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Short wavelength light administered just prior to waking: a pilot study

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Abstract

Bright light in the blue-green range, administered in the early morning hours (prior to waking) may be particularly effective in shifting circadian rhythms and may increase gonadotropin production. Accordingly, we tested the feasibility and utility of a mask that emits bright blue/green light (compared to a similar mask that emitted a dim red light) towards the end of sleep in a randomized, placebo-controlled pilot study. The study included a 3-day baseline period, immediately followed by a 12-day intervention period. Subjects were 30 healthy young men with minimal-mild depression. The bright light masks were well-tolerated and demonstrated adequate safety and feasibility. Following the intervention, those who wore the bright light mask demonstrated altered sleep timing suggestive of an earlier sleep period, and excreted a slight increase in follicle-stimulating hormone. Overall, light masks may prove useful in future studies of bright light therapy.

Keywords

Sleep; light; hormones; circadian rhythms; depression

Introduction

Administration of bright light as a therapeutic intervention has been well-characterized for a number of clinical conditions. In circadian rhythm and sleep disorders, bright light is an effective treatment for Delayed Sleep Phase Disorder (Bjorvatn and Pallesen 2009, Morgenthaler et al. 2007, Okawa and Uchiyama 2007, Lack and Wright 2007, Barion and Zee 2007, Chesson et al. 1999) and jet lag (Bjorvatn and Pallesen 2009, Morgenthaler, Lee-Chiong, Alessi, Friedman, Aurora, Boehlecke, Brown, Chesson, Kapur, Maganti, Owens, Pancer, Swick and Zak 2007, Barion and Zee 2007, Sack 2010, Arendt 2009, Sack et al. 2007). In the domain of affective disorders, bright light is an effective treatment for depression that is seasonal in nature (Boyce and Barriball 2010, Monteleone et al. 2010, Terman 2007, Golden et al. 2005, Terman and Terman 2005) as well as depression that is non-seasonal (Terman 2007, Golden, Gaynes, Ekstrom, Hamer, Jacobsen, Suppes, Wisner

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and Nemeroff 2005, Terman and Terman 2005, Even et al. 2008, Tuunainen et al. 2004, Lieverse et al. 2011). Additionally, in individuals without clinically-relevant circadian, sleep or mood disorders, bright light has been found to enhance functioning and quality of life (Einon 1997, Grandner et al. 2006, Kaida et al. 2006, Jean-Louis et al. 2005, Campbell and Dawson 1990).

The timing of bright light administration plays a role in its physiological effect (Kripke et al. 2007, Evans et al. 2007, Johnson 1999). Increasing evidence suggests that bright light presented in the morning hours may be optimal for treating both Delayed Sleep Phase Disorder (Lack and Wright 2007) and most depression (Youngstedt et al. 2004, Avery et al. 2002, Avery et al. 2001, Avery et al. 1990). It is possible that bright light in the very early morning might be particularly effective (Terman et al. 2001).

In addition to effects on circadian rhythms and mood, recent evidence suggests that bright light, particularly light administered in the early morning, may stimulate production of gonadotropins, particularly Follicle-Stimulating Hormone (FSH) and Luteinizing Hormone (LH) (Kripke et al. 2010, Danilenko and Samoiloova 2007, Baker and Driver 2007, Yoon et al. 2003). If this is the case, this could constitute a new application of light therapy, as well as potentially elucidate additional mechanistic pathways through which light exerts effects on circadian rhythms and mood.

Most of the studies of light on circadian rhythms and mood used bright white light, in an attempt to simulate the non-harmful components of sunlight (Wehr 2001, Lam and Levitan 2000, Tam et al. 1995, Rosenthal and Wehr 1992). More recently, melanopsin-producing retinal ganglion cells were discovered to be the primary mechanism through which environmental light is encoded as circadian information (Panda et al. 2003, Hattar et al. 2002, Bellingham and Foster 2002, Hannibal 2002). The peak spectral sensitivity of this system is approximately 480nm (Peirson and Foster 2009), confirming the finding, almost 20 years earlier, that light in this part of the spectrum is optimal for melatonin suppression (Brainard et al. 1984). Since that time, a number of studies have found that narrow-band light with a wavelength of 480 $\pm$ 20 nm may be optimal for biologic effect (Henderson and Grimes 2010, Ackermann et al. 2009, Smith and Eastman 2009, Smith et al. 2009, Burkhart and Phelps 2009, Strong et al. 2009, Lockley 2008, Hanifin et al. 2008, Gooley et al. 2008, Desan et al. 2007, Glickman et al. 2006, Campbell 2006, Lockley et al. 2006, Revell et al. 2006, Revell et al. 2005, Herljevic et al. 2005, Wright et al. 2004, Herljevic et al. 2004, Lockley et al. 2003, Warman et al. 2003).

Though most of the studies of blue light utilized light at or below 480 nm wavelengths, direct comparisons of light at approximately 480 nm to light at approximately 500 nm are few. Berson and colleagues (Berson et al. 2002) found that the response to 500 nm and 480 nm were nearly equivalent. This finding was demonstrated in humans as well (Brainard et al. 2001). Further, the premise that 480 nm would be more effective than 500 nm was partially based upon the assumption that a single opsin curve would explain the physiologic spectral sensitivity. However, several recent studies have demonstrated that no single opsin curve explains the entire spectral response (Gooley et al. 2010, Lall et al. 2010, Revell et al. 2010). This supports the empirical observation that 500 nm produces a response roughly equivalent to that of 480 nm. In addition, it is possible that light at the higher end of this range (i.e., 500 nm) would be safer, since high intensity blue light can be harmful especially at the shortest visible wavelengths (Okuno 2008, Algreve et al. 2006, Reichow et al. 2006, Grandner and Gehrman In Press) and there are no known, published reports of safety profiles of bright blue LEDs used for bright light therapy. Notably, Ham and colleagues (Ham et al. 1976) found a 2–5-fold increase in risk of retinal damage from 480 nm light,

relative to 500 nm light. In addition to these safety issues, there may be an effect of age, as 480nm is less effective in aging subjects with yellowing ocular lenses (Sletten et al. 2009).

Thus, bright light in the early morning may be particularly beneficial in the treatment of circadian and affective disorders, and this effect might be maximized using light close to the 480 nm peak of melanopsin sensitivity (preferably >480 nm for safety). One potential delivery system for bright light in the early morning would be a mask worn to bed, fitted with light emitting diodes (LEDs) that would be timed to deliver light in the early morning during sleep. Past studies have shown that light presented during the latter portion of sleep can be an effective treatment for seasonal affective disorder (Golden, Gaynes, Ekstrom, Hamer, Jacobsen, Suppes, Wisner and Nemeroff 2005, Avery, Eder, Bolte, Hellekson, Dunner, Vitiello and Prinz 2001, Avery et al. 1992). Although closed eyelids will attenuate most of the light (Ando and Kripke 1996), enough light may penetrate to have a biologic effect (Cole et al. 2002, Ando et al. 1999, Riesenberger et al. 2003).

Light masks might increase exposure and compliance, since the mask can be aimed directly at the eyes and treatment requires no effort during sleep. Bright light administered during sleep may minimize negative side effects of light, such as glare, which occur during treatment and reduce tolerability of effective dosages. Finally, light masks may be a more energy-efficient (through the use of only 8 LEDs) and portable method, compared to traditional light boxes.

Masks such as the ones used in the present study have been investigated previously. Using white light masks, Ando and colleagues (Ando, Kripke, Cole and Elliott 1999) found that a mask administering 500 lux of white light during sleep had slight benefit in the treatment of Delayed Sleep Phase Disorder. Additionally, a slight mood improvement was detected. Cole and colleagues (Cole, Smith, Alcala, Elliott and Kripke 2002) found that masks produced a significant advance of the melatonin rhythm in subjects with Delayed Sleep Phase Disorder. Thus, bright white light via masks during sleep can a significant biological effect. The light masks used in this study were used in one previous pilot study (Riesenberger, Kripke, Elliott and Cole 2003), which demonstrated their efficacy in suppressing melatonin during sleep.

To further evaluate the capabilities of short wavelength light masks, the present study was planned as a randomized, placebo-controlled trial of a short wavelength light mask (SW-Mask) worn in bed, contrasted to a dim red light control mask, for the shifting of sleep timing and the improvement of mood in young men with minimal-mild depression. Our hypotheses for this study were: (1) The SW-Mask is a safe and feasible method of bright light delivery, (2) The SW-Mask would produce an advance in sleep timing, (3) The SW-Mask would improve sleep, (4) The SW-Mask would improve mood, and (4) The SW-Mask would increase production of gonadotrophic hormones.

Material and methods

Overview

The study was a randomized, placebo-controlled pilot study of a bright blue/green light mask versus a dim red light mask. There was a 3-day baseline and a 12-day intervention period. Participants were randomly assigned to short wavelength light masks (SW-Mask) or dim red light masks (DR-Mask), using structured block randomization (which occurred immediately following consent and prior to baseline recording). This protocol was reviewed and approved by the Human Subjects Protection Program at the University of California, San Diego, as well as the Institutional Review Board at San Diego State University.

Subjects

Participants in this study were 30 young adult males mainly recruited from students at UCSD. As this pilot study included study of reproductive hormones, women were excluded to reduce variability related to gender and menstrual cycles. There were no drop-outs after consent was signed. To examine effects on depressive symptoms, we sought a sample with mild depressive symptoms not so severe as to require immediate clinical intervention. Nine screened subjects were excluded for depression severity as described below.

Light masks

The masks were molded plastic, fitted with foam padding. The SW-Mask emitted approximately 10,000 lux to the eyelid with light from blue/green LEDs set at 100% intensity. These masks were originally manufactured as prototypes to be used for the study by Cole and colleagues described earlier (Cole, Smith, Alcala, Elliott and Kripke 2002) and later modified with blue/green LEDs for the study described earlier by Riesenbergs and colleagues (Riesenbergs, Kripke, Elliott and Cole 2003). They are non commercial prototypes. The DR-Mask emitted approximately 0.5 lux from white LEDs set at 1% intensity, filtered through red gel. Spectrophotometry of the blue/green light mask output showed a peak at approximately 500 nanometers (see Figure 1). Observed irradiance measures were $1.566 \times 10^{-3} \text{ cm}^2(\text{w}-1)$ for the SW-mask at 100% intensity and $5.34 \times 10^{-8} \text{ cm}^2(\text{w}-1)$. For the DR-mask set at 10% intensity (though 1% intensity was used for the study).

The rationale for comparing bright blue/green light to dim red light was to replicate the methodology of many previous studies in non-seasonal depression which used a bright light treatment versus a dim red placebo (Tuunainen, Kripke and Endo 2004). Because brightness is confounded with wavelength, it is impossible to discern experimentally whether the effect was due to the intensity or the color of the light. However, past research has established red light as generally incapable of melatonin suppression (Brainard, Richardson, King and Reiter 1984), while white light, as well as light near 480nm, has been repeatedly shown to be effective (see above). Although it is unlikely that bright red light would have achieved similar effects, it is possible that bright white light, bright blue light (e.g., 460 nm) or bright green light (e.g., 550 nm) would produce similar effects.

Sleep measurement

Objective estimation of sleep continuity was based on a Sleep Watch with Light actigraph (Ambulatory Monitoring, Inc., Ardsley, NY) on the non-dominant wrist. Actigraphic records were scored using empirically supported algorithms for determining sleep, supplemented with hand editing of scoring (Jean-Louis, Kripke, Cole, et al. 2001, Jean-Louis, Kripke, Mason, et al. 2001). Variables included total sleep time, time awake after sleep onset, sleep latency and sleep efficiency.

Participants completed daily sleep diaries (SD). Each morning, participants were asked to record: bedtime (BEDT), sleep onset latency (SOL; minutes between BEDT and start of sleep), number of awakenings, final awakening time, and estimated wake duration after sleep onset, defined as total estimated minutes awake between time asleep and last awakening time (WASO). Total sleep time (TST) was computed as number of minutes from sleep onset until last awakening, minus estimated WASO. Participants were instructed to complete a short compliance diary (CD) each morning, at the same time that they complete the SD. This daily diary was completed every morning and asked the following questions: "Did you wear the mask last night as instructed?" "For how long?" "What problems did you have with the mask last night?" "Did the mask wake you up last night?" "Did you remember to reset the mask today?" and "Do you have any other comments about the study at this

time?” As the primary purpose of this study was to evaluate tolerability and feasibility, participants were informed that compliance with the light mask on any given night was requested but not required for continuation.

Questionnaires

The Center for Epidemiological Studies–Depression Scale (CESD (Radloff 1977)) was administered at screening. Since depressed mood was an outcome, the goal was to recruit individuals with at least some complaint to avoid floor effects; however, since this was not meant to be a clinical trial for major depression, those with clinically-relevant symptoms (CESD score >15) were excluded from study and referred for treatment (n=9).

In addition, all participants completed a Mood Visual Analog Scale (100mm) to measure daily fluctuations in mood (MVAS). The Quick Interview of Depressive Symptomatology (QIDS (Rush et al. 2003)), Epworth Sleepiness Scale (ESS (Johns 1991)), Pittsburgh Sleep Quality Index (PSQI (Buysse et al. 1989)), Horne-Östberg Morningness-Eveningness Questionnaire (HOMEQ (Horne and Ostberg 1976)) and the Systematic Assessment for Treatment-Emergent Effects (SAFTEE (Moynihan 1983)) were administered prior to and following the treatment period. Finally, participant expectations were measured via a set of two 100mm visual analogue scales administered before the first use of the mask and after its final use, to assess effectiveness of the placebo.

Urine Samples

Participants were instructed to collect urine for one 24-hour period both before and after treatment. Both of these sets of collections utilized the same protocol: before the first collection, the participant recorded the last time they voided during the six hours prior to sleep. Within an hour of bedtime, they voided and measured the total volume. They then collected a small urine sample and placed it in a tube, recording the time and volume of urine in a log. Then, they immediately placed the urine in the freezer section of the refrigerator. This procedure was repeated every time the subject voided until bedtime the next day. Drinking patterns were not evaluated. At the end of the study, samples were collected and immediately transported to a -70° freezer.

Urine assays for FSH and LH are widely accepted for their clinical suitability (Clough et al. 1992, Lasley et al. 1994, Kesner et al. 1999). An advantage of urine assays is the integration of the pulsatile blood secretion, so that a much smaller number of urine assays is needed per 24 hours than for blood. Urine collections also avoid the potential pain and risks related to blood sampling. Aliquots (2 ml) were stored at -70° C until assay. Urinary concentrations of FSH and LH were measured using double antibody immunoassay kits offered by Diagnostic System Laboratories, Inc (Webster, TX). The DSL-10-4600 ActiveR LH ELISA is an enzymatically amplified “one-step” sandwich-type immunoassay. Standards (0 to 100 mIU/ml), controls and unknowns were incubated with an anti-LH antibody in micro plate wells coated with another anti-LH antibody. After incubating and washing, the wells were incubated with tetramethylbenzidine (TMB) substrate and the timed reaction stopped with an acidic solution. Then, enzymatic turnover of the substrate was quantified by dual wavelength (450 and 630 nm) absorbance measurement in a micro plate reader. With the above protocol the DSL LH EIA displayed a sensitivity of 0.1 mIU/ml with intra-assay and inter-assay coefficients of variation ranging with mean dose (2.8 to 69.2) from 5.3 to 7.6%. Urine samples were typically measured by diluting 1:1 with zero standard. For greater accuracy, high LH urine samples (> 180 mIU/ml) were re-assayed at increased dilutions. Urinary rates of LH excretion (mIU/hr) were computed by multiplying the urine LH concentration (mIU/ml) by the urine excretion rate (ml/hr) calculated over the interval between voidings. The DSL FSH EIA (DSL-10-4700) involved an extra step but was

otherwise similar to the LH EIA in all key performance characteristics (sensitivity is 0.1 mIU/ml with standard range 0 to 150 mIU/ml). The specificity of the LH and FSH antibodies have been extensively validated for use on serum and urine samples both by the manufacturer and earlier with RIA methods (Santner et al. 1981).

Baseline measurement

The baseline period for this study lasted for study days 1–3 (until night 3). During day 1, the participant began wearing the actigraph and completed the MVAS. Upon awakening on day 2, participants completed the SD and MVAS. The participant continued to wear the actigraph and complete SD and MVAS on baseline day 3 when participants also completed the QIDS, ESS (with a specified 1-week time frame), PSQI (with a specified 12-day time frame), SAFTEE and HOMEQ.

Intervention period

Each participant was asked to maintain a regular sleep and wake schedule (determined by baseline sleep diaries), with special emphasis placed on maintaining a regular wake time. They were asked to maintain this schedule throughout the entire treatment period. During days 4–15, the participant wore the mask as instructed each night (starting night 3). The masks were programmed to begin to emit light 2.5 hours prior to the participant's usual wake time, linearly increasing in intensity from 0% to 100% of the desired intensity over the course of 29 minutes. At 121 minutes prior to usual wake time, the masks reached 100% of the target intensity and remained at that level for 120 minutes. At 1 minute prior to the usual wake time, the mask gradually decreased light intensity from 100% to 0% over 1 minute. The total duration of the mask light exposure was 150 minutes. Also during days 4–15, the participant completed a daily SD, MVAS and CD. The participant was also instructed to call research staff each day to ask any questions and report compliance. On day 15, on the morning following the final night of light treatment, the participant completed another QIDS, ESS (with specified 1-week time frame), and PSQI (with specified 2-week time frame). Additionally, on day 15, a research associate again visited the participant to collect the mask, actigraph, diaries and questionnaires, and answer any questions the participant may have had.

Data analysis

To assess safety and feasibility, we utilized Mann-Whitney U tests to examine SAFTEE overall and subscale scores. We also utilized an independent-samples t-test to compare groups on compliance and expectation ratings. We qualitatively examined compliance diaries (CDs). To assess sleep timing, MANOVA examined change scores for actigraphic time to bed, time awake and acrophase (cosine-fitted midpoint of sleep) across groups. This was followed by post-hoc one-way ANOVA. For sleep questionnaires (ESS, PSQI, HOMEQ), subjective sleep (SD variables) and objective sleep (actigraphic variables), a similar approach was taken. Independent-samples t-tests were used to compare difference scores on the QIDS. The volume and the LH and FSH concentration of each urine sample collected were measured, and excretion was estimated in international units per hour.. Difference scores for mean LH and FSH excretion were examined with independent-samples t-tests. Urinary excretion was expected to closely reflect glandular secretion and functional circulating blood levels (Santner, Santen, Kulin and Demers 1981). Within each domain, Type-I error was attenuated with Bonferroni corrections.

Results

Characteristics of the Sample

The SW-Mask group was 66.6% White, 26.7% Asian, and 6.7% Hispanic/Latino, with a mean age of 23.1. The DR-Mask group was 53.3% White, 40.0% Asian, and 6.7% Hispanic/Latino, with a mean age of 22.1.

Feasibility and safety of blue/green light masks

As an indicator of feasibility, participants reported using the mask as instructed 10.7 of 12 nights for the SW-Mask group and 11.3 of 12 nights for the DR-Mask group. No significant difference in adherence was found between groups. Only one subject, from the SW-Mask group, was not compliant with the light mask for at least 10 of 12 nights and was excluded from analysis. Independent-samples t-tests did not show significant differences between groups or testing periods (pre/post) on any expectation ratings, further supporting the notion that perceptions of the SW-Mask and DR-Mask as active treatments did not differ.

In before/after change scores between groups, Mann-Whitney U scores for overall SAFTEE score and all subscales showed no significant difference by Bonferroni criteria ($\alpha=.003$, as seen in Table 1); however 2 subscales (“Eye” and “Chest”) were nominally significantly different between groups ($P<0.05$). The SW-Mask group reported a slight increase in symptoms on the “Eye” subscale and the DR-Mask group reported a slight decrease. As an exploratory analysis, Mann-Whitney U comparisons were performed on each item in this subscale. No differences were found on the item level. The largest trend was an increase in Light Sensitivity, where those in the red light group reported slightly lowered sensitivity on average, whereas those in the bright light group reported increased sensitivity to light on average. This difference may be clinically relevant, though not statistically conclusive. The SW-Mask group also reported a slight increase in symptoms on the “Chest” subscale, and the DR-Mask group reported a slight decrease. Although this overall difference was nominally significant, no significant differences or notable trends were found on the item level.

In addition to checklist reports of symptoms, all participants were asked to informally evaluate the masks during a debriefing interview. Anecdotally, all subjects reported some physical discomfort from the plastic masks, irrespective of group, and all of those with the SW-Mask reported discomfort resulting from the brightness and early timing of illumination. This is supported by the data showing that the SW-Mask group advanced wake time to a greater degree than the DR-Mask group, although the latter advanced bedtime more than the former.

Effects of nocturnal blue/green light masks on sleep timing

The MANOVA for change scores for actigraphic time to bed, time out of bed, and sleep acrophase as dependent variables and light group as the independent variable was not significant. Means, overall and post-hoc tests are reported in Table 2. Although there were no statistically significant differences, the SW-Mask group went to bed earlier than the DR-Mask group at baseline (1:05 AM vs. 1:30 AM) and following treatment (12:30 AM vs. 1:01 AM), and the SW-Mask group advanced time to bed more than the DR-Mask group (35 mins vs. 29 mins). Although also non-significant, the findings for time out of bed and sleep acrophase also reflected a greater advance in the SW-Mask group, with an advance of 43 minutes vs. 13 minutes for time to bed and 36 vs. 28 minutes for sleep acrophase.

Effects of nocturnal blue/green light masks on mood

Mean CESD at screening was 8.3 in the DR-Mask group and 7.8 in the SW-Mask group, with no significant difference between groups ($t=.315$, $p=.76$). The correlation between CESD at screening and QIDS at baseline was significant ($r=.577$, $p=.002$). A t-test of QIDS difference scores (after-before) by group was not significant, suggesting that there were no differences in mood rating changes between treatments. Group means and statistical analysis are reported in Table 2.

Effects of nocturnal blue/green light masks on sleep

Group means at baseline and end of study, as well as overall and post-hoc analyses, are found in Table 2. The MANOVA for sleep questionnaires (PSQI, ESS, HOMEQ) difference scores as dependent variables and group as the independent variable was not significant, suggesting that there were no differences in sleep quality, sleepiness or morningness/eveningness difference scores between treatment groups. The MANOVA for subjective sleep diary items (sleep latency, TST, WASO and sleep efficiency) difference scores as dependent variables and group as the independent variable was significant, but post-hoc tests of between-groups differences did not distinguish between mask assignments on any of the individual SD items. This suggests that groups differed overall, but not on any specific measure. The MANOVA for actigraphic TST, WASO, sleep efficiency, sleep latency, and awakenings difference scores as dependent variables and group as the independent variable was not significant, suggesting that there were no differences in these actigraphic sleep variables between groups.

Effects of nocturnal blue/green light masks on FSH and LH

Of participants randomized, 4 subjects in the SW-Mask group and 5 in the DR-Mask group were excluded from hormone analysis because at least one of their 24-hour collections contained samples with undetectable LH. While periods of low secretion were expected, it may be unlikely that such low levels would actually represent undetectable levels. Rather, these low levels could be due to contamination, improper storage, or excessive urinary dilution. Of the participants whose samples were used, the mean age was 23.9 in the blue/green light group and 22.6 in the red light group. No significant differences in Baseline LH or FSH were observed.

Mean baseline and final FSH excretion (mIU/hr) and the change scores in both groups are reported in Table 3, and change scores are displayed graphically in Figure 2. The SW-Mask group showed approximately 0.17 mIU/hr (SD = 0.89) mean increase in FSH excretion, whereas the decrease seen in the DR-Mask group was approximately 0.81 mIU/hr (SD = 1.45). A one-tailed independent-samples t-test was significant ($t = 1.89$, $P = 0.035$, $N=19$).

Mean baseline, end, and change in LH excretion (mIU/hr) are also reported in Table 3, and change scores are displayed graphically in Figure 2. Both groups showed a decrease in LH excretion during the study. The SW-Mask group showed approximately 1.5 mIU/hr average decrease, whereas the decrease seen in the DR-Mask group was approximately 4 times as great. However, a one-tailed independent-samples t-test was not significant ($t= 1.59$, $p = 0.064$ $N=19$). This might be explained by an observed power of only 0.38, suggesting that there was not sufficient power to detect the difference between groups.

Discussion

The present study evaluated the feasibility and utility of a mask emitting bright, short wavelength light, worn at night, for improving mood and changing sleep. The hypothesis that the SW-Mask would be safe and tolerable was partially supported, as was the

hypothesis that the SW-Mask would alter gonadotropin secretion. The hypotheses that the SW-Mask would alter sleep timing and improve mood and sleep were not supported.

Light masks were safe and tolerable for research

That no subject dropped out of the study, or reported serious adverse events, suggests that overall, the masks were tolerable and practical. Additionally, overall adherence was good. This suggests that even though the masks may be uncomfortable at times, this method of delivery of light attracts compliance on par with other studies of bright light (Tuunainen, Kripke and Endo 2004). Had the protocol encouraged subjects to awaken earlier as their phases advanced, there might have been less discomfort due to early waking from bright light. Moreover, the contrast between SW-Mask and DR-Mask groups might have been greater (Cole, Smith, Alcala, Elliott and Kripke 2002). Although no previous studies have systematically examined or reported safety data, these results are consistent with previous studies of light masks, which have indicated good compliance and low rates of drop-outs (Cole, Smith, Alcala, Elliott and Kripke 2002, Ando, Kripke, Cole and Elliott 1999, Riesenberger, Kripke, Elliott and Cole 2003).

This was supported by the results of the SAFTEE symptom inventory, which suggest that the SW-Masks produced no significant side effects in relatively healthy young males. Although no side effects were statistically significant by Bonferroni criteria, there were trends towards significance for “Eye” and “Chest” symptoms. The most likely cause of an elevation in “Eye” symptoms was the greater light sensitivity following use of the SW-Mask. Although this side effect was not statistically significant, it could be expected, as light sensitivity has been reported as a common side effect in earlier studies of bright light (Hebert et al. 2002). Examination of the results of “Chest” items reveals no clear pattern despite the statistical trend, and no apparent causes of these symptoms were found. It should be noted that these symptoms have not been reported by others previously and that when 17 comparisons are tested, one nominally significant contrast is to be expected by chance.

Light masks and sleep timing

Previous studies of light masks have suggested that they may be effective in suppressing melatonin and/or advancing circadian phase (Cole, Smith, Alcala, Elliott and Kripke 2002, Ando, Kripke, Cole and Elliott 1999, Riesenberger, Kripke, Elliott and Cole 2003). Although this study did not find significant differences, this may be due to the relative underpowering of the study to detect such modest effects -- compared to the DR-Mask group, the SW-Mask group demonstrated a 6-minute greater advance of time to bed and 30-minute greater advance of time out of bed, as well as an 8-minute greater advance in sleep acrophase. Masks such as these, especially in non-clinical samples such as that chosen for this study, may not be useful for more than very small changes in sleep timing. This is supported by recent research showing that a similar light mask (also 500 nm narrow-band) was not effective in altering timing and duration of naps (Harrison et al. 2011).

Light masks did not improve mood

Numerous studies have documented the effectiveness of bright light in altering mood in depressed (Golden, Gaynes, Ekstrom, Hamer, Jacobsen, Suppes, Wisner and Nemeroff 2005, Even, Schroder, Friedman and Rouillon 2008) and in non-depressed individuals (Grandner, Kripke and Langer 2006, Grandner et al. 2004, Kohsaka et al. 1999, Partonen and Lonnqvist 2000). The present study did not detect any significant mood change in young men with minimal-mild depression, though there was a notable floor effect in depression symptoms.

One possible explanation of there being no change in mood symptoms is that clinically relevant mood symptoms were exclusion criteria. Previous studies have suggested that reductions in depressive symptoms are particularly difficult to detect, especially in smaller samples with only mild symptoms (Fournier et al. 2010). Additionally, benefits may be more difficult to detect in men (Rochlen 2005, Rochlen et al. 2005). Finally, studies documenting the benefits of bright light in non-depressed groups suggest that measuring increases in positive experience, rather than decreases in depression, may be most informative (Grandner, Kripke and Langer 2006, Partonen and Lonnqvist 2000, Hasler and Bootzin 2008). Perhaps the inclusion of a measure of positive affect (Watson et al. 1988) or quality of life (Ware and Sherbourne 1992) would have more fully addressed the issue of improvement related to bright light in this sample.

Light masks did not improve sleep

A significant difference between groups was detected for changes in the subjective experience of sleep recorded with sleep diary, such that the SW-Mask group reported worsening of sleep overall. Although no specific factors were significant, the SW-Mask users reported an overall decrease in total sleep time, as well as a slight increase in WASO and slight decreases in sleep efficiency and sleep latency. Notably, this pattern was also found (though was not significant) in the actigraphic data. This may be due to the notable discomfort reported by all light mask users, compounded by the additional discomfort reported by SW-Mask users, due to waking up to bright light. However, a lack of other group differences, or even simple effects within this domain, suggests that the light mask produces worsening perceptions of sleep parameters overall, rather than specific alterations in sleep. Thus, the SW-Mask users had a general impression of having slept less well overall. Also, sleep complaints are often a proxy for depressive mood, and most subjects reported at least some depressive symptoms.

Change scores on questionnaires measuring sleep quality (PSQI), daytime sleepiness (ESS) and morningness/eveningness (HOMEQ) did not distinguish groups. This suggests that despite changes in self-reported sleep on sleep diary, the SW-Masks did not significantly increase daytime sleepiness or worsen sleep quality, nor were they improved.

Light masks demonstrate weak effects on gonadotropins

Two previous studies have shown that light presented soon after awakening (at approximately the same time of night as in this study) increased LH and/or FSH production more than a dim red placebo (Danilenko and Samoilova 2007, Yoon, Kripke, Elliott and Youngstedt 2003). Though an increase in FSH was noted in the present study, there was no significant difference in LH with the SW-Mask. Perhaps the light was attenuated too much by the eyelids during sleep (Ando and Kripke 1996) or the study was underpowered to detect a difference. The issues of light attenuation by the eyelid and sample size will need to be more effectively addressed by future studies of light masks.

In both groups, a trend toward decrease in LH production was noted. Although the decrease was attenuated in the SW-Mask group, it is unclear why any decrease would take place. Since the collections took place in the home, perhaps samples were not properly collected or volume and time were not measured correctly at the end of the protocol, despite efforts made. If there was a problem with storage, then initial values would be artificially decreased, since they were stored at participants' homes 2 weeks longer than measurements collected at the end of study. However, the end-of-study values were lowest (and initial values higher). No current hypothesis explains this observation.

Limitations of the study

This study presents several important limitations. Due to various constraints, the sample consisted of only 30 people (15 per group), and only healthy young males studied in the spring and summer months. Thus, any results must be interpreted cautiously in the presence of possible seasonal, gender, and age effects, as well as floor effects for treatment and underpowering of the study. Treatment effects may be underestimated. Thus, the results of the present study may be understating the potential usefulness of nocturnal bright blue/green light. Additional, larger studies, with more diverse samples could reveal additional benefit.

A second important limitation was the reliance on sleep timing as a circadian marker. No body temperature, melatonin or other circadian biomarkers were obtained. Thus, these results should be interpreted with the caveat that other measures of endogenous rhythms may not corroborate these findings. It should be noted that due to the pilot nature of this study, these results are meant to be taken as a “proof of concept” that should be replicated in future studies resourced to measure other circadian biomarkers.

Third, actigraphy insufficiently measures arousals and sleep architecture which may be related to sleep quality. Actigraphy does monitor arousals and midsleep awakenings, though not as well as it monitors total sleep time (Krystal and Edinger 2008). It is true that actigraphy does not detect some brief sleep arousals without movement, but such brief arousals are only scored with considerable difficulty in polysomnography (Mathur and Douglas 1995). It is likewise true that actigraphy does not distinguish the sleep stages, but it is widely recognized that insomnia and other disturbances of sleep have more to do with total sleep time, time awake in bed, and arousals than with quantities of each sleep stage (Smith et al. 2003).

Fourth, since blue/green light was not compared to equally bright red light, it is unclear whether the wavelength of the light had any relevant effect. It is possible that white (or red) light of equal intensity would produce similar effects. Moreover, there are some indications that some green or yellow light is required along with blue light to optimally maintain activation of melanopsin (Gooley, Rajaratnam, Brainard, Kronauer, Czeisler and Lockley 2010, Lall, Revell, Momiji, Al Enezi, Altimus, Guler, Aguilar, Cameron, Allender, Hankins and Lucas 2010). However, this study was designed to mimic clinical studies of bright light therapy, which do not aim to determine the physiologic effects of different wavelengths; rather, the intended goal is to compare a treatment (e.g., bright light) to a placebo condition (e.g., dim red light). This is a common practice in studies of light therapy (Terman 2007, Terman and Terman 2005, Tuunainen, Kripke and Endo 2004, Lieveise, Van Someren, Nielen, Uitdehaag, Smit and Hoogendijk 2011). In a clinical paradigm, an effective placebo should be physiologically inactive, yet participants should not think so. For example, in a drug trial, participants should not be able to tell which pill is intended to have a desired effect, yet one of the pills should be inactive. In the case of bright light therapy, an effective placebo condition would involve light that is as physiologically inactive as possible (i.e., dim and red), while still bright enough to seem plausible as a treatment. That there were no differences in expectation ratings showed that subjects expected equal effects from both masks, suggesting that it was an effective placebo.

Ambient illumination in participants' bedrooms during the night was not recorded. However, since the masks are form-fitting, with foam inserts that attenuate all ambient light, the impact of this confound is likely small.

Finally, compliance was only recorded via self-report. As there is currently no way to monitor such compliance at home through more objective means, future studies may utilize as-yet-undeveloped measurements of compliance.

Conclusions

This study provides evidence that bright blue/green light, presented in the early morning hours, may increase gonadotropins, even in healthy young men. Future studies may explore this intervention in those with circadian rhythm disorders or other conditions that can be treated with bright light in the morning.

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References

- Bjorvatn B, Pallesen S. A practical approach to circadian rhythm sleep disorders. *Sleep Med Rev.* 2009; 13(1):47–60. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=18845459 S1087-0792(08)00044-0 [pii]. 10.1016/j.smrv.2008.04.009 [PubMed: 18845459]
- Morgenthaler TI, Lee-Chiong T, Alessi C, Friedman L, Aurora RN, Boehlecke B, Brown T, Chesson AL Jr, Kapur V, Maganti R, et al. Practice parameters for the clinical evaluation and treatment of circadian rhythm sleep disorders. An American Academy of Sleep Medicine report. *Sleep.* 2007; 30(11):1445–1459. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=18041479. [PubMed: 18041479]
- Okawa M, Uchiyama M. Circadian rhythm sleep disorders: characteristics and entrainment pathology in delayed sleep phase and non-24-h sleep-wake syndrome. *Sleep Med Rev.* 2007; 11(6):485–496. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17964201 S1087-0792(07)00102-5 [pii]. 10.1016/j.smrv.2007.08.001 [PubMed: 17964201]
- Lack LC, Wright HR. Clinical management of delayed sleep phase disorder. *Behav Sleep Med.* 2007; 5(1):57–76. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17313324. 10.1207/s15402010bsm0501_4 [PubMed: 17313324]
- Barion A, Zee PC. A clinical approach to circadian rhythm sleep disorders. *Sleep Med.* 2007; 8(6): 566–577. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17395535 S1389-9457(06)00704-0 [pii]. 10.1016/j.sleep.2006.11.017 [PubMed: 17395535]
- Chesson AL Jr, Littner M, Davila D, Anderson WM, Grigg-Damberger M, Hartse K, Johnson S, Wise M. Practice parameters for the use of light therapy in the treatment of sleep disorders. Standards of Practice Committee, American Academy of Sleep Medicine. *Sleep.* 1999; 22(5):641–660. Available. [PubMed: 10450599]
- Sack RL. Clinical practice. Jet lag *N Engl J Med.* 2010; 362(5):440–447. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=20130253 362/5/440 [pii]. 10.1056/NEJMcp0909838
- Arendt J. Managing jet lag: Some of the problems and possible new solutions. *Sleep Med Rev.* 2009; 13(4):249–256. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=19147377 S1087-0792(08)00086-5 [pii]. 10.1016/j.smrv.2008.07.011 [PubMed: 19147377]
- Sack RL, Auckley D, Auger RR, Carskadon MA, Wright KP Jr, Vitiello MV, Zhdanova IV. Circadian rhythm sleep disorders: part I, basic principles, shift work and jet lag disorders. An American Academy of Sleep Medicine review. *Sleep.* 2007; 30(11):1460–1483. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=18041480. [PubMed: 18041480]

- Boyce P, Barriball E. Circadian rhythms and depression. *Aust Fam Physician*. 2010; 39(5):307–310. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=20485718. [PubMed: 20485718]
- Monteleone, P.; Martiadis, V.; Maj, M. Circadian rhythms and treatment implications in depression. *Prog Neuropsychopharmacol Biol Psychiatry*. 2010. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=20691746S0278-5846(10)00294-0 [pii] 10.1016/j.smr.2007.06.003 [PubMed: 17964200]
- Terman M. Evolving applications of light therapy. *Sleep Med Rev*. 2007; 11(6):497–507. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17964200S1087-0792(07)00087-1 [pii]. 10.1016/j.smr.2007.06.003 [PubMed: 17964200]
- Golden RN, Gaynes BN, Ekstrom RD, Hamer RM, Jacobsen FM, Suppes T, Wisner KL, Nemeroff CB. The efficacy of light therapy in the treatment of mood disorders: a review and meta-analysis of the evidence. *Am J Psychiatry*. 2005; 162(4):656–662. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=15800134162/4/656 [pii]. 10.1176/appi.ajp.162.4.656 [PubMed: 15800134]
- Terman M, Terman JS. Light therapy for seasonal and nonseasonal depression: efficacy, protocol, safety, and side effects. *CNS Spectr*. 2005; 10(8):647–663. quiz 672. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=16041296. [PubMed: 16041296]
- Even C, Schroder CM, Friedman S, Rouillon F. Efficacy of light therapy in nonseasonal depression: a systematic review. *J Affect Disord*. 2008; 108(1–2):11–23. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17950467S0165-0327(07)00336-9 [pii]. 10.1016/j.jad.2007.09.008 [PubMed: 17950467]
- Tuunainen A, Kripke DF, Endo T. Light therapy for non-seasonal depression. *Cochrane Database Syst Rev*. 2004; (2):CD004050. Available. [PubMed: 15106233]
- Lieveer R, Van Someren EJ, Nielen MM, Uitdehaag BM, Smit JH, Hoogendijk WJ. Bright light treatment in elderly patients with nonseasonal major depressive disorder: a randomized placebo-controlled trial. *Arch Gen Psychiatry*. 2011; 68(1):61–70. Available from <http://www.ncbi.nlm.nih.gov/pubmed/21199966>68/1/61 [pii]. 10.1001/archgenpsychiatry.2010.183 [PubMed: 21199966]
- Einin D. The influence of ambient light and menstrual status on the moods of a nonclinical population of young women. *Psychosom Med*. 1997; 59(6):616–619. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=9407581. [PubMed: 9407581]
- Grandner MA, Kripke DF, Langer RD. Light exposure is related to social and emotional functioning and to quality of life in older women. *Psychiatry Res*. 2006; 143(1):35–42. Available. [PubMed: 16725207]
- Kaida K, Takahashi M, Haratani T, Otsuka Y, Fukasawa K, Nakata A. Indoor exposure to natural bright light prevents afternoon sleepiness. *Sleep*. 2006; 29(4):462–469. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=16676779. [PubMed: 16676779]
- Jean-Louis G, Kripke D, Cohen C, Zizi F, Wolintz A. Associations of ambient illumination with mood: contribution of ophthalmic dysfunctions. *Physiol Behav*. 2005; 84(3):479–487. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=15763587S0031-9384(05)00029-6 [pii]. 10.1016/j.physbeh.2005.01.011 [PubMed: 15763587]
- Campbell SS, Dawson D. Enhancement of nighttime alertness and performance with bright ambient light. *Physiol Behav*. 1990; 48(2):317–320. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=22557380031-9384(90)90320-4 [pii]. [PubMed: 2255738]

- Kripke DF, Elliott JA, Youngstedt SD, Rex KM. Circadian phase response curves to light in older and young women and men. *J Circadian Rhythms*. 2007; 5:4. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17623102 1740-3391-5-4 [pii]. 10.1186/1740-3391-5-4 [PubMed: 17623102]
- Evans JA, Elliott JA, Gorman MR. Circadian effects of light no brighter than moonlight. *J Biol Rhythms*. 2007; 22(4):356–367. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17660452 22/4/356 [pii]. 10.1177/0748730407301988 [PubMed: 17660452]
- Johnson CH. Forty years of PRCs--what have we learned? *Chronobiol Int*. 1999; 16(6):711–743. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=10584173. [PubMed: 10584173]
- Youngstedt SD, Leung A, Kripke DF, Langer RD. Association of morning illumination and window covering with mood and sleep among post-menopausal women. *Sleep and Biological Rhythms*. 2004; 2(3):174–183. Available.
- Avery DH, Kouri ME, Monaghan K, Bolte MA, Hellekson C, Eder D. Is dawn simulation effective in ameliorating the difficulty awakening in seasonal affective disorder associated with hypersomnia? *J Affect Disord*. 2002; 69(1–3):231–236. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=12103471 doi S0165032700003608 [pii]. [PubMed: 12103471]
- Avery DH, Eder DN, Bolte MA, Hellekson CJ, Dunner DL, Vitiello MV, Prinz PN. Dawn simulation and bright light in the treatment of SAD: a controlled study. *Biol Psychiatry*. 2001; 50(3):205–216. Available. [PubMed: 11513820]
- Avery D, Khan A, Dager S, Cohen S, Cox G, Dunner D. Is morning light exposure superior to evening light in treating seasonal affective disorder? *Psychopharmacol Bull*. 1990; 26(4):521–524. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=2087545. [PubMed: 2087545]
- Terman JS, Terman M, Lo ES, Cooper TB. Circadian time of morning light administration and therapeutic response in winter depression. *Arch Gen Psychiatry*. 2001; 58(1):69–75. Available. [PubMed: 11146760]
- Kripke DF, Elliott JA, Youngstedt SD, Parry BL, Hauger RL, Rex KM. Weak evidence of bright light effects on human LH and FSH. *J Circadian Rhythms*. 2010; 8:5. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=20459826 1740-3391-8-5 [pii]. 10.1186/1740-3391-8-5 [PubMed: 20459826]
- Danilenko KV, Samoilova EA. Stimulatory effect of morning bright light on reproductive hormones and ovulation: results of a controlled crossover trial. *PLoS Clin Trials*. 2007; 2(2):e7. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17290302. 10.1371/journal.pctr.0020007 [PubMed: 17290302]
- Baker FC, Driver HS. Circadian rhythms, sleep, and the menstrual cycle. *Sleep Med*. 2007; 8(6):613–622. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17383933 S1389-9457(06)00621-6 [pii]. 10.1016/j.sleep.2006.09.011 [PubMed: 17383933]
- Yoon IY, Kripke DF, Elliott JA, Youngstedt SD. Luteinizing hormone following light exposure in healthy young men. *Neurosci Lett*. 2003; 341(1):25–28. Available. [PubMed: 12676335]
- Wehr TA. Photoperiodism in humans and other primates: evidence and implications. *J Biol Rhythms*. 2001; 16(4):348–364. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=11506380. [PubMed: 11506380]
- Lam RW, Levitan RD. Pathophysiology of seasonal affective disorder: a review. *J Psychiatry Neurosci*. 2000; 25(5):469–480. Available. [PubMed: 11109298]
- Tam EM, Lam RW, Levitt AJ. Treatment of seasonal affective disorder: a review. *Can J Psychiatry*. 1995; 40(8):457–466. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=8681269. [PubMed: 8681269]

- Rosenthal NE, Wehr TA. Towards understanding the mechanism of action of light in seasonal affective disorder. *Pharmacopsychiatry*. 1992; 25(1):56–60. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=1579608. [PubMed: 1579608]
- Panda S, Provencio I, Tu DC, Pires SS, Rollag MD, Castrucci AM, Pletcher MT, Sato TK, Wiltshire T, Andahazy M, et al. Melanopsin is required for non-image-forming photic responses in blind mice. *Science*. 2003; 301(5632):525–527. Available. [PubMed: 12829787]
- Hattar S, Liao HW, Takao M, Berson DM, Yau KW. Melanopsin-containing retinal ganglion cells: architecture, projections, and intrinsic photosensitivity. *Science*. 2002; 295(5557):1065–1070. Available. [PubMed: 11834834]
- Bellingham J, Foster RG. Opsins and mammalian photoentrainment. *Cell Tissue Res*. 2002; 309(1): 57–71. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=12111537. 10.1007/s00441-002-0573-4 [PubMed: 12111537]
- Hannibal J. Neurotransmitters of the retino-hypothalamic tract. *Cell Tissue Res*. 2002; 309(1):73–88. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=12111538. 10.1007/s00441-002-0574-3 [PubMed: 12111538]
- Peirson, SN.; Foster, RG. *The Circadian Clock*. NY: Springer; 2009. Non-image-forming photoreceptors; p. 105–113.
- Brainard GC, Richardson BA, King TS, Reiter RJ. The influence of different light spectra on the suppression of pineal melatonin content in the Syrian hamster. *Brain Res*. 1984; 294(2):333–339. Available. [PubMed: 6704731]
- Henderson BA, Grimes KJ. Blue-blocking IOLs: a complete review of the literature. *Surv Ophthalmol*. 2010; 55(3):284–289. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=20499436. [PubMed: 20499436]
- Ackermann K, Sletten TL, Revell VL, Archer SN, Skene DJ. Blue-light phase shifts PER3 gene expression in human leukocytes. *Chronobiol Int*. 2009; 26(4):769–779. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=19444755 [pii]. 10.1080/07420520902929045 [PubMed: 19444755]
- Smith MR, Eastman CI. Phase delaying the human circadian clock with blue-enriched polychromatic light. *Chronobiol Int*. 2009; 26(4):709–725. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=19444751 [pii]. 10.1080/07420520902927742 [PubMed: 19444751]
- Smith MR, Revell VL, Eastman CI. Phase advancing the human circadian clock with blue-enriched polychromatic light. *Sleep Med*. 2009; 10(3):287–294. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=18805055 [pii]. 10.1016/j.sleep.2008.05.005 [PubMed: 18805055]
- Burkhart K, Phelps JR. Amber lenses to block blue light and improve sleep: a randomized trial. *Chronobiol Int*. 2009; 26(8):1602–1612. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=20030543. 10.3109/07420520903523719 [PubMed: 20030543]
- Strong RE, Marchant BK, Reimherr FW, Williams E, Soni P, Mestas R. Narrow-band blue-light treatment of seasonal affective disorder in adults and the influence of additional nonseasonal symptoms. *Depress Anxiety*. 2009; 26(3):273–278. Available from <http://www.ncbi.nlm.nih.gov/pubmed/19016463>. 10.1002/da.20538 [PubMed: 19016463]
- Lockley, SW. Intensity- and duration-dependent changes in the spectral sensitivity of human circadian photoreception. Paper presented at: 20th Anniversary Meeting of the Society for Research on Biological Rhythms; Destin, FL. 2008.
- Hanifin, J.; Cecil, K.; West, K.; Jablonski, M.; Warfield, B.; James, M.; Thiessen, M.; Jasser, S.; Stone, M.; Fucci, R., et al. Efficacy of blue-enriched fluorescent light for melatonin suppression and circadian phase resetting. Paper presented at: 20th Anniversary Meeting of the Society for Research on Biological Rhythms; Destin, FL. 2008.

- Gooley, JJ.; Rajaratnam, SM.; Brainard, GC.; Kronauer, RE.; Czeisler, CA.; Lockley, SW. The spectral sensitivity of human circadian photoreception Is dynamic and changes depending on the irradiance and duration of light. Paper presented at: 20th Anniversary Meeting of the Society for Research on Biological Rhythms; Destin, FL. 2008.
- Desan PH, Weinstein AJ, Michalak EE, Tam EM, Meesters Y, Ruiter MJ, Horn E, Telner J, Iskandar H, Boivin DB, et al. A controlled trial of the Litebook light-emitting diode (LED) light therapy device for treatment of Seasonal Affective Disorder (SAD). *BMC Psychiatry*. 2007; 7:38. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17683643 1471-244X-7-38 [pii]. 10.1186/1471-244X-7-38 [PubMed: 17683643]
- Glickman G, Byrne B, Pineda C, Hauck WW, Brainard GC. Light therapy for seasonal affective disorder with blue narrow-band light-emitting diodes (LEDs). *Biol Psychiatry*. 2006; 59(6):502–507. Available. [PubMed: 16165105]
- Campbell SS. Short-wavelength sensitivity for activating effects of light: an ascent to the arcane? *Sleep*. 2006; 29(2):140–141. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=16494079. [PubMed: 16494079]
- Lockley SW, Evans EE, Scheer FA, Brainard GC, Czeisler CA, Aeschbach D. Short-wavelength sensitivity for the direct effects of light on alertness, vigilance, and the waking electroencephalogram in humans. *Sleep*. 2006; 29(2):161–168. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=16494083. [PubMed: 16494083]
- Revell VL, Arendt J, Fogg LF, Skene DJ. Alerting effects of light are sensitive to very short wavelengths. *Neurosci Lett*. 2006; 399(1–2):96–100. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=16490309 S0304-3940(06)00066-8 [pii]. 10.1016/j.neulet.2006.01.032 [PubMed: 16490309]
- Revell VL, Arendt J, Terman M, Skene DJ. Short-wavelength sensitivity of the human circadian system to phase-advancing light. *J Biol Rhythms*. 2005; 20(3):270–272. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=15851533 20/3/270 [pii]. 10.1177/0748730405275655 [PubMed: 15851533]
- Herljevic M, Middleton B, Thapan K, Skene DJ. Light-induced melatonin suppression: age-related reduction in response to short wavelength light. *Exp Gerontol*. 2005; 40(3):237–242. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=15763401 S0531-5565(04)00348-1 [pii]. 10.1016/j.exger.2004.12.001 [PubMed: 15763401]
- Wright HR, Lack LC, Kennaway DJ. Differential effects of light wavelength in phase advancing the melatonin rhythm. *J Pineal Res*. 2004; 36(2):140–144. Available. [PubMed: 14962066]
- Herljevic M, Middleton B, Thapan K, Skene DJ. Light-induced melatonin suppression: age-related reduction in the response to short wavelength light. *Society for Research on Biological Rhythms, Program and Abstracts*. 2004; 124:1. Available.
- Lockley SW, Brainard GC, Czeisler CA. High sensitivity of the human circadian melatonin rhythm to resetting by short wavelength light. *J Clin Endocrinol Metab*. 2003; 88(9):4502–4505. Available. [PubMed: 12970330]
- Warman VL, Dijk DJ, Warman GR, Arendt J, Skene DJ. Phase advancing human circadian rhythms with short wavelength light. *Neurosci Lett*. 2003; 342(1–2):37–40. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=12727312 S0304394003002234 [pii]. [PubMed: 12727312]
- Berson DM, Dunn FA, Takao M. Phototransduction by retinal ganglion cells that set the circadian clock. *Science*. 2002; 295(5557):1070–1073. Available. [PubMed: 11834835]
- Brainard GC, Hanifin JP, Greenson JM, Byrne B, Glickman G, Gerner E, Rollag MD. Action spectrum for melatonin regulation in humans: evidence for a novel circadian photoreceptor. *J Neurosci*. 2001; 21(16):6405–6412. Available from <http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?>

- cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=1148766421/16/6405 [pii]. [PubMed: 11487664]
- Gooley JJ, Rajaratnam SM, Brainard GC, Kronauer RE, Czeisler CA, Lockley SW. Spectral responses of the human circadian system depend on the irradiance and duration of exposure to light. *Sci Transl Med*. 2010; 2(31):31ra33. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=204633672/31/31ra33 [pii]. 10.1126/scitranslmed.3000741
- Lall GS, Revell VL, Momiji H, Al Enezi J, Altimus CM, Guler AD, Aguilar C, Cameron MA, Allender S, Hankins MW, et al. Distinct contributions of rod, cone, and melanopsin photoreceptors to encoding irradiance. *Neuron*. 2010; 66(3):417–428. Available from <http://www.ncbi.nlm.nih.gov/pubmed/20471354> S0896-6273(10)00330-2 [pii]. 10.1016/j.neuron.2010.04.037 [PubMed: 20471354]
- Revell VL, Barrett DC, Schlangen LJ, Skene DJ. Predicting human nocturnal nonvisual responses to monochromatic and polychromatic light with a melanopsin photosensitivity function. *Chronobiol Int*. 2010; 27(9–10):1762–1777. Available from <http://www.ncbi.nlm.nih.gov/pubmed/20969522>. 10.3109/07420528.2010.516048 [PubMed: 20969522]
- Okuno T. Hazards of solar blue light. *Appl Opt*. 2008; 47(16):2988–2992. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=18516116 160547 [pii]. [PubMed: 18516116]
- Algvere PV, Marshall J, Seregard S. Age-related maculopathy and the impact of blue light hazard. *Acta Ophthalmol Scand*. 2006; 84(1):4–15. Available. [PubMed: 16445433]
- Reichow AW, Citek K, Edlich RF. Ultraviolet and short wavelength visible light exposure: why ultraviolet protection alone is not adequate. *J Long Term Eff Med Implants*. 2006; 16(4):315–325. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17073573 2079c9ee5d0479b2,3eeb53d03074818a [pii]. [PubMed: 17073573]
- Grandner, MA.; Gehrman, PR. *Encyclopedia of Lifestyle Medicine and Health*. Thousand Oaks, CA: Sage; Sleep. In Press
- Ham WT Jr, Mueller HA, Sliney DH. Retinal sensitivity to damage from short wavelength light. *Nature*. 1976; 260(5547):153–155. Available from <http://www.ncbi.nlm.nih.gov/pubmed/815821>. [PubMed: 815821]
- Sletten TL, Revell VL, Middleton B, Lederle KA, Skene DJ. Age-related changes in acute and phase-advancing responses to monochromatic light. *J Biol Rhythms*. 2009; 24(1):73–84. Available from <http://www.ncbi.nlm.nih.gov/pubmed/19227580>. [PubMed: 19227580]
- Avery DH, Bolte MA, Cohen S, Millet MS. Gradual versus rapid dawn simulation treatment of winter depression. *J Clin Psychiatry*. 1992; 53(10):359–363. Available. [PubMed: 1429475]
- Ando K, Kripke DF. Light attenuation by the human eyelid. *Biol Psychiatry*. 1996; 39(1):22–25. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=8719122 0006-3223(95)00109-3 [pii]. 10.1016/0006-3223(95)00109-3 [PubMed: 8719122]
- Cole RJ, Smith JS, Alcala YC, Elliott JA, Kripke DF. Bright-light mask treatment of delayed sleep phase syndrome. *J Biol Rhythms*. 2002; 17(1):89–101. Available. [PubMed: 11837952]
- Ando K, Kripke DF, Cole RJ, Elliott JA. Light mask 500 lux treatment for delayed sleep phase syndrome. *Prog Neuropsychopharmacol Biol Psychiatry*. 1999; 23(1):15–24. Available. [PubMed: 10368853]
- Riesenberg T, Kripke DF, Elliott JA, Cole R. Green Light Suppression of Melatonin. *Chronobiol Int*. 2003; 20(6):1183. Available.
- Jean-Louis G, Kripke DF, Cole RJ, Assmus JD, Langer RD. Sleep detection with an accelerometer actigraph: comparisons with polysomnography. *Physiol Behav*. 2001; 72(1–2):21–28. Available. [PubMed: 11239977]
- Jean-Louis G, Kripke DF, Mason WJ, Elliott JA, Youngstedt SD. Sleep estimation from wrist movement quantified by different actigraphic modalities. *J Neurosci Methods*. 2001; 105(2):185–191. Available. [PubMed: 11275275]

- Radloff LS. The CES-D scale: A self-report depression scale for research in the general population. *Applied Psychological Measurement*. 1977; 1:385–401. Available.
- Rush AJ, Trivedi MH, Ibrahim HM, Carmody TJ, Arnow B, Klein DN, Markowitz JC, Ninan PT, Kornstein S, Manber R, et al. The 16-Item Quick Inventory of Depressive Symptomatology (QIDS), clinician rating (QIDS-C), and self-report (QIDS-SR): a psychometric evaluation in patients with chronic major depression. *Biol Psychiatry*. 2003; 54(5):573–583. Available. [PubMed: 12946886]
- Johns MW. A new method for measuring daytime sleepiness: the Epworth sleepiness scale. *Sleep*. 1991; 14(6):540–545. Available. [PubMed: 1798888]
- Buysse DJ, Reynolds CF 3rd, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Res*. 1989; 28(2):193–213. Available. [PubMed: 2748771]
- Horne JA, Ostberg O. A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *Int J Chronobiol*. 1976; 4(2):97–110. Available. [PubMed: 1027738]
- Moynihan, C. *Systematic Assessment For Treatment Emergent Events*. Washington, DC: DHHS; 1983.
- Clough KM, Cole FX, Seaver SS, Vesprini A, Kuo AY, Lasley BL. Enzyme immunoassay method for total alpha gonadotropin in human urine samples. *Fertil Steril*. 1992; 57(6):1241–1246. Available. [PubMed: 1601145]
- Lasley BL, Mobed K, Gold EB. The use of urinary hormonal assessments in human studies. *Ann N Y Acad Sci*. 1994; 709:299–311. Available. [PubMed: 8154723]
- Kesner JS, Knecht EA, Krieg EF Jr. Measuring endocrine profiles of women in field studies. *Scand J Work Environ Health*. 1999; 25(Suppl 1):17–19. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=10235400. [PubMed: 10235400]
- Santner SJ, Santen RJ, Kulin HE, Demers LM. A model for validation of radioimmunoassay kit reagents: measurement of follitropin and lutropin in blood and urine. *Clin Chem*. 1981; 27(11):1892–1895. Available. [PubMed: 6794948]
- Hebert M, Dumont M, Lachapelle P. Electrophysiological evidence suggesting a seasonal modulation of retinal sensitivity in subsyndromal winter depression. *J Affect Disord*. 2002; 68(2–3):191–202. Available. [PubMed: 12063147]
- Harrison, EM.; Gorman, MR.; Mednick, SC. The Effect of Narrowband 500 nm Light on Daytime Sleep in Humans. *Physiol Behav*. 2011. Available from <http://www.ncbi.nlm.nih.gov/pubmed/21281656> S0031-9384(11)00035-7 [pii]
- Grandner M, Kripke D, Youngstedt S, Langer R. Light exposure, social and emotional functioning, and quality of life in postmenopausal women. *Society for Light Treatment and Biological Rhythms Program and Abstracts*. 2004; 16 Available.
- Kohsaka M, Fukuda N, Honma H, Kobayashi R, Sakakibara S, Koyama E, Nakano T, Matsubara H. Effects of moderately bright light on subjective evaluations in healthy elderly women. *Psychiatry Clin Neurosci*. 1999; 53(2):239–241. Available. [PubMed: 10459699]
- Partonen T, Lonnqvist J. Bright light improves vitality and alleviates distress in healthy people. *J Affect Disord*. 2000; 57(1–3):55–61. Available. [PubMed: 10708816]
- Fournier JC, DeRubeis RJ, Hollon SD, Dimidjian S, Amsterdam JD, Shelton RC, Fawcett J. Antidepressant drug effects and depression severity: a patient-level meta-analysis. *JAMA*. 2010; 303(1):47–53. Available from <http://www.ncbi.nlm.nih.gov/pubmed/20051569> 303/1/47 [pii]. 10.1001/jama.2009.1943 [PubMed: 20051569]
- Rochlen AB. Men in (and out of) therapy: central concepts, emerging directions, and remaining challenges. *J Clin Psychol*. 2005; 61(6):627–631. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=15732139. 10.1002/jclp.20098 [PubMed: 15732139]
- Rochlen AB, Whilde MR, Hoyer WD. The Real Men, Real Depression Campaign: Overview, Theoretical Implications, and Research Considerations. *Psychology of Men & Masculinity*. 2005; 6:186–194. Available.

- Hasler BP, Bootzin RR. Couples with divergent diurnal preferences or sleep schedules show reduced affective synchrony and lower relationship satisfaction, although the specific patterns differ for male and female partners. *Sleep*. 2008; 31(Abstract Supplement):A378. Available.
- Watson D, Clark LA, Tellegen A. Development and validation of brief measures of positive and negative affect: the PANAS scales. *J Pers Soc Psychol*. 1988; 54(6):1063–1070. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=3397865. [PubMed: 3397865]
- Ware JE Jr, Sherbourne CD. The MOS 36-item short-form health survey (SF-36). I. Conceptual framework and item selection. *Med Care*. 1992; 30(6):473–483. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=1593914. [PubMed: 1593914]
- Krystal AD, Edinger JD. Measuring sleep quality. *Sleep Med*. 2008; 9(Suppl 1):S10–17. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=18929313 S1389-9457(08)70011-X [pii]. 10.1016/S1389-9457(08)70011-X [PubMed: 18929313]
- Mathur R, Douglas NJ. Frequency of EEG arousals from nocturnal sleep in normal subjects. *Sleep*. 1995; 18(5):330–333. Available. [PubMed: 7676165]
- Smith, LJ.; Nowakowski, S.; Soeffing, JP.; Orff, HJ.; Perlis, M. *Treating Sleep Disorders: Principles and Practice of Behavioral Sleep Medicine*. Hoboken, NJ: Wiley; 2003. The measurement of sleep; p. 29-73.

Figure 1.

Spectrophotometry of the 2 Green Light Masks Used in the Study compared to daytime sunlight. The peaks were at 496.82 nm for Blue/Green Mask 1 and 499.58 nm for Blue/Green mask 2. Red light masks peaked at 655.99 nm. Sunlight was recorded at approximately 1400 hrs with the photometer aimed towards the horizon.

Figure 2. Mean change in excretion of FSH and LH (mIU/hr) in SW-Mask (Bright Blue/Green Light) and DR-Mask (Dim Red Light) Groups.

Table 1
Mean Values for Baseline, End and Difference Scores for SAFTEE, by Light Mask Group.

Variable	Blue/Green Light			Red Light			Comparison	
	Baseline	End	Difference	Baseline	End	Difference	Mann-Whitney U	P
SAFTEE overall score	139.13	140.00	0.87	139.13	131.26	-7.87	67.50	0.061
SAFTEE "head"	7.13	7.00	-0.13	6.60	6.27	-0.33	99.00	0.504
SAFTEE "eye"	8.93	9.33	0.40	9.40	8.60	-0.80	57.00	0.014
SAFTEE "ear"	6.67	6.60	-0.07	6.13	6.07	-0.07	110.50	0.915
SAFTEE "mouth and teeth"	8.53	8.47	-0.07	8.93	8.33	-0.60	80.00	0.148
SAFTEE "nose and throat"	8.93	8.40	-0.53	8.07	7.73	-0.33	99.00	0.535
SAFTEE "chest"	8.27	8.53	0.27	8.53	8.13	-0.40	67.50	0.021
SAFTEE "heart"	4.07	4.07	0.00	4.13	4.00	-0.13	105.00	0.317
SAFTEE "abdomen"	6.40	6.53	0.13	6.47	6.33	-0.13	94.50	0.356
SAFTEE "bowel"	9.00	9.13	0.13	8.93	9.07	0.13	106.00	0.765
SAFTEE "appetite"	9.33	9.53	0.20	10.07	8.73	-1.33	67.50	0.053
SAFTEE "urination"	8.47	8.20	-0.27	8.27	8.07	-0.20	105.00	0.674
SAFTEE "genitals"	8.27	8.60	0.33	8.47	8.27	-0.20	81.00	0.13
SAFTEE "muscle, bone and joint"	5.87	5.87	0.00	6.00	5.33	-0.67	84.00	0.212
SAFTEE "walking and moving"	8.67	8.60	-0.07	8.47	8.20	-0.27	100.50	0.553
SAFTEE "scalp and skin"	6.60	6.60	0.00	6.80	6.27	-0.53	100.00	0.565
SAFTEE "other"	24.00	24.53	0.53	23.87	21.87	-2.00	89.50	0.337

Table 2

Mean Values for Baseline, End and Difference Scores for Mood, Sleep Questionnaire, Sleep Diary, and Actigraphy Variables, by Light Group, with Group Comparisons

Variable	Blue/green Light			Red Light		
	Baseline	Ends	Difference	Baseline	End	Difference
ACTIGRAPHY (TIMING) [Hotelling's Trace (3,14) = 0.492, p = 0.69]						
Time Into Bed	1:05:30	00:30:03	-00:35:26	01:30:20	01:01:44	-00:28:36
Time Out of Bed	09:46:52	09:03:41	-00:43:10	09:01:55	08:48:52	-00:13:04
Sleep Acrophase	05:37:36	05:01:15	-00:36:21	05:28:10	05:00:26	-00:27:44
MOOD [t (29) = -1.46, p=0.16]						
QIDS	4.13	5.00	0.87	4.60	3.33	-1.27
SLEEP DIARY [Hotelling's Trace (4,24) = 2.99, p = .04]						
Diary SL	11.66	10.37	-1.29	12.04	12.14	0.10
Diary WASO	9.26	14.26	5.90	7.96	7.64	-0.32
Diary TST	465.78	416.63	-49.15	438.64	433.82	-4.82
Diary SEFF	95.62%	94.47%	-1.15%	95.68%	95.49%	-0.19%
ACTIGRAPHY (SLEEP) [Hotelling's Trace (5,12) = 1.19, p = 0.37]						
Actigraphic TST	393.19	370.54	-22.65	325.78	348.44	22.66
Actigraphic WASO	128.25	139.98	11.73	117.88	121.46	3.57
Actigraphic SEFF	76.16%	74.08%	-2.08%	73.17%	74.41%	1.24%
Actigraphic NOA	29.75	29.95	0.20	25.10	27.44	2.34
Actigraphic SL	13.56	12.07	-1.49	11.35	10.83	-0.52
SLEEP QUESTIONNAIRES [Hotelling's Trace (3,21) = 1.06, p = 0.39]						
PSQI	5.13	5.47	0.33	5.33	4.60	-0.73
HOMEQ	50.08	49.87	-0.08	46.33	47.69	1.33
ESS	7.20	8.00	0.80	8.67	7.40	-1.27

(SL = sleep latency, WASO = wake after sleep onset, SEFF = sleep efficiency, NOA = number of awakenings, TST = total sleep time)

Table 3

Mean (and SD) excretion of FSH and LH (mIU/hr) for groups exposed to Blue/Green and Dim Red Light

Variable	Blue/Green Light (n=11)			Dim Red Light (n=10)		
	Baseline	Final	Change	Baseline	Final	Change
FSH						
M	0.69	0.87	0.17	1.51	0.70	-0.81
SD	(0.56)	(0.83)	(0.89)	(2.26)	(0.84)	(1.45)
LH						
M	8.41	6.91	-1.50	11.51	5.50	-6.01
SD	(5.58)	(4.27)	(6.51)	(8.19)	(2.78)	(6.44)