Master’s Project Report:

Evaluating Human Factors of Desktop Light Therapy Fixtures

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Introduction

Light therapy has become a popular method to treat various health issues such as sleep disorders, jet lag, mood disorders, and Seasonal Effective Disorder. Light therapy is often preferred as it has been proven to alleviate some of the aforementioned symptoms without the side effects of pharmaceuticals and time commitment of cognitive behavioral counseling. However, industry ignorance about the science behind these disorders and the roll light plays in causing or preventing these symptoms have led to the production of light therapy lamps that are large, clunky, and often too bright to use comfortably. This report seeks to specify ways in which designers can better understand the stimulus provided by their light therapy lamps and evaluate how their lamps can be more comfortable for the user.

Bright Light Therapy

Before going into the various illnesses light therapy can treat, it is important to understand the role light plays in the human biological system. Scientific experiments relating light exposure to disruptions in biological rhythms were pioneered by Dr. Norman E. Rosenthal and colleagues Dr. Thomas Wehr and Dr. Alfred Lewy in the early 80s during their work at the National Institute of Mental Health (NIMH)[2] . Together, their research produced the theory that melatonin hormone production in humans signified time spent in darkness and conversely melatonin hormone suppression was signified by light exposure. Since Serotonin (5HT) is both the precursor of melatonin and associated with the regulation of appetite, sleep, mood, and sexual behavior[1] , it's absence [characterized by the presence of melatonin] is a seen to play a key role in depressive mood and behavior in humans. Melatonin levels are also a bio marker of circadian rhythms in humans. Circadian rhythms are cyclic changes in endogenous biological behavior that have been observed in plants and animals. The biological system self produces endogenous rhythms such as melatonin production and can be influenced by exogenous factors such as light exposure. These circadian rhythms persist in the absence of exogeneous rhythms and , for humans, occur in a periodic cycle approximately every 24 hours. Though, individual biological differences may produce cycles slightly above or below 24 hours[3]. The circadian system is regulated by the circadian pacemaker or clock located in the suprachiasmatic nucleus (SCN) in the hypothalamus region of the brain. The pacemaker regulates circadian rhythms to be synchronized with the external light dark/cycle or time givers[3]. External time givers like light exposure can entrain the circadian system to phase advance or delay circadian rhythms. The NIMH researchers understood the basis of circadian rhythms and discovered that shortened photoperiods, or daily light exposure duration, lead to phase shifts in the circadian system such as the overproduction of melatonin into the morning hours often seen during winter months[2]. A healthy circadian system sees low levels of melatonin in the morning hours during day time activities and high levels of melatonin in the evening hours to promote healthy sleep. Hence, a robust light and dark cycle is required to remain entrained. The NIMH researchers attributed circadian disruption to symptoms of depression that many patients experienced with a seasonal pattern. Dr. Alfred Lewy's research discovered ways to measure melatonin levels in patients with seasonal depression and determined that bright light, like sunlight in the morning, could suppress melatonin levels and treat seasonal depression[4]. Lewy and his research team experimented with exposing patients to bright light in the morning for 1-2 hours which resulted in subjective reports of dramatically improved mood and depressive symptoms after a few weeks of use. In fact, this research lead to Seasonal Affective Disorder (SAD) being officially recognized in the 1987

American Psychiatric Association diagnostic manual with recommendations of increased light exposure and/or light therapy[5]. As a result, until this day, light therapy is a widely recognized alternative treatment for seasonal depression and many other ailments associated with circadian disruption such as jet lag, sleep disorders, and non-seasonal depression[6]. However, the NIMH researchers did not fully understand the spectral qualities of the light used in their light therapy and how the qualities of that light effected the biological system. Dr. Rosenthal recommended a "suitable light therapy" to be sitting in front of a light box for 20-90 minutes approximately 2' by .5' containing "ordinary white fluorescent light bulbs" providing 2,500-10,000 lux behind a diffusive screen to filter out UV rays" (Rosenthal, 109). The duration of exposure, light source, and geometry to the light source were relatively arbitrary parameters based on what had worked in their experiments with the idea that 10,000 lux was 10% of that provided by sunlight and much higher than the 300-700 lux commonly found indoors at that time. However, Rosenthal was missing the scientific knowledge of spectral qualities of light and their effects on the human system. Thus, this type of ignorance has pervaded the medical product industry as bright light therapy manufacturers continue to design large light boxes with intense light levels with little knowledge of the stimulus they are providing, let alone how the user will actually enjoy comfortable use. Research proceeding the work of Dr. Rosenthal and colleagues has shed more light onto the key pathways between our eyes and brain that result in circadian shifts as well as the spectral qualities of light that induce these shifts.

Circadian Stimulus

Circadian Stimulus (CS) is a metric created by the Lighting Research Center (LRC) that is proposed for designers and lamp specifiers to better understand and apply circadian light effectively[7]. The metric correlates the spectral distribution of a light source with circadian outcome measures of acute melatonin suppression and dim light melatonin onset (DLMO) phase shifts[7]. The metric was created based off of previous research by Brainard et al. 2001 and Thapan et al 2001 that measured melatonin suppression using monochromatic light and discovered that suppression peaked at levels shorter than that of photopic or scotopic functions indicating that the circadian system is provided input by mechanism other than the traditional rods and cones[8]. Hence, intrinsically photosensitive ganglion cells (IPRGC's) located in the ganglion layer of the retina are instrumental in the photo transduction of light to the SCN in the brain through the retinal hypothalamic tract (RHT) resulting in changes in melatonin levels produced in the pineal gland[9]. The peak sensitivity for nocturnal melatonin suppression is 460nm which is shorter than that of the IPRGC photopigment melanopsin which peaks at around 480nm[10]. Rea et al 2005 , concluded that circadian photo transduction includes input from both iPRGC's and classical photoreceptors, and exhibits subadditivity as a result of the spectral opponency that IPRGC's are sensitive to from the B-Y channel. Although the visual and circadian system are sensitive to the 400-500nm wavelength region, the circadian system is not concerned with image formation and is blind to longer wavelengths greater than 600nm[11]. As a result, Rea and Figueiro et al 2013 published a working threshold for acute nocturnal melatonin suppression from "white light" sources validated numerous times by empirical studies with practical sources[11]. They created a metric that relates the spectral distribution of a light source to the equivalent circadian outcome of acute nocturnal melatonin suppression after one hour of exposure. The amount of light, in lux, of a light source stimulus that the circadian system sees is denoted as circadian light (Cl_a) while the circadian response of nocturnal melatonin suppression it denoted as circadian stimulus (CS). The metric proposes that a CS between .3 and .7 or 30 and 70 percent acute nocturnal melatonin suppression is required to effectively result in a circadian phase shifting system response.

Anything higher than .7 percent results in saturation and does not increase the circadian effect of the light source. As a result, light therapy intended to suppress melatonin and phase shift a patient with SAD to be better entrained to the seasonally shortened photoperiods only needs a light source with more energy in the short wavelength region and intensity levels resulting in CS over .3. Hence, Dr. Rosenthal's light boxes likely worked on his patients because the light source incorporated fluorescent light with higher correlated color temperatures (CCT) which have more short-wavelength energy. However, 10,000 lux intensities with this light source likely saturated the circadian stimulus response and is much higher than is needed to produce the desired effects. These extreme light levels result in the common complaint of excess brightness and eye strain from inefficient light intensities from traditional light boxes. Similarly, many popular bright light therapy lamps on market sell their lamps with high CCT and light intensities, but no specification as to what light levels are needed to actually provide the intended results. Utilizing the CS metric provides a more practical way for designers to understand the stimulus they are providing and bridge the gap between circadian knowledge and how their therapy lamps should be used to provide desired outcomes. This can be exemplified in field research done by LRC researchers using light fixtures at office desks behind monitors to deliver CS levels over .3 to result in better adaptation to their light/dark cycles.

Circadian Stimulus Used in the Field

The LRC has performed various field studies to evaluate the effectiveness of the CS metric in real world applications. In 2017, LRC researches conducted one of these field studies in two federal office sites in which they installed two types of circadian light delivery fixtures; overhead ceiling troffers and desktop luminaires that go behind computer monitors [see figure 1]. This study took place over three days with baseline data collected on day 1 and intervention data

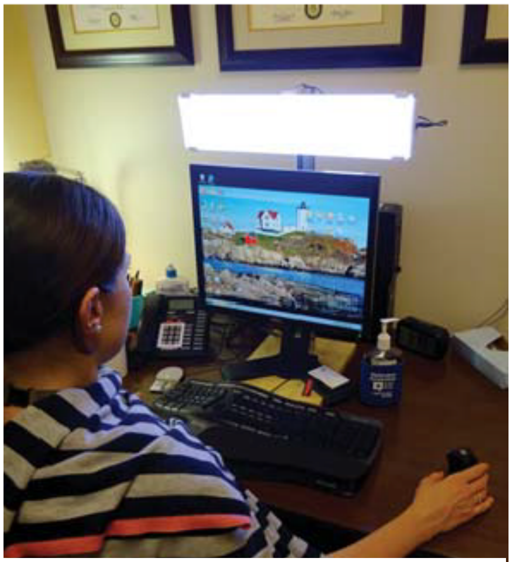


Figure 1: CS effective Light Therapy Lamps used in the LRC field office experiment[12]

collected on days 2 and 3. Also, the study was done in both the Fall and Summer seasons. The LRC researchers hypothesized that by delivering CS greater than .3 at the eye throughout the workday [general 9am-5pm schedule] , subjective assessments of sleepiness, stress, vitality and alertness would improve[12]. These subjective responses were evaluated using questionnaires such as the Karolinska Sleepiness Scale (KSS) and Subjective Vitality Scale (SVS). Individual CS exposure levels were tracked using Daysimeters developed by LRC researchers which are placed around the subject's neck or wrist that convert illuminance (lux) and circadian illuminance (CLa) into CS values. The results showed that CS levels were dramatically higher after the intervention with Daysimeter data from the different seasons combined [see figure 2]. Similarly, subjective reports of vitality and sleepiness significantly increased between baseline and intervention day 3 with a more dramatic improvement in the fall than in the summer [see figure 3]. Taken together, the results of this study demonstrate how using the CS metric is effective for light therapy for various issues from sleepiness to alertness and mood throughout the day. However, comfort with using the fixtures was not formerly assessed in this experiment. For light sources, this study used cool white or blue light [470nm] which concurs with the spectral

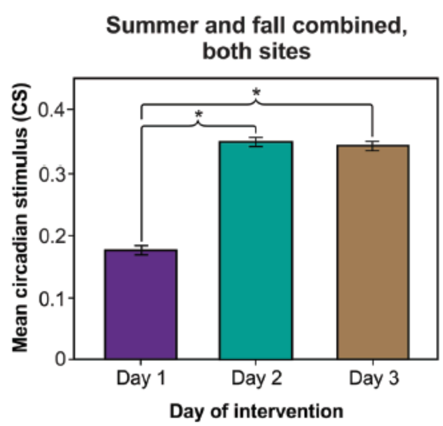


Figure 2: Graph from the LRC field office experiment showing that CS levels were dramatically higher after light therapy intervention[12]

power distributions most effective for stimulating the circadian system. The study does note that some participants mentioned a preference for the blue to the white light presumably because it takes higher levels of white light to achieve the same CS as a lower blue light level[12]. However, with regard to subjective reports of sleepiness, energy, and alertness no significant difference between the blue or white light sources was shown[12]. Similarly, the study notes the need for tuning the light intervention spectrum to decrease light levels needed to deliver necessary CS level at the eye to increase comfort in the working environment. As a result, this report will document an experiment to formerly asses comfort with using desktop luminaries for light therapy by altering light levels and light source type. Ultimately, comfort with CS effective desktop luminaries will be compared to that of traditional light therapy on market today.

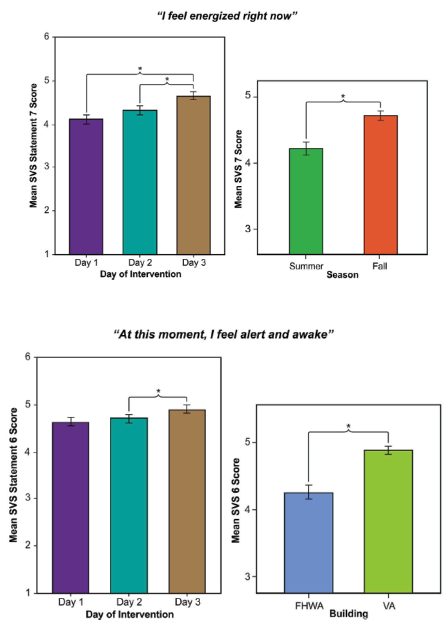


Figure 3: Graphs from the LRC field office experiment showing subjective feelings of alertness and energy increased significantly after light therapy intervention[12].

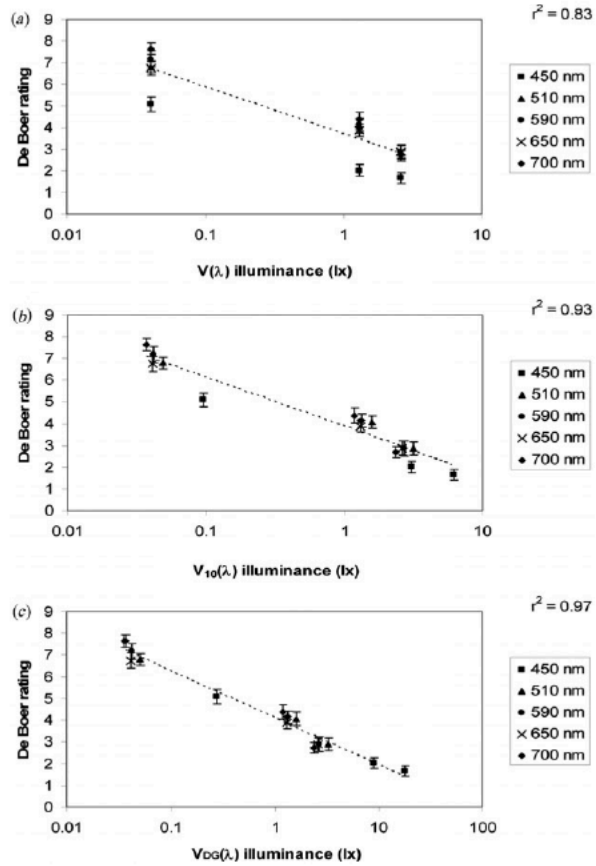
Tools for Evaluating Human Factors of Desktop Light Therapy Fixtures

When approaching the evaluation of comfort with light therapy lamps, it is important to provide a-priori analysis of how both the light source and the surrounding environment can effect subjective levels of comfort. One of the main human responses to light sources that effect comfort is discomfort glare. Glare is defined as harsh uncomfortably bright light that occurs from too much light or too large of a luminance range from a light source[15]. The effects of this glare can range from photobiological impairment such as retinal cell damage or discomfort glare.

Discomfort glare causes subjective feelings of annoyance or pain caused by excess luminance in the field of view[15]. This study documented further in this report focuses on discomfort glare as an assessment of comfort with using light therapy lamps in the work environment. Discomfort glare is measured subjectively using the De Boer Scale created in 1967. This scale measures discomfort from 1-9 with 1 being “unbearable,” 5 being just acceptable, 7 being satisfactory and 9 being just noticeable. Literature evaluating discomfort glare uses the De Boer scale as a metric and correlate subjective glare ratings to factors such as ambient light levels, light source size, light source spectral power distribution, age, and illuminance at the eye. Schmidt-Clausen and Bindels et al 1974 found that a positive correlation between glare illuminance and increased discomfort[15]. Rosenhahn and Lampen et al 2004 found a positive correlation between increased glare luminance from smaller light source sizes and increased discomfort[15]. Fu et al 2002 found that for the same illuminance, light sources with more energy in the shorter wavelength portion of the spectrum causes more discomfort glare[15]. Similarly, Dee et al 2003 found evidence suggesting short wavelength cone receptors can play a role in increased discomfort glare[15]. Lastly, Scmidt-Clausen and Bindels et al 1974 found that increased ambient light levels decreased discomfort glare[15]. Also, Olson and Sivak et al 1984 found that age has a small impact on increased feelings of discomfort glare[15].

As a result of the literature surrounding this topic, studies have been done use factors such as ambient light levels, geometry to light source, and the human visual response to light source SPD to characterize how a light source may influence subjective comfort. LRC researcher John Bullough 2009 performed a series of experiments in 2009 intended to characterize spectral sensitivity for discomfort glare from nearly monochromatic light sources presented in the near extrafovea five to ten degrees off axis (Bullough, 1). In these experiments, subjects were placed in a black laboratory facing an experiment apparatus consisting of the De Boer scale chart with a luminance of .1 cd m^{-2} produced from a halogen source out of subject view. A fixation point was located in the middle of the chart to direct subject attention. Glare stimuli were presented 5 to 10 degrees of axis from line of sight with peak wavelengths of 450, 510, 590, 650, and 700nm[13]. Each light source was tuned to produce three illuminances of .04, 1.3, and 2.6 lux providing 15 total lighting conditions per subject. Each stimulus was presented for 3 seconds and De Boer scale ratings were taken. 45-60s passed between each stimulus presentation. The results showed that 450 nm produced the lowest ratings and the ratings followed a logarithmic function as wavelength increased, indicating that greater discomfort glare was a result of S-cone participation [see figure 4]. As a result, the following luminous efficiency function was produced:

Figure 4: Graphs from Bullough's experiment results showing De Boer scale ratings were lowest for 450nm light sources[13].



$\boldsymbol{V_{DG}(\lambda) = V_{10}(\lambda) + kS(\lambda)}$. Here, $S(\lambda)$ is the luminous efficiency function with a maximum value of 1 at 440nm and k is a scaling factor adjusted to provide the best goodness of fit value for a logarithmic function to fit the data [13]. Bullough concluded from his study that this equation is better for correcting the stimulus for discomfort glare from extrafoveal light sources compared to traditional photopic functions and thus can be used to specify light sources that may contribute to discomfort glare[13].

Similarly, Bullough, Brons, Qi, and Rea et al 2008 performed a series of experiments to assess how photometric characteristics of glare sources and light levels surrounding the glare sources may effect subjective ratings of discomfort glare. The researchers defined light source illuminance (E_l) as the vertical illuminance from the light source at the eye using a baffle that blocked light surrounding the light source from reaching the eye[11]. Light source luminance (L_l) was measured at a distance where the luminance meter aperture covered as much of the light source as possible without producing dark areas. Ambient illuminance (E_a) was measured vertically at the eye with the light source turned off . Surround illuminance (E_s) was estimated by measuring total vertical illuminance at the eye with the light source on and subtracting (E_l) and (E_a) from that value. This framework was done for outdoor experiments and adapted to indoor experiments by measuring (E_a) vertically at the eye with a baffle permitting only a direct view of the light source[11]. The following formulas converting the aforementioned measurements to discomfort glare to De Boer scale predictions were derived:

$$\mathrm{DG} = a\ \log(E_\ell + E_\mathrm{s}) + b\ \log(E_\ell / E_\mathrm{s}) - c\ \log(E_\mathrm{a}) \qquad \mathrm{DB} = 6.6 - 6.4\ \log\ \mathrm{DG}$$

After applying these formulas to lab measurements, subjective De Boer scale ratings were recorded from subjects and plotted against the lab calculations. Figure 5 shows that the prediction closely models the real-world results. The experimenters note that spectral sensitivity to light source SPD was not incorporated in this model and could be used to improve prediction

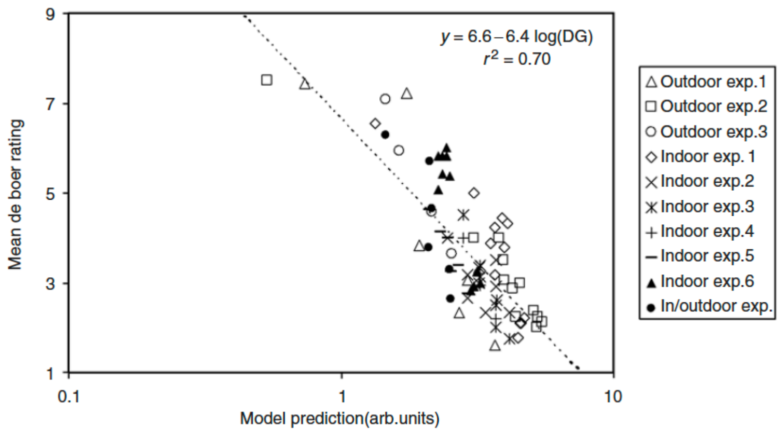


Figure 5: Graph from the experiment results showing De Boer scale ratings in the field closely matched those predicted from the derived logarithmic De Boer scale prediction formula[11]

quality. As a result, the experiment in this report will use both the De Boer scale prediction function and the aforementioned glare spectral sensitivity formula to develop an a-priori hypothesis as to how desktop light therapy lamps contribute to discomfort glare.

Experiment Apparatus

An experiment was conducted at the LRC using an experiment apparatus designed to model that of a typical office environment. The experiment was placed near the LRC Philips lab in an area with blacked out windows so that ambient light levels can be controlled. For this experiment, two light fixtures were built similar to those in the aforementioned LRC office field experiment. One fixture contained seven blue LEDs with an SPD peak at 460nm, and the other contained three cool white LED strips producing 6500k correlated color temperature (CCT) [see appendix A for fixture light source specs]. These SPDs were chosen since they are most effective for circadian stimulus. Each fixture was tuned to produce a CS greater or equal to .3 approximately 20 inches away from the screen at three light levels ranging from high (A) to middle (B) to low (C). These measurements also included those taken at various angles from the eye to the apparatus to ensure that the desired CS levels are reached from each lamp in most of the angles the head will be tilted when using the a desktop computer in the real world. Point (1) was located on the computer monitor at the location viewed when looking straight at the monitor. Point (2) was measured directly below the face of the monitor, and point (3) was measured below the monitor in the area where the keyboard would be. Diagrams of the fixture dimensions are shown in figure 6, diagrams of the experiment apparatus with the measured points are in figure 7, and a table of the results from measurements at all points for each fixture are in figure 8.

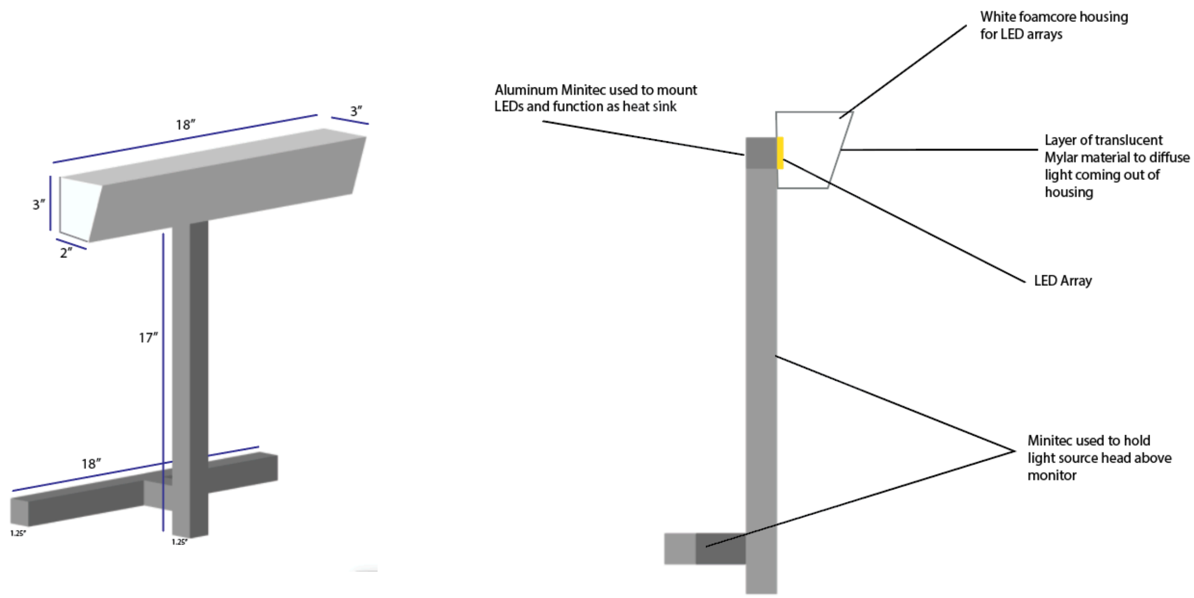


Figure 6: Diagrams of the CS effective fixtures including dimensions and part names/materials.

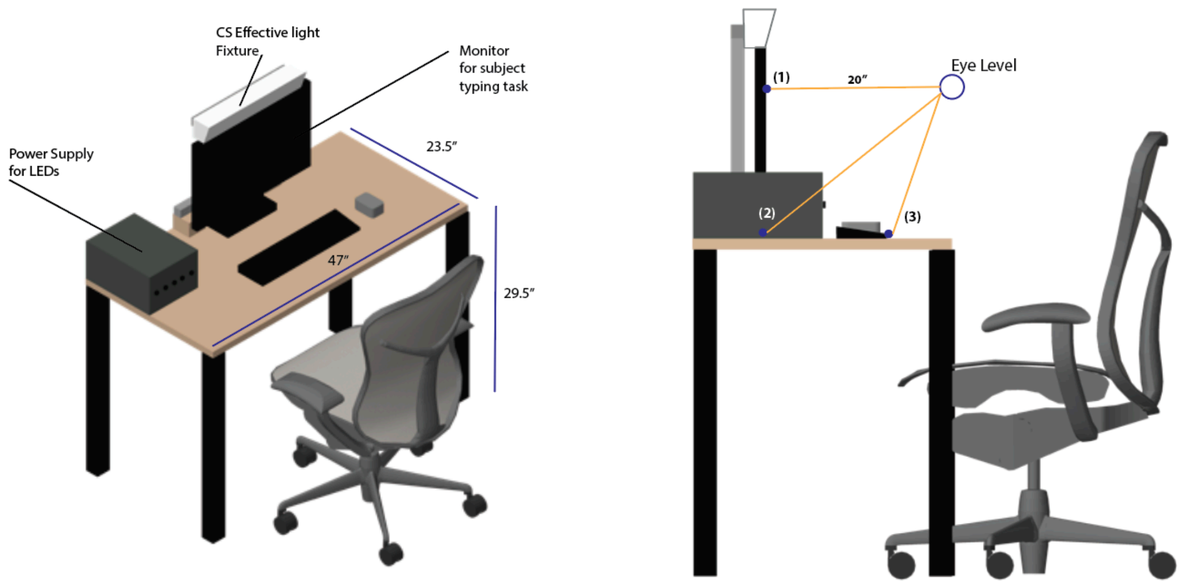


Figure 7: (Right) Isometric view of experiment set up including dimensions and important components. (Left) Section view of experiment set up showing where measurements were taken.

Figure: White LED Light Fixture Measurements					
Light Level Name	Measure Point	Current Level (mA)	Illuminance At Eye (lux)	CS	Fixture Luminance (cd/m^2)
A	1	0.7	394	0.49	2524
A	2	0.7	263	0.43	2524
A	3	0.7	196	0.37	2524
B	1	0.544	353	0.45	2337
B	2	0.544	243	0.41	2337
B	3	0.544	219	0.38	2337
C	1	0.346	279	0.37	1651
C	2	0.346	208	0.38	1651
C	3	0.346	155	0.29	1651

Blue LED Light Fixture Measurements					
Light Level Name	Measure Point	Current Level (mA)	Illuminance At Eye (lux)	CS	Fixture Luminance (cd/m^2)
A	1	0.35	225	0.6	1170
A	2	0.35	140	0.57	1170
A	3	0.35	119	0.54	1170
B	1	0.2	194	0.55	850
B	2	0.2	115	0.5	850
B	3	0.201	106	0.48	850
C	1	0.07	161	0.4	357
C	2	0.07	98.4	0.36	357
C	3	0.07	83.7	0.32	357

Figure 8: Tables for each light source fixture showing measurements recorded at each measurement point. Both fixtures successfully reached a CS over .3 at each measure point.

The monitor was tuned to the brightest backlight level with a “cool color” appearance to work in tandem with the light fixtures. CS measurements at the eye both with and without the monitor or ambient lights on were insignificantly effected. As a result, CS measurements shown in the figure above included all lights sources on to ensure what the subject’s saw were the same as the calculations. Both empirically derived functions mentioned in the previous section were used to predict how the glare from these fixtures would be perceived by subjects in an office environment. The spectral sensitivity for discomfort glare function was calculated for each light source using their spectral power distributions (SPD). A k value of .75 was used as this value was used in Bullough’s as best fit for the derived equation for glare sources 10 degreees off axis. Each SPD was multiplied by Bullough’s function for glare sources 10 degrees off axis. A glare ratio was calculated by taking each source’s SPD, multiplying by V lambda, then dividing that total by the results of Bullough’s function for each SPD. This glare ratio was then taken and multiplied by the light source illuminance at the eye (E_l) to produce a glare illuminance. These results are shown in below:

Spectral Sensitivity for Discomfort Glare Calculations				
Light Source Name	Fixture Light Level Name	Measured Illuminance @ eye (lux)	Glare Ratio	Glare Illuminance (lux)
460nm Blue	A	88.1	6.46	568
6500k+ White	A	222	1.94	430

These results show that the blue light source will produce 32% more glare than the white light source.

De Boer scale prediction calculations were also measured twenty inches away from the monitor but for all light conditions (A,B,C). Ambient illuminance (E_a) was found by measuring vertical illuminance at the eye with the light fixture on, monitor on, and electric lighting in the room on with a baffle placed roughly two inches from the eye blocking direct light from the monitor and fixture. Light fixture illuminance (E_l) was found by measuring vertical illuminance at the eye with only the light fixture and monitor on since both were direct light sources to the eye. Surround illuminance (E_s) was found by measuring total vertical illuminance at the eye with all components on (E_{total}), taking that measurement and subtracting ($E_l + E_a$) from it. The resulting measurements were applied to the glare prediction formula mentioned in the previous section including luminance measurements from each fixture. The results of these calculations are shown below:

CS Effective Light Fixture De Boer Scale Predictions					
Light Source/ Light Level Name	**Light Source Luminance (cd/m^2)**	**Light Source Illuminance (E_l) (lux)**	**Ambient Illuminance (E_a) (lx)**	**Surround Illuminance (E_s) (lx)**	**DB Scale prediction**
Blue (A)	1170	108	30	155	**5.3**
Blue (B)	850	120	27	150	**7**
Blue (C)	357	95	25	146	**7.1**
White (A)	2524	265	33	166	**6.5**
White (B)	2337	210	28	160a	**6.6**
White (C)	1651	170	26	158	**7**

The results from these calculations develop the prediction that the the lowest light condition (C) for each light source will be satisfactory for discomfort glare and the highest condition (A) will be just acceptable for the blue light source and almost satisfactory for the white light source.

A control condition for the experiment was also set up using a traditional light therapy box from litebook.com [see figure 9]. The same analysis used for the CS effective fixtures was performed on the light box. The light box was placed next to the monitor angled at the eye from 20 inches away producing a .5 CS level. The results of the analysis showed that the fixture produced a 1.75 glare ratio from 360 lux measured at the eye resulting in a 631 lux glare illuminance. This is 11% worse than the blue light source and 46% worse than the white light source. De Boer scale calculations show that this fixture is predicted to have a 2.8 rating which is disturbing on the scale.

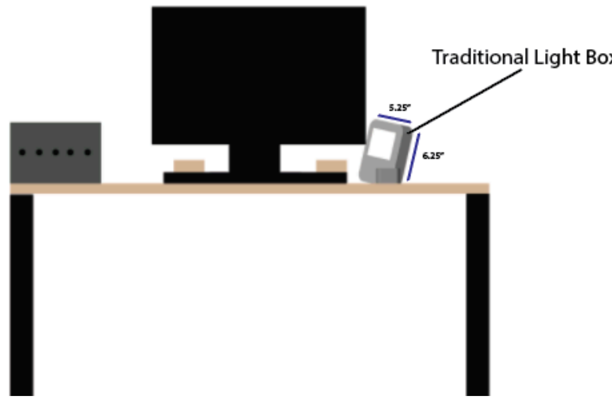


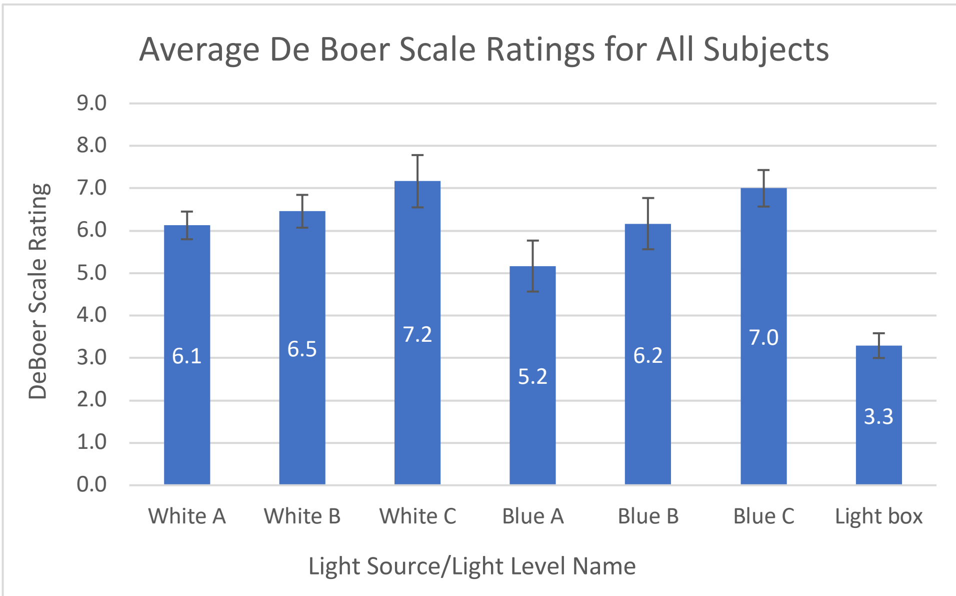
Figure 9: A diagram showing the orientation of the traditional light box control condition

Experiment Methods

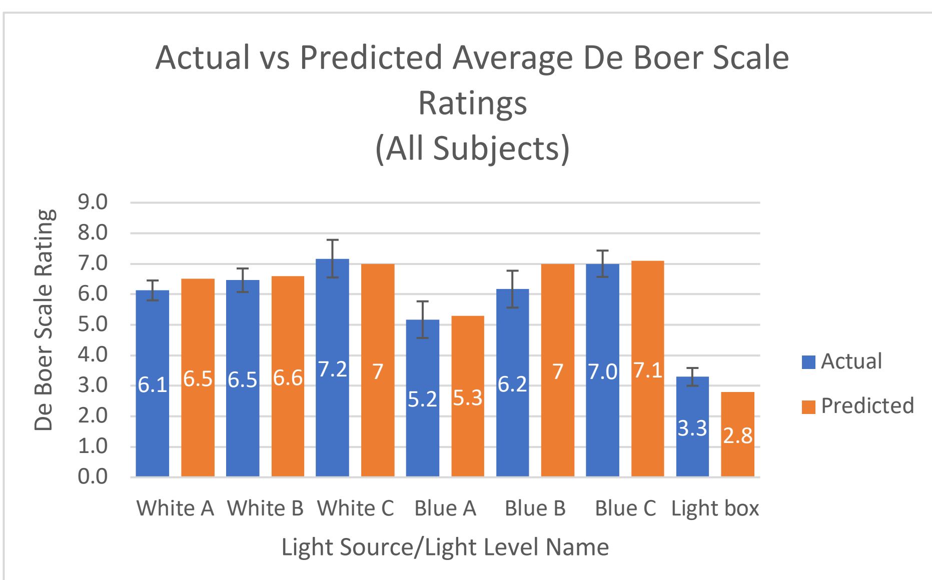
A within subject experiment was conducted using this experiment apparatus to determine subjective feelings of discomfort glare from the CS effective desktop fixtures in comparison to traditional light therapy lamps. 12 subjects, 6 females and 6 males from the LRC volunteered to be a part of this experiment. 7 of the subjects wore glasses and one wore contacts due to an astigmatism. All subjects had sufficient vision enabling them to legally drive. Subjects were classified in categories based on age; 6 subjects were 22-30 years, 4 subjects were 30-50 years, and 2 subject were 50+. Each subject saw seven total light conditions; high, mid, and low levels for each CS effective fixture and the only light level provided by the traditional light box. Since the light sources used LEDs connected to a driver, light levels needed to be dropped steadily from high to low which required each condition to be shown from high to low consecutively to ensure LED performance sustainability. It is important to keep the LED source stable to ensure the conditions used for the predicted calculations matched those of the experiment. To mitigate the possibility of subjects altering responses as a result of predicting light level changes, they were instructed to tilt their heads down and close their eyes while light levels were altered. During each light condition, subjects were instructed to type text on a document shown on the computer monitor for approximately 45 seconds. This was intended to help better asses comfort with glare sources form desktop light fixtures while doing actual work at a desk and give subjects time to adapt to the changes. After 45 seconds, the experiment proctor showed the subject the De Boer scale and asked for their ratings of comfort and recorded the results. Then, the subject was instructed to close their eyes and tilt their head down while the next light condition was tuned. The last condition the subjects saw was the control condition with a traditional desktop light therapy box angled at their eyes at the same distance as the other fixtures. After the experiment, follow up interviews were conducted with each subject to see which light sources and orientation was more comfortable and why. Similarly, three of the subjects actually used different light therapy devices at their desks and their experiences with these fixtures were also featured in the interviews. Two had light therapy devices built at the LRC and tuned for CS, while one had a light therapy tablet sold on Amazon.com.

Experiment results

The results of the average De Boer scale ratings for each light source type and light level produced by each subject are graphed below:



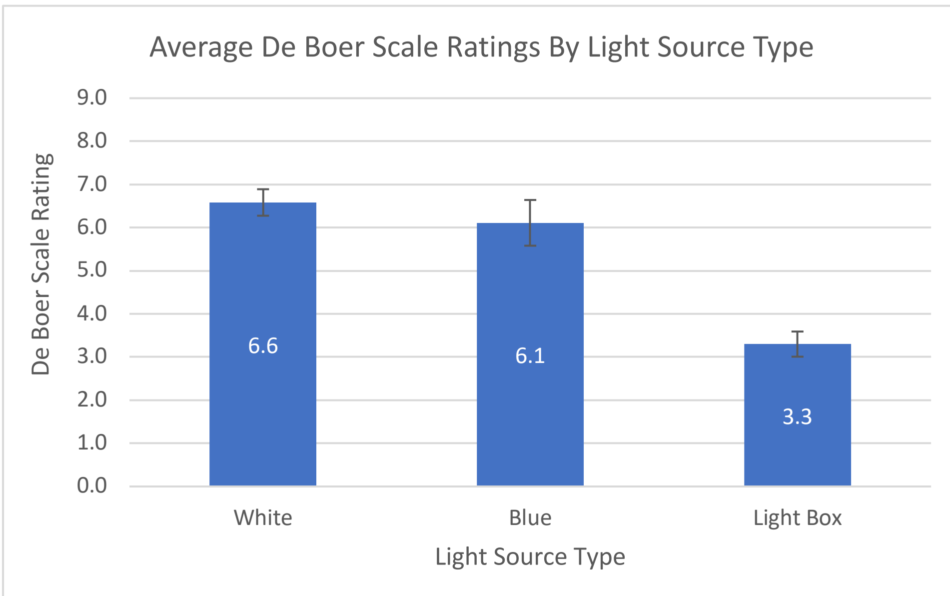
It can be seen here that the traditional light therapy lamp was significantly worse than the CS effective fixtures matching calculation predictions. Similarly, the calculation predictions were



lined up relatively well with the actual De Boer scale ratings. As the light source levels decreased, comfort increased. These results are graphed above.

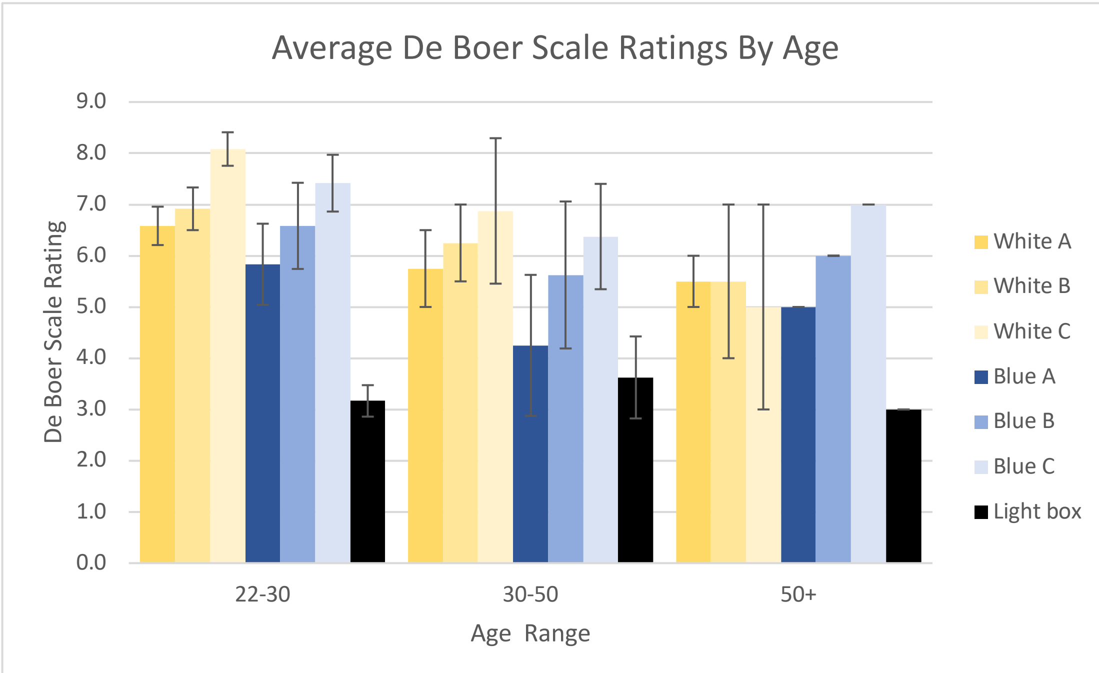
These results indicate that the De Boer scale prediction formula is effective for predicting comfort from indoor glare sources.

The graph below shows the average glare ratings for each light source type:



Here, it can be seen that the white source was more comfortable than the blue source. The difference in glare ratings between the blue and white sources was insignificant ($p \sim 0.14$) which also matches De Boer scale prediction calculations. However, spectral sensitivity calculations predicted the blue light source to be much worse than the white which was not reflected in the real-world results. Furthermore, the light box source spectral sensitivity calculations did line up with the real-world results as it was significantly less comfortable ($p \sim 0.03$ for blue lamp and $p \sim 7.29E^{-6}$ for white lamp) than the CS effective light fixtures.

Based on age, there were differences in comfort preferences for the CS effective light fixtures. The results of De Boer scale ratings by age category are graphed below:



Here, it can be seen that subjects over fifty years old actually preferred the blue light source over the white light. Meanwhile, subjects younger than fifty years old preferred the white light source to the blue. Although all populations preferred the CS effective light sources over the light box, differences in preferences within each age group differed. When comparing the highest light level of the white light source to the light box, the 22-30 years age group rated the white light source significantly higher ($p \sim .001$). However, the 30-50 and 50+ age groups rated the white light source insignificantly ($p \sim .17$) higher than the light box. Similarly, when comparing the highest light level of the blue light source to the light box, the 22-30 years age group rated the blue light significantly higher ($p \sim .01$) than the light box while the 30-50 and 50+ age group rated the blue light source insignificantly higher (p~ .77) than the light box. Lastly, there was no significant pattern detected between users with glasses and without glasses.

Discussion

Taken together, the results seem to show that the De Boer scale glare prediction formula is a useful tool for predicting comfort with desktop light therapy fixtures. The spectral sensitivity function may have accuracy, however, it seems that the way these light sources are delivered may make predictions for this function better or worse. For instance, the formula predicted that the blue light source would produce significantly more glare than the white light source. It also predicted that the light box source would produce significantly more glare than the CS effective light sources. However, real world results showed that comfort between each light CS effective light source was insignificant. This suggests that ambient and surrounding light levels as well as light source delivery plays an important role in comfort from these sources seeing that the De Boer scale prediction formula more accurately predicted the real-world results. The CS effective light boxes delivered light through a diffusing filter while the light box had no lenses to diffuse the light. This may explain part of why it was significantly less comfortable. Also, with the blue and white light sources being tuned to produce CS effective light levels, the lower light levels seemed to produced more comfort than the higher light levels of the traditional light box. When interviewing subjects after the experiment on their experiences and preferences, everyone stated that the lowest light conditions for each light source were the best. Hence, low light levels can still be CS effective and comfortable. Interestingly, during the interviews, all subjects but one stated feeling more comfortable with the blue light source. This runs contrary to the De Boer scale ratings they stated in the experiment. This discrepancy may be a result of the subjects being part of the LRC where it is of common knowledge that blue light for light therapy in the mornings is beneficial. With regard to fixture orientation on the desk, subjects stated preferring light sources to be in their line of sight as fixtures resting on the desk below their general line of view felt distracting. This could also help explain the significant differences in comfort between the light box and the monitor mounted CS effective light fixtures. When observing various staff members in the office working next to light therapy lamps, they tend to never actually look straight at the lamp and rather at the work they are doing. This further shows the importance of designing light therapy fixtures to work in tandem with the task being performed. Generally, office workers work at desks with laptops and monitors. As a result, light fixtures off to the side or below the line of sight are not as effective since they can be distracting. These orientation can be made effective if they are tuned to be CS effective, but it is important to analyze the way a user may angle their eyes related to fixture orientation to ensure that CS is actually being reached. For example, the subject with the Amazon.com light therapy tablet had it sitting on their desk next to the monitor, however, the light was so bright it was angled away from their eyes. The subject noted feeling like the fixture might be helping them but this may be more of a placebo effect. Those with the CS effective therapy fixtures oriented to the side tended to have the lamps angled to actually hit their eyes perhaps since the light levels were much lower than the Amazon.com tablet. As far as light source type, the experiment results suggest that white or blue light sources tuned to be CS effective can be equally comfortable for the general population, however, older folk over fifty years old may be more comfortable with blue light perhaps as a result of the yellowing of the eye’s lenses with age. However, it is best to choose the lowest light level possible that still achieves the CS threshold desired as age may increase glare effects from higher light levels regardless of stimulus type. Finally, it is important to note that all subjects only saw each condition for 45 seconds and accuracy of work done on the computer was not evaluated. Follow up experiments can be done to further evaluate whether desktop light therapy fixtures light level, type, and exposure direction effect ability to accurately detect figures on a computer screen. Also, further studies can alter the light levels on the computer screen itself to see how that may effect perception of glare. Lastly, a larger population size could be beneficial to test the strength of the aforementioned results in the field.

Conclusion

Traditional desktop light therapy fixtures lack sufficient analysis to ensure that users will actually be comfortable using them. Tools such as the Circadian Stimulus (CS) metric produced by the Lighting Research Center (LRC) are a good way to ensure that light therapy products are producing intended results. However, solving user circadian needs is only one part of the picture. It is important to understand how the light source characteristics such as spectral power distribution and geometry to the source can affect comfort. The experiment documented in this report exemplifies that the spectral sensitivity for glare and the De Boer scale prediction functions produced by LRC researchers are useful tools for painting a more accurate picture of how comfortable light therapy fixtures are for their users. It is therefore recommended that lighting therapy fixture designers use these tools along with the CS metric to ensure successful and effective use of their products.

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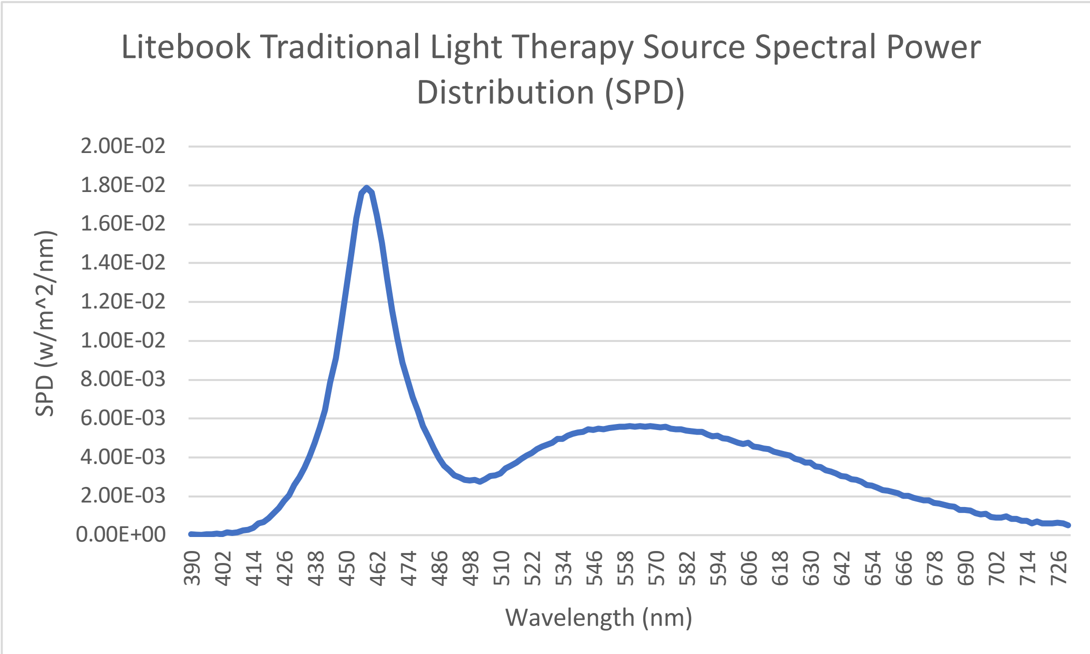
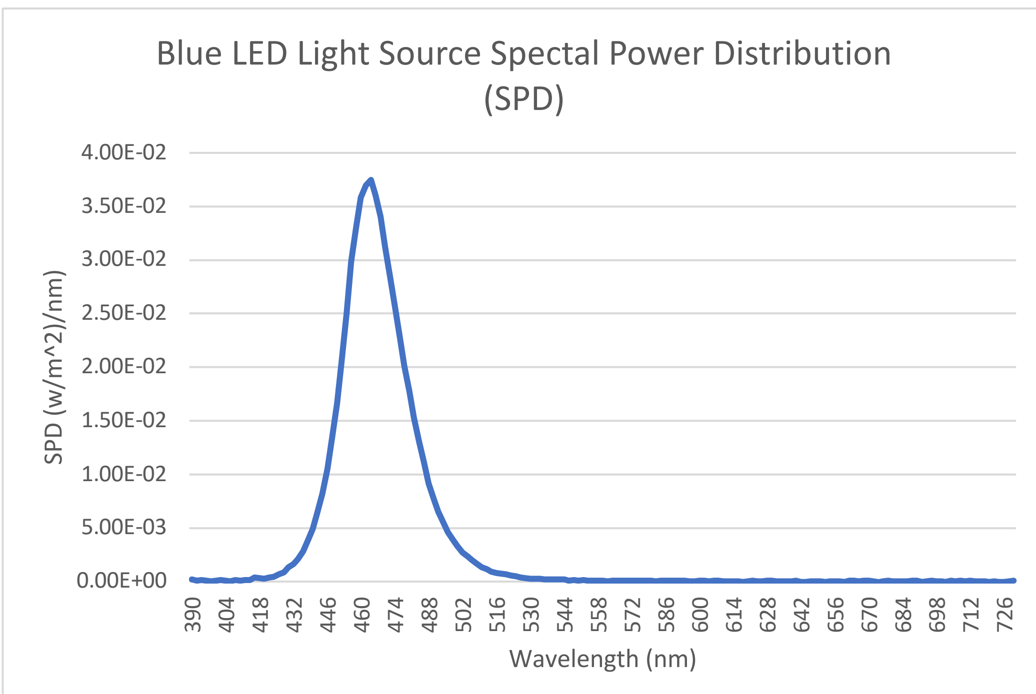
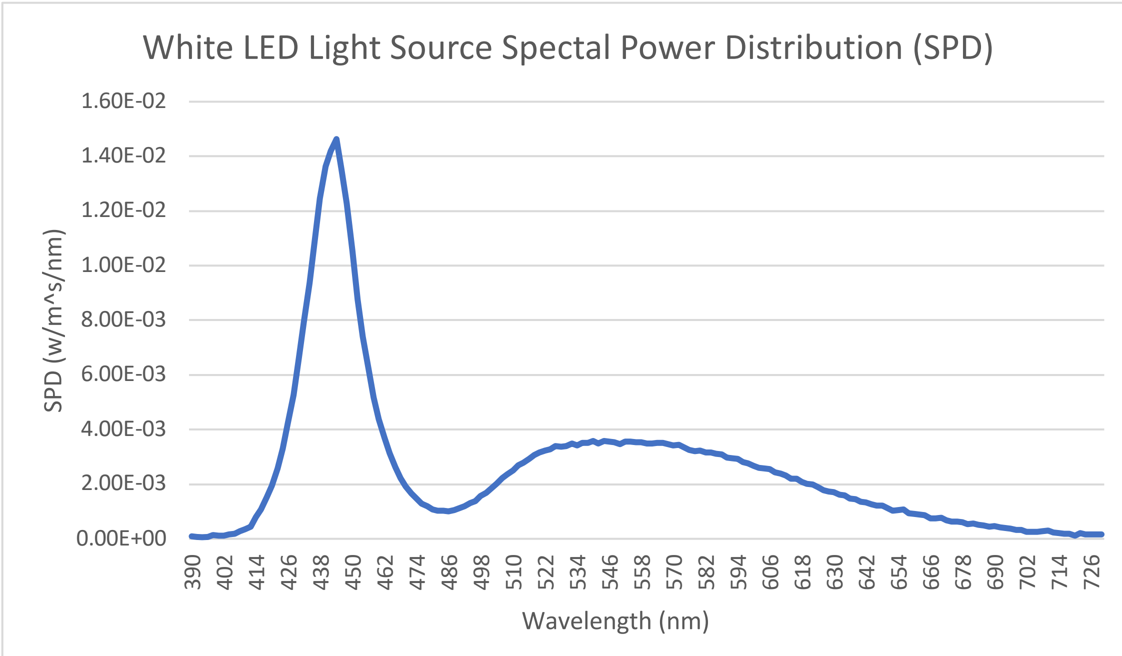
Appendix A: Spectral Power Distribution for White and Blue CS Effective Sources and Traditional Light Therapy Box






White LED Light Source Spectal Power Distribution (SPD)
SPD (w/m^s/nm)
1.60E-02
1.40E-02
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
390 402 414 426 438 450 462 474 486 498 510 522 534 546 558 570 582 594 606 618 630 642 654 666 678 690 702 714 726
Wavelength (nm)

Appendix B: Equipment Used In Experiment

Equipment	Manufacturer	SN	Unit #
DC power supply	Agilent	MY52080085	E3632A
Spectrometer	Red Tide USB 650 Ocean Optics	296-25429-ND	3201
Illuminance meter	Gigagertz-Optic	12178M	X91
Luminance meter	Minolta	LS100	032120/78013008