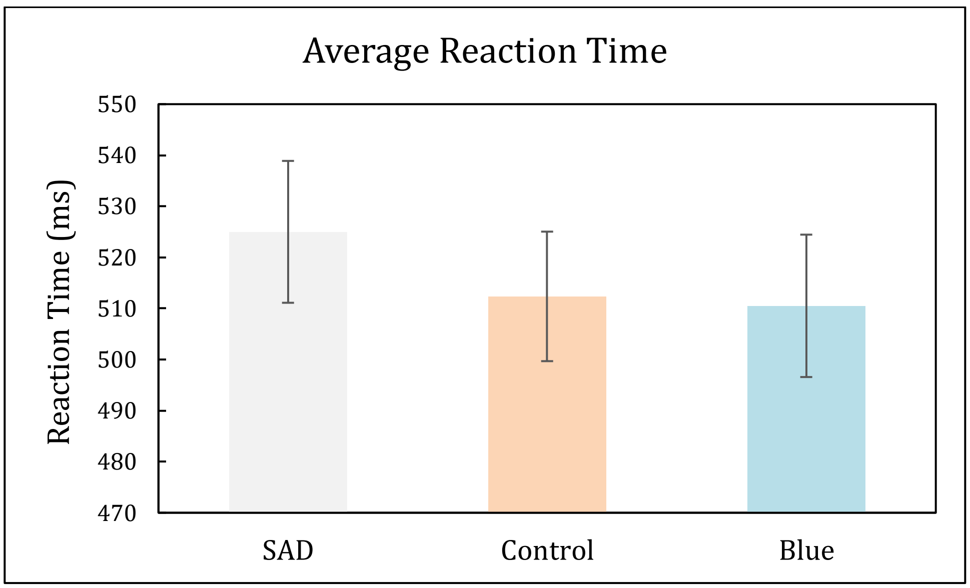

Figure 11: Average Reaction Time in the CCPT by Light Condition
The figure shows the average reaction times in milliseconds for responses across three lighting conditions on the Conjunctive Continuous Performance Task. The lighting conditions included one 10,000 lux white light (SAD), one warm, dim light (Control), and one dim, blue light (Blue). The error bars reflect the standard error of the mean.

A one-way ANOVA indicated that average reaction time during the CCPT was not significantly different across light condition, $F(2,10) = 1.34$, $p = .28$. Although the statistical tests show no significant differences between the groups, the numeric pattern of the results matches the hypothesized outcome (means: SAD = 525; Control = 512.36; Blue = 510.51). The average reaction time for participants' while they were in the SAD condition was higher than the reaction times in both the control and blue light conditions, indicating that in the SAD condition participants found it harder, or were less likely to have their full attention on the task.

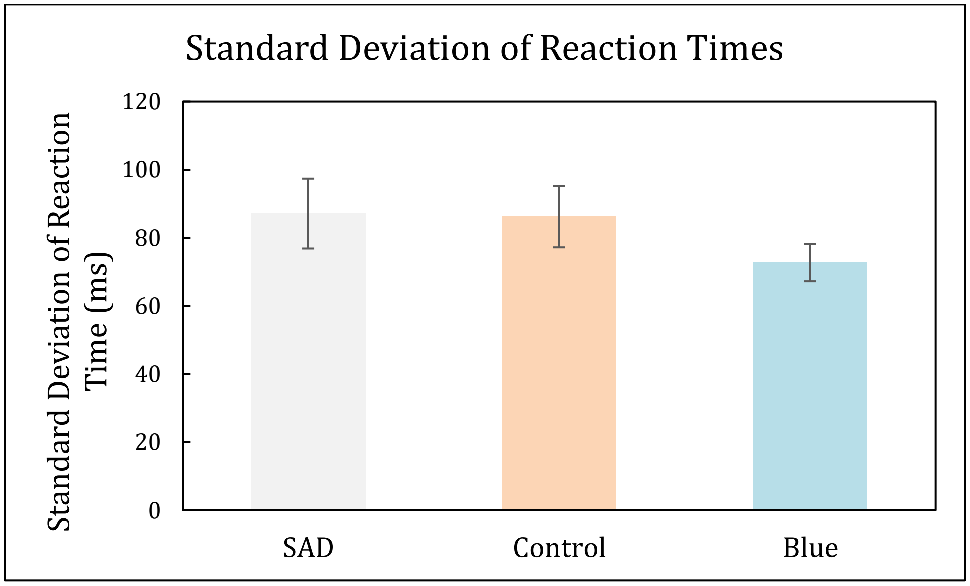

Figure 12: Standard Deviation of Reaction Times by Light Condition
The figure shows the standard deviation, in milliseconds, of the reaction times collected during the Conjunctive Continuous Performance Task across three different lighting conditions. The lighting conditions included one bright, white light (SAD), one dim, warm light (Control), and one dim, blue light (Blue). The error bars reflect the standard error of the mean.

A one-way ANOVA indicated that the standard deviation of reaction times during the CCPT was not significantly different across light condition, $F(2,10) = 1.18$, $p = .33$. (means: SAD = 87.1; Control = 86.21; Blue = 72.7). Standard deviation of reaction times indicates the variance in the amount of time it took someone to respond. Large variances in how long it took a person to respond can indicate waxing and waning of attention from trial-to-trial throughout the session. This statistical test found no significant differences between conditions, although numerically it appears that response times varied less in the blue light condition than in the SAD or control condition, potentially indicating a trend toward heighted (or more consistent) attention in the blue light condition, although without statistical verification the results are inconclusive.

Figure 13: Omission Errors in the CCPT by Light Condition

The figure shows the percentage of omission errors made on the Conjunctive Continuous Performance Task across three separate lighting conditions. Omission error percentages were calculated for each participant by finding the number of times that they did not respond to the target stimulus and then converting that number into a percentage. The lighting conditions included one bright, white light (SAD), one dim, warm light (Control), and one dim, blue light (Blue). The error bars reflect the standard error of the mean.

A one-way ANOVA indicated that omission errors were not significantly different across light condition, $F(2,10) = 0.5$, $p=.62$. Although there is no significant statistical effect between the three lighting conditions, the numerical pattern of the data matches what was predicted (means: SAD = 1.99; Control = 1.42; Blue = 1.32). The increase of omission errors in the SAD light condition indicates that participants were unable to commit their full attention to the task and, as a result, were less likely to respond to the target stimulus when it was presented.

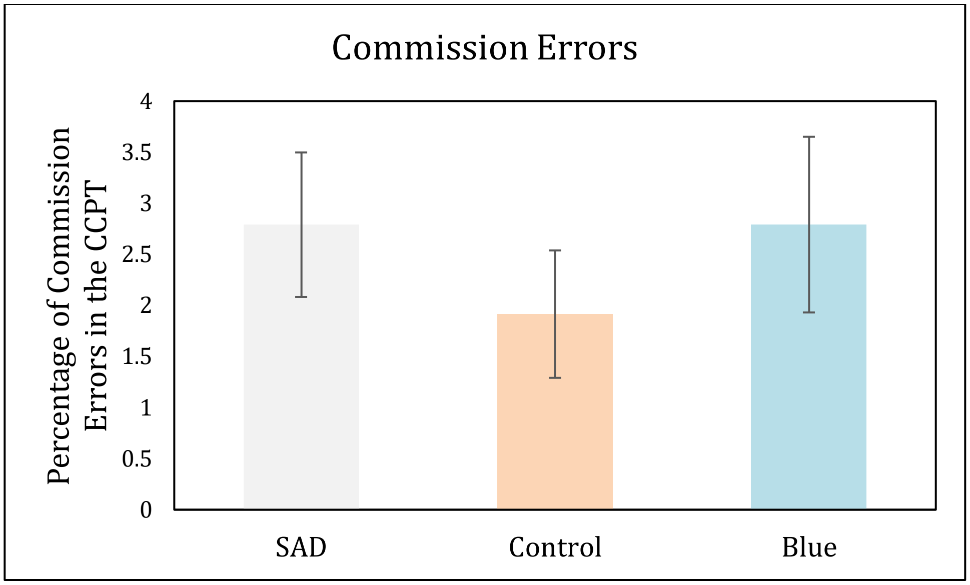

Figure 14: Commission Errors in the CCPT by Light Condition
The figure shows the percentage of commission errors on the Conjunctive Continuous Performance Task across three lighting conditions. Percentage of commission errors was found by combining false hit rates for non-target stimuli that shared one feature with the target, either its color (red) or shape (square) and converting those rates into a percentage. The lighting conditions included one bright, white light (SAD), one dim, warm light (Control), and one dim, blue light (Blue). The error bars reflect the standard error of the mean.

A one-way ANOVA indicated that commission errors were not significantly different across light condition, $F(2,10) = 0.9$, $p=.42$. Although not statistically significant, when the data is visualized, there is a numeric pattern that contrasts the other three CCPT measures. This graph shows a similar false-hit rate in both the SAD light condition as well as the blue light condition (means: SAD = 2.79; Control = 1.91; Blue =2.79). It is possible that the reason for this discrepancy is that color discrimination, which was necessary for this task, could have been more difficult in the blue light condition because of the after-image left following the exposure to the blue light for 45 minutes.

Discussion

According to the results, neither mood, heart rate, nor attention were significantly affected by each lighting condition. This pattern of results suggests that either there is not an effect of lighting condition on these specific psychological constructs, or that flaws in the study prevented reproduction of previously reported effects. Potential flaws include but are not limited to: effect sizes that were too small to be captured with a small sample size (N=11), experimental procedures that were not sensitive enough or flawed in some way, or extraneous variables that affected the quality of the data. A few trends in the data do appear to hint at preliminary support for certain hypotheses. These trends were evident for the reaction times and omission error measures of the sustained attention task (CCPT).

4.1 Limitations

4.1.1 Limitations of the Current Study

There were a number of possible limitations that could have possibly affected the outcome of this study, including sample size and confounding variables such as effect size, weather, time of day, and the time in the semester in which this study took place.

4.1.1.1 Sample Size

With only 11 participants it is possible that there was simply not enough statistical power to detect genuine differences between the three lighting conditions. It is important to note that there were times when the results followed the expected pattern numerically, although the variability resulted in statistically indistinguishable differences. This was true of the average of the reaction times for the CCPT as well as for the omission errors for the CCPT, where, as predicted, the SAD condition showed less of a propensity toward paying careful attention, with longer reaction times and more omission errors.

4.1.1.2 Weather Patterns

Although SAD manifests most clearly during the winter on cloudy, sunless days, there was not uniform, cloudy weather during the time of the experiment. A few days when sessions were scheduled it snowed. There were also quite a few days when the sun was out. Change in the weather patterns may have influenced participants' mood or levels of stress, causing extra variation in the dataset. In order to avoid such variation in the data, future studies should make an effort to run participants in mid-winter, rather than late winter, as this experiment did.

4.1.1.3 Time of Day

Participants also completed the experimental sessions during various times of day. Although each participant was run on the same day each week, very few participants came in at the same time each day (due to scheduling conflicts). Most participants were scheduled during the daytime and only three were scheduled during the evenings, when effects would presumably be stronger and easier to detect because of the impact of blue light on circadian rhythms. This may be why the blue light condition showed such a marked difference from the hypothesized result on the POMS-SF Fatigue scale (see Figure 8 in section 3.1). Without the marked changes that come from a shift in melatonin production, identifying effects of lethargy would be more difficult. In future studies, it would be prudent to schedule sessions in the evening rather than during the day in order to more accurately see the effects of the lights on fatigue and possible melatonin suppression.

4.1.1.4 Time of Semester

It is also important to note that the study took place at an academically rigorous college where participants' workloads shifted week-to-week. Data collection took place over several weeks of school, a normal week of school, a week of midterms, and partially into spring break. With this much variation in workload, it is possible that stress and unregulated sleep patterns may have also affected the data. The week immediately before spring break is often more likely to have various projects, papers, and tests due. Because of this, students are more likely to be stressed and have atypical sleep schedules as they complete all of their work. More than one participant reported higher levels of stress or indicated that they would be changing their sleep schedule to accommodate their work. Inversely, during spring break students have little to no work, living relatively stress-free. More than one participant scheduled for a session during spring break indicated that they felt incredibly relaxed before the session began because they did not have any pressing deadlines. Participants were also able to maintain more normative sleep schedules. Future follow-up studies, if done in a college setting, would be wise to avoid points in the semester where the majority of participants will likely have uneven workloads across the experimental conditions.

4.2.1 Risk of Unfit Measures

It is possible that even if the limitations of this study were addressed and a larger sample size was obtained that the particular measures were inappropriate for assessing the constructs that they were meant to.

While it has been proven that the CCPT measures sustained attention, there are many varieties of attention, and it is possible that the type of attention affected by lighting condition is a separate type of attention. For example, it may have been more prudent to examine the participants' ability to multitask or suppress distracting information instead of their ability to attend to a single task for an extended period of time.

The POMS-SF is meant to assess current mood state, but it is possible that the measure was not sensitive enough to detect a more minor change in mood, or that certain subscales of the POMS-SF could have possibly been targeting aspects of mood that were completely unaffected by the lighting conditions. For example, subscales included irrelevant measures for the study, such as “Confusion” and “Anger,” which were not expected to make any change related to lighting condition. Participants also commented that they found some of the adjectives listed in the POMS-SF to be so closely related they were practically synonymous, indicating that the specificity each word was trying to convey could have been lost. Participants were also not always aware of the meaning of the words. Almost every participant asked for the definition of the last item, “Bushed,” because the word is so uncommonly used in current vernacular. If participants had a hard time even knowing what a word meant it is unlikely that the word could be used to properly measure their emotional state. This would not be an error due to lack of sensitivity or lack of effect, but rather just a flawed measure. Another limitation was that the same POMS-SF measure was taken twice in each session, once before exposure to the light, and once after. It is possible that participants remembered their responses from the first questionnaire and intentionally tried to maintain consistency when completing the second questionnaire.

Heart rate may not have actually fully captured the physiological arousal of the participants as well a measure of skin conductance or cortisol would have. While stress can be determined by heart rate, heart rate's variability can make it a less precise measure than assessing the amount of cortisol one has in their system. This measurement is also very easily influenced, with a marked change in the heart rate of participants when the researcher was present and when the participant was alone.

4.2.2 Possibility of Null Effect

This study may have been accurate in its findings and, contrary to other studies, in this case, lighting condition could have no effect on the constructs measured in this study. Although contrary to previous literature, it is also possible that there is no effect of lighting condition on these constructs at all. This would imply that previously published literature erroneously reported effects of lighting. It is possible that this could be because of the methods used in the studies. A meta-analysis reported that many of the studies on the effects of SAD lamps on seasonal depression have methodological issues that affect their quality (Mårtensson, Pettersson, Berglund, & Ekselius, 2015). Therefore, it is possible that due to a lack of methodological control the effects of lighting are being exaggerated or erroneously observed.

It is also possible that the subjective opinions people have on lighting conditions could also influence the outcomes of studies. Personal preferences for certain lights may have affected participant's psychological state more than the effects of blue light on their photoreceptive ganglion cells. This would explain the unexpected pattern of results shown across the POMS-SF, as a participant's subjective idea of a "favorite" lighting condition would possibly skew their emotive response to that lighting condition. If this preference did, in fact, influence participant's emotional state, it is also possible that it had a domino effect, also influencing their attention and feelings of stress. Maybe their heightened mood also heightened their attention and lowered their stress levels, skewing the data.

It is also possible that effects of lighting condition cannot be found in samples that do not predominantly include participants with SAD. If participants do not have SAD in the first place it is reasonable to assume that their mood, attention, and stress would be less likely to change, meaning that those without SAD could possibly be unaffected by these various lighting conditions.

4.3 Broader Implications

Overall, it is still important to continue researching the effects of light on human behavior and cognition, especially if previous studies are methodologically flawed. It is relevant to study the effects of blue light in this technologically-driven age to continue to research the effects of the devices that we use each and every day. This is especially true in light of evidence that because of the light they emit they can possibly affect not only our mood, but also our sleep cycles. Interference in our biological mechanisms could cause dysregulation that affects multiple aspects of our lives, including but not limited to increase in stress, decrease in energy, and increase in negative mood (Ting & Malhotra, 2005). In order to avoid these affects careful analysis should be done to determine the best way to evade these repercussions.

There are other practical reasons for these investigations as well, outside of the technological. There should be further inquiry into lighting's effects in the built environment to see if it is possible to increase the productivity of an office or a school by modulating lighting for specific tasks. A previous study suggested that a dim, warm lighting condition specifically for relaxing in a classroom actually made children fidget less and act less aggressively, even though they were not consciously aware of their change in behavior (Wessolowski, Koenig, Schulte-Markwort, & Barkmann, 2014). Indicating that even if it was unconscious there was an observable change in behavior due to the classroom's lighting. However, this relaxed atmosphere may not be as appropriate for doing schoolwork as a brighter light condition. Prior research has shown that people are more likely to feel self-aware and reflective in brightly lit rooms (Steidle & Werth, 2014). Yet, exactly how bright and evenly distributed these lights are cannot be overlooked, as another study found that redesigning the lights in an office setting could reduce or increase discomfort from glare depending on both the illuminance and pattern of luminance in the lights (Geerdinck, Van Gheluwe, & Vissenberg, 2014). This suggests that even relatively small amendments to lighting design can change the comfort level of a workspace. More environmentally based research could even better answer questions about the efficacy of large lighting redesigns and how those redesigns impact the people occupying the spaces that they are in. This could be especially interesting if the connections between lighting and circadian rhythms were more effectively integrated into the built environment, with modulated lighting for different tasks across the different times of the day in order to create the most optimal setting for the designated task.

Lighting design could also be used in a more personal way, making sure that comfortable spaces are actually relaxing. These small changes, possible by just switching out a lightbulb, should not be overlooked. Subjective enjoyment of a comfortable environment is always worth pursuing.

4.4 Conclusion

In short, this study sought to investigate the effects of lighting condition on attention, mood, and stress and theorized that three separate lighting conditions would influence participant's emotions, sustained attention, and physiological stress. Although there were no statistically significant results, there were some measures that had the expected numerical pattern, specifically the pattern of results on the CCPT reaction times and omission errors that indicated that being in the SAD condition reduced participants' ability to pay attention. Further investigations should be made in this vein in order to determine if the results from this study were due to limitations or if they indicate a larger pattern of null results.

Appendix A: POMS-SF

Below is a list of words that describes feelings that people have.
Please read each one carefully.

Circle ONE answer to the right that best describes how you are feeling RIGHT NOW.

		Not at all	A little	Moderately	Quite a bit	Extremely
1)	Tense	0	1	2	3	4
2)	Angry	0	1	2	3	4
3)	Worn out	0	1	2	3	4
4)	Unhappy	0	1	2	3	4
5)	Lively	0	1	2	3	4
6)	Confused	0	1	2	3	4
7)	Peeved	0	1	2	3	4
8)	Sad	0	1	2	3	4
9)	Active	0	1	2	3	4
10)	On edge	0	1	2	3	4
11)	Grouchy	0	1	2	3	4
12)	Blue	0	1	2	3	4
13)	Energetic	0	1	2	3	4
14)	Hopeless	0	1	2	3	4
15)	Uneasy	0	1	2	3	4
16)	Restless	0	1	2	3	4
17)	Unable to concentrate	0	1	2	3	4
18)	Fatigued	0	1	2	3	4
19)	Annoyed	0	1	2	3	4
20)	Discouraged	0	1	2	3	4

21)	Resentful	0	1	2	3	4
22)	Nervous	0	1	2	3	4
23)	Miserable	0	1	2	3	4
24)	Cheerful	0	1	2	3	4
25)	Bitter	0	1	2	3	4
26)	Exhausted	0	1	2	3	4
27)	Anxious	0	1	2	3	4
28)	Helpless	0	1	2	3	4
29)	Weary	0	1	2	3	4
30)	Bewildered	0	1	2	3	4
31)	Furious	0	1	2	3	4
32)	Full of pep	0	1	2	3	4
33)	Worthless	0	1	2	3	4
34)	Forgetful	0	1	2	3	4
35)	Vigorous	0	1	2	3	4
36)	Uncertain about things	0	1	2	3	4
37)	Bushed	0	1	2	3	4

Appendix B: SPAQ

If you experience changes with the season, do you feel that these changes are problems for you?

(circle one)

YES or **NO**

IF YES, is this problem:

mild

moderate

severe

disabling

To what degree do the following change with the seasons?

	No change	**Slight Change**	**Moderate Change**	**Marked Change**	**Extremely Marked Change**
Sleep length	0	1	2	3	4
Social activity	0	1	2	3	4
Mood (overall feeling of wellbeing)	0	1	2	3	4
Appetite	0	1	2	3	4
Energy Level	0	1	2	3	4

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