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ORIGINAL ARTICLE

The impact of light from computer monitors on melatonin levels in college students

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Abstract

OBJECTIVES: Self-luminous electronic devices emit optical radiation at short wavelengths, close to the peak sensitivity of melatonin suppression. Melatonin suppression resulting from exposure to light at night has been linked to increased risk for diseases. The impact of luminous cathode ray tube (CRT) computer monitors on melatonin suppression was investigated.

DESIGN: Twenty-one participants experienced three test conditions: 1) computer monitor only, 2) computer monitor viewed through goggles providing 40 lux of short-wavelength (blue; peak $\lambda \approx 470$ nm) light at the cornea from light emitting diodes (LEDs), and 3) computer monitor viewed through orange-tinted safety glasses (optical radiation <525 nm ≈ 0). The blue-light goggles were used as a "true-positive" experimental condition to demonstrate protocol effectiveness; the same light treatment had been shown in a previous study to suppress nocturnal melatonin. The orange-tinted glasses served as a "dark" control condition because the short-wavelength radiation necessary for nocturnal melatonin suppression was eliminated. Saliva samples were collected from subjects at 23:00, before starting computer tasks, and again at midnight and 01:00 while performing computer tasks under all three experimental conditions.

RESULTS: Melatonin concentrations after exposure to the blue-light goggle experimental condition were significantly reduced compared to the dark control and to the computer monitor only conditions. Although not statistically significant, the mean melatonin concentration after exposure to the computer monitor only was reduced slightly relative to the dark control condition.

CONCLUSIONS: Additional empirical data should be collected to test the effectiveness of different, brighter and larger screens on melatonin suppression.

INTRODUCTION

Melatonin is a hormone produced by the pineal gland at night and under conditions of darkness in both diurnal and nocturnal species (Arendt 1995). In 1980, Lewy *et al.* were the first to demonstrate that nocturnal light exposure suppressed melatonin (Lewy *et al.* 1980). At the time, it was believed that high levels of white (polychromatic) light (at least 2 500 lux at the cornea) but not low levels (500 lux at the cornea) significantly suppressed melatonin in humans. Subsequent studies performed under controlled laboratory conditions demonstrated that 6.5-hr exposure to 80 lux at the cornea of white light (4 000K fluorescent light source) can significantly suppress melatonin (Zeitzer *et al.* 2000).

In addition to light level, the spectral sensitivity of acute melatonin suppression has also been a subject of extensive investigation. It is now well established that short-wavelength ("blue") light is maximally effective at suppressing melatonin (Brainard *et al.* 2001; Thapan *et al.* 2001; Rea *et al.* 2005). The peak spectral sensitivity of acute melatonin suppression is close to 450 nm (Rea *et al.* 2005). Classical photoreceptors (rods and cones) as well as the intrinsically photosensitive retinal ganglion cells (ipRGCs), a new class of photoreceptor discovered by Berson and colleagues (Berson *et al.* 2002), participate in circadian phototransduction (Hattar *et al.* 2003).

Melatonin has been shown to inhibit cancer (Reiter 2004). Epidemiological studies have shown that rotating shift-workers, who are more likely to suppress their melatonin by light at night, are at higher risks of breast and colorectal cancer (Hansen 2001; Schernhammer *et al.* 2001; Schernhammer *et al.* 2003). Therefore, it has been postulated that light at night, with consequent melatonin suppression, may increase health risks (Stevens *et al.* 2007).

Technology developments have led to bigger and brighter self-luminous electronic devices, such as televisions, computer screens, and cell phones. These new devices are more affordable and are more common in the homes where they would be viewed in the evening and at night. Since these electronic devices tend to have a strong short-wavelength component for good color gamut, they may be effective sources for suppressing nocturnal melatonin or may delay the onset of melatonin in the evening.

Rea and colleagues developed a model of human circadian phototransduction that can be used to calculate the effectiveness of a light stimulus for suppressing nocturnal melatonin (circadian stimulus or CS) (Rea *et al.* 2005). The model utilizes the spectral irradiance distribution of a given light source to calculate circadian illuminance (CL_A) (Rea *et al.* 2010) and a fitted functional relationship between CL_A and empirically measured nocturnal melatonin suppression values for humans from the literature where either monochromatic or polychromatic light source were used as stimuli.

The present study was designed to investigate the impact of self-luminous, commercially available cathode ray tube (CRT) computer monitors on nocturnal melatonin concentrations in saliva. Reflecting *a priori* predictions from the model of human circadian phototransduction (Rea *et al.* 2005), three test conditions were employed: 1) computer monitors only, initially set to deliver 7 lux at the cornea 2) computer monitors at 7 lux viewed through goggles providing 40 lux of short-wavelength (blue; peak $\lambda \approx 470$ nm) light at the cornea from light emitting diodes (LEDs), and 3) computer monitors at 7 lux viewed through orange-tinted safety glasses (optical radiation <525 nm ≈ 0). The orange-tinted glasses served as a "dark" control condition since they removed short-wavelength radiation that maximally stimulates the circadian system while subjects performed their computer tasks. The blue-light goggles served as a "true-positive" experimental condition because, as previously demonstrated, the light delivered by the LEDs would reliably suppress nocturnal melatonin (Figueiro *et al.* 2009). Based upon model predictions (Rea *et al.* 2005) the computer monitors themselves were not expected to suppress nocturnal melatonin at the calibrated corneal illuminance level (i.e., 7 lux). Since, however, luminous monitors will deliver different corneal irradiances depending on the computer application and on the postures of the viewers, seven subjects were selected to wear the Daysimeter (Bierman *et al.* 2005), a photopic and circadian illuminance meter located at eye level, to sample actual light exposures from the computer monitors only over the course of a session. Saliva samples were collected from every participant three times, first at 23:00, before exposure to the test conditions, and then at 00:00 and 01:00 while performing personalized computer applications under the three test conditions.

METHODS

Participants

Twenty-one subjects were recruited into this within-subjects study through e-mail notices, posters, and word-of-mouth. The mean ± standard deviation (STDEV) age of the subjects was 28.0±9.9 years. Eligibility for the study required subjects to be free of any major health problems, such as cardiovascular disease, diabetes, or high blood pressure. They were excluded from the experiment if they were taking over-the-counter melatonin or prescription medication such as blood pressure medicine, antidepressants, sleep medicine, or beta-blockers. They were not excluded from the experiment if they were taking oral contraceptive. Subjects were asked to self report any eye diseases, such as cataract or glaucoma, and color blindness. Potential subjects who stated they had an eye disease were excluded from the study. Potential subjects were also asked to fill out the Munich Chronotype Questionnaire (MCTQ) (Roenneberg *et al.* 2003) to assure they were

not extreme early or extreme late types. This eligibility criterion would help assure that selected subjects would be producing melatonin between 23:00 and 01:00, when data were to be collected. The mean ± STDEV MCTQ score for the selected subjects was 2.5±1.7.

Computer monitors

Nineteen-inch Dell (Trinitron) and Gateway computer monitors were used in the experiment. Before taking any photometric measurements, each computer monitor was energized for 30 minutes. Every monitor was then set to a common, uniform background that provided 7 lux at a 51 cm measurement location, the reference viewing position for the subjects. A Gigahertz-Optik photometer with the sensor located at eye level and oriented toward the computer monitor was used to make the reference illuminance measurements (mean ± STDEV illuminance was 7.1±0.15 lux). Based on model predictions (Rea *et al.* 2005), the computer screens calibrated to deliver 7 lux at the cornea should not suppress nocturnal melatonin. Because subjects were allowed to work on any application they wished during the experiment, it was important to monitor at least some of the actual light exposures subjects experienced during the study. As detailed below, seven subjects experiencing the computer screen only lighting condition wore a Daysimeter to monitor their actual light exposures over the course of one session.

Experimental and control conditions

Three lighting conditions were simultaneously employed in a single test room (9 × 12 ft; 2.7 × 3.7 m) on a given session night. In one experimental condition, subjects viewed computer monitors that had been initially set to deliver 7 lux at the expected plane of their corneas. Although subjects did not physically adjust the CRT screen luminous output, each subject was allowed to perform personalized computer tasks during the experimental session so the actual irradiances at the corneas varied among subjects. In a second experimental condition, subjects again performed personalized computer tasks displayed on the computer monitors initially set at 7 lux, but they always viewed the CRT screen through clear safety goggles that had been modified to deliver a prescribed level of narrowband, short-wavelength light to their corneas. Specifically, subjects in this blue-light goggle condition were exposed to 40 lux (40 μW/cm^2) of short-wavelength (blue; peak λ ≈ 470 nm) light at each cornea from light emitting diodes (LEDs) while performing the personalized computer tasks. Two LEDs were mounted to each of the goggle lenses; one LED was attached above and one was attached below the field of view. To minimize discomfort glare, the LEDs were diffused using polycarbonate translucent tape. Prior to every experiment, the blue-light goggles were calibrated in the laboratory using a spectrometer (Action Research double monochrometer (model 2300i) and Spectra Sense (version 4.3.0)) with an UV-VIS optical fiber ending in a lambertian diffuser. Left and right goggle lens irradiances were measured separately and the voltage from a remote 9V battery was adjusted until the mean corneal illluminance (left and right side) reached 40 lux. The third condition served as a "dark" control. Subjects again performed personalized computer tasks displayed on the computer monitors initially set at 7 lux, but the CRT screens were always viewed through orange-tinted safety glasses. These safety glasses (SAF-T-CURE® Orange UV Filter Glasses) filtered out all optical radiation below approximately 525 nm that could otherwise be effective for suppressing nocturnal melatonin suppression.

The ambient lighting in the room was turned off during every session night and only stray light from the luminous CRT screens illuminated the room. No measurable stray light from the blue-light goggles reached other subjects because those subjects wearing the goggles were facing away from those subjects who were in the other two lighting conditions.

Daysimeter measurements

To estimate the light exposures subjects were actually experiencing while performing the computer tasks without the blue-light goggles or the orange glasses, seven subjects, selected at random, wore a Daysimeter during one of the night sessions. The Daysimeter is a personal circadian and photopic light exposure meter. The version of the Daysimeter worn by these subjects employed two photosensors separately calibrated to provide a photopic (visual) and a short-wavelength ("blue") response to optical radiation. The two sensors were juxtaposed at the end of a printed circuit board. This created a compact, in-line package that rested on the side of the subject's head and placed the sensors close to the same plane as the corneas. The photopic sensor measures illuminance in lux. The "blue" light sensor has peak sensitivity at short wavelengths, near the peak of the spectral sensitivity of the human circadian system. Data were stored in a flash memory drive, which was then downloaded to a computer for processing. CL_A levels were determined using post-processing software of the data obtained from the Daysimeter's two calibrated light measurement channels. The mean CS levels to which people were exposed during the session were determined from the CL_A. Values of CS are numerically equal to the amount of expected melatonin suppression from the CL_A exposures according to the model by Rea and colleagues(Rea *et al.* 2005). For these calculations, pupil area was estimated using measurements obtained with one subset who viewed the same monitor screen display (calibrated to deliver 7 lux at the cornea when using the blue background) at two screen conditions: colored background and white background; the mean pupil area obtained from these measurements was used in the CS calculations.

Protocol

Every subject participated in the experiment on three different nights, one week apart. Since only 12 subjects could be accommodated in the test room at a time, subjects were assigned to two groups, one group of 12 subjects and one group of nine. All subjects were asked to maintain regular sleep schedules for the week prior to each session, waking no later than 07:30 and going to bed no later than 23:00. In order to verify compliance, subjects were asked to keep sleep logs during the three weeks of the experiment, wear an actigraph that was downloaded weekly, and call into the lab every day at 7:30 and 8:30 am. Subjects were also asked to refrain from napping and using products containing caffeine (coffee, tea, chocolate, or soda) starting at 10:00 on the day of the experiment. All subjects followed the protocol.

During the first session, subjects in both groups were randomly assigned to one of three sub-groups to counterbalance the three test conditions across session nights. During a given session night, subjects from all three sub-groups were intermixed. At the end of the third night of the experiment, all subjects had experienced every test condition.

The subjects arrived each night of the experiment at 22:30 and remained in dim red light (less than 2 lux at the cornea from an LED traffic signal light, λ_{max} = 630 nm) until 23:00. At 23:00, the first saliva sample was collected while subjects were still in the dim red light. Saliva samples were collected using the salivette system (ALPCO Diagnostics, Salem, NH, USA). To provide a saliva sample for assessment of melatonin concentration, the subject removed a self-contained plain cotton cylinder from the plastic test-tube, moved the cotton around in the mouths until saturated with saliva, and returned the saturated cotton cylinder to the plastic test-tube. The experimenter collected the test-tube and then spun it in a centrifuge for 5 minutes at 1 000 g to remove the saliva impregnated in the cotton cylinder. The cotton cylinder was discarded and the saliva sample was immediately frozen (–20 °C). Later the frozen sample was sent to a laboratory (Pharmasan Labs, Osceola, WI) for melatonin radioimmunoassay. The sensitivity of the saliva sample assay was reported to be 0.7 pg/ml and the intra- and inter-assay coefficients of variability (CVs) were 12.1% and 13.2%, respectively.

After providing the first set of saliva samples all subjects moved to an adjacent room and sat in front of a functional, luminous computer monitor until 01:00. During this time, subjects were free to work on the computer (e.g., word processing) or use the Internet. Two additional saliva samples were collected while subjects were sitting in front of the luminous computer monitors, one at 00:00 and another at 01:00.

Data Analyses

In order to reduce individual variability, a normalization factor was determined for each subject based upon the ratio of that subject's mean saliva melatonin concentration to the grand mean saliva melatonin concentration. The melatonin concentrations from one subject did not appear reliable, so this subject's data were removed from the analyses.

Based upon the data from 20 subjects, a 3 × 2 factor (one control and two experimental conditions at two sample times) analysis of variance (ANOVA) was performed using the normalized melatonin *concentrations*. The concentrations at 23:00 were not included in the analyses. Determined too were the values of nocturnal melatonin suppression by the computer monitor only and by the computer monitor plus blue-light goggles at 00:00 and at 01:00, relative to the "dark" control (i.e., the computer monitor plus orange glasses lighting condition). A 2 × 2 factor (two experimental conditions at two sample times) ANOVA was performed using the calculated melatonin *suppressions*. Where appropriate, post-hoc two-tailed paired Student's t-tests were also performed.

RESULTS

In terms of the normalized melatonin concentrations, the main effect of test condition ($F_{2,38}$ = 6.5; p=0.004) reached statistical significance, whereas the main effect of time ($F_{1,19}$ = 2.1; p=0.16) and the test condition by time interaction ($F_{2,38}$ = 1.6; p=0.21) did not. The mean

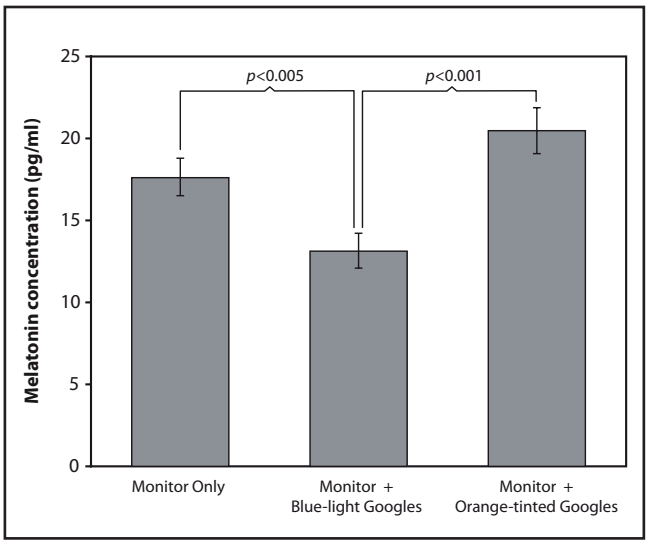

Fig. 1. Mean ± S.E.M. of the combined normalized melatonin concentrations (pg/ml) at 00:00 and at 01:00 for all three lighting conditions. Significantly lower melatonin concentrations were obtained for the computer monitor plus blue-light goggles condition than obtained for the other two lighting conditions. Although overall melatonin concentrations were lower after exposure to computer screen alone compared to computer monitor plus orange-tinted glasses, these differences were not statistically significant.

± standard error of the mean (S.E.M.) of the melatonin concentrations (pg/ml) was 13.14 ± 1.06, 17.65 ± 1.16 and 20.5 ± 1.41 for the blue-light goggles, computer monitor and orange-tinted glasses lighting conditions respectively. The results of the Student's t-test showed that the computer monitor plus blue-light goggles condition was associated with significantly lower melatonin concentrations than those for the computer monitor only condition (p=0.002) and for the computer monitor plus orange-tinted glasses, control condition (p<0.001). There was no significant difference (p>0.05) between the melatonin concentrations for the computer monitor plus orange-tinted glasses and those for the computer monitor only lighting conditions. Figure 1 illustrates these statistical comparisons.

In terms of melatonin suppression, the ANOVA revealed a significant main effect of lighting condition ($F_{1,19}$ = 4.4; p=0.049). There was no significant main effect of time ($F_{1,19}$ = 1.16, p=0.304) nor a significant interaction ($F_{1,19}$ = 1.52; p=0.233). The mean ± standard deviation (STDEV) suppression after exposure to light from computer screens (calculated with respect to the melatonin concentrations during exposure to the orange-tinted glasses control condition) was –6% ± 85% and the mean ± STDEV suppression after exposure to the blue-light goggles was 23% ± 46%. Because the variance was so high, as demonstrated by the large STDEV values, the median suppressions were also calculated; median suppression levels were 11% for the computer screen only experimental condition and 30% for the blue-light goggles experimental condition.

Daysimeter data from the subset of seven subjects who wore the devices while exposed to computer screen alone lighting condition were analyzed. The mean ± STDEV photopic light levels was 28 ± 12 lux (median = 33 lux) and the mean ± STDEV predicted suppression from the CS values obtained with the Daysimeter was 19% ± 8% (median = 20%). The actual mean ± STDEV melatonin suppression for these 7 subjects was 16% ± 31% and the median suppression was 23%. Although slightly higher suppression was obtained from this subset of subjects than for the entire set of subjects, the suppression values for the subset are in good agreement with the CS values actually measured for these subjects.

DISCUSSION

In general, the results converge to indicate that a two-hour exposure to light from CRT monitors like those used in the present study, delivering approximately 30 lux at the cornea (from the Daysimeter measurements), will result in measurably small, but not statistically significant, melatonin suppression. Figueiro *et al.* (2006) proposed that a working threshold dose of light for melatonin suppression was 30 lux of an incandescent light at the cornea for a 30-minute exposure. A white light source with more short-wavelength content than an incandescent light source, such as daylight or a computer screen monitor emitting short-wavelength, would result in nearly 20% suppression, which is close to the suppression levels obtained in this study. Their proposed threshold of 30 lux for 30 minutes (pupil size = 2.3 mm) was based on calculations using the model by Rea and colleagues(Rea *et al.* 2005) and that estimate appears valid as a working threshold based upon the present data.

A novel piece of information presented here was obtained from the Daysimeter measurements (Bierman *et al.* 2005). Although the computer screens were calibrated to deliver a set amount of light at the subjects' corneas, the actual exposures experienced by the subjects were different. The calibrated levels probably would not have suppressed melatonin, but as shown by the Daysimeter measurements, the subset of subjects was actually exposed to higher levels of light than the calibrated amounts. The present study underscores the importance of measuring the light stimulus while collecting melatonin suppression data, especially when experiments, such as the one employed here, are designed to mimic real-life situations. In other words, a set calibrated lighting condition does not necessarily represent actual light exposures.

The present results have practical significance because they show that these dimmed CRT screens are slightly above threshold for nocturnal melatonin suppression. It is obviously important to emphasize that the results presented here are from only one type of computer monitor. Additional empirical data should be collected to test the effectiveness of different, brighter and larger screens on melatonin suppression. The health consequences of regular exposure to luminous devices that cause some level of melatonin suppression at night are not known. Until more empirical data are available, it is probably prudent to dim large and bright computer screens (above 30 lux at the cornea for 30 minutes) during the evening hours, or even consider placing an orange-tilted filter in front of them while working for long periods of times in the evening.

Finally, it should be noted that even if melatonin suppression is avoided, there is no guarantee that the use of electronic devices before sleeping will not interfere with people's ability to fall asleep; the computer or gaming tasks themselves may be alerting or stressful stimuli that can lead to sleep disruption.

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