

Red light at night to enhance cognitive functioning for society's special needs groups

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ABSTRACT: While human life expectancy may be increasing due to advances in public health, technology and medicine, there are serious questions as to whether the quality of human life can keep up with this increase in longevity. Postindustrial society is experiencing a proliferation of light-related disorders and diseases specifically because our technologically-based society can operate 24 hours per day in illuminated indoor environments. Natural changes in daylight synchronize and help coordinate the body's circadian rhythms, which determine sleeping and eating patterns, brain wave activity and hormone production. Disturbing circadian rhythms by changing the 24-hour light/dark cycle can lead to jetlag, seasonal affective disorder (SAD), delayed sleep phase syndrome (DSPS), and other abnormalities, and is implicated in various diseases and disorders, including cancer. These effects are particularly pronounced with special needs populations whose physiological systems are already under more pronounced stresses such as children with autism spectrum disorder, older adults with dementia and homeless individuals.

1 INTRODUCTION

In June 2012 at their annual meeting in Chicago, the House of Delegates (HOD) of the American Medical Association (AMA) declared that light at night results in adverse health outcomes (Blask 2012). The Council on Science and Public Health recommended that the AMA support the need for developing and implementing light technologies at home and at work that minimize circadian disruption, while maintaining visual efficiency. Adverse light effects can be minimized by using natural daylight or daylight-matching electric light during the day and a new HOD policy recommends dim red lighting in the nighttime indoor environment.

Research has shown that individuals working in natural sunlight are more productive, more effective, and happier than those who work under traditional artificial light (Perrin 2004). Natural changes in daylight synchronize and help coordinate the body's circadian rhythms, which influence every biochemical, physiological and behavioral parameter in the human body. Disruption of circadian rhythms can lead to jetlag, seasonal affective disorder (SAD), delayed sleep phase syndrome (DSPS), and other abnormalities, and is implicated in various diseases and disorders, including cardiovascular disease, psychiatric disorders and cancer (McEachron 2012). Furthermore, the Council on Science and Public Health recognizes that exposure to excessive light at

night, including extended use of various electronic media, can disrupt sleep or exacerbate sleep disorders (Blask 2012).

The dLUX light lab at Drexel University has developed an LED lighting system that auto-tunes natural daylighting in its full diurnal changing color spectrum and light intensity during the day and changes to dim red lighting during the nighttime hours. This 24/7 LED luminaire mimics the full spectrum of natural daylight in both color temperature and light intensity. Through a combination of white and RGB (red, green, blue) LEDs the lighting system is programmed to change color throughout the day to mimic the full spectrum of natural daylight from dawn to dusk; to change in color from the amber rising sun to the red setting sun and to illuminate the indoor environment with a low-intensity red light throughout the nighttime hours.

This integrated 24-hour 7-day daylight-mimicking LED lighting system was installed in the 25-men dormitory at St. Columba Safe Haven for Homeless Men and evaluated in three phases: Phase I LED downlights as usual; Phase II LED downlights in the daytime (6am-9pm), red downlights at night (9pm-6am); Phase III gradual onset/offset daylight LED downlights in the daytime, red downlights at night. Resident data was collected for all three phases using a Demographic Form and the standard research instruments PANAS (Positive And Negative Affect Schedule) Scale and WEMWBS (The

Warwick-Edinburgh Mental Well-being Scale). Additionally, staff performed a dormitory check every hour of the day to determine if the residents were awake, sleeping, or out of the dorm. The six months of staff observations of 24-hour day bed-checks of the 25 person dormitory were used to evaluate the effects of the light.

2 EVOLUTIONARY CHANGES

2.1 Introduction

Human beings are the result of biological evolution rather than engineering design. It is impossible to overstate the implications of this rather simple sentence on human health, well-being and productivity. This is because of the existence of two vastly different rates of change – cultural and biological evolution. As the rate of cultural evolution continues to accelerate, there is evidence of a growing disconnect between the artificial environments humans create and the environments to which our ancestors were adapted. Despite the incredible adaptability of human beings, there are limitations and these limitations may now be beginning to impact the interaction of humans with the artificial structures they create. How we deal with this impact will determine the quality of life for millions of our fellow citizens.

2.2 Background

The process of biological evolution is primarily dependent on the twin mechanisms of random mutation and natural selection. This has rather profound implications for the interaction of humans with their environments – natural or artificial. First, evolution proceeds by way of increasing and decreasing gene frequencies over generations, irrespective of how these changes are produced. Thus, it is possible – and often observed – that the welfare of individual organisms is sacrificed in order to promote gene propagation. As a result, evolutionarily determined physiology and behavior may or may not promote the welfare of the individual processing those traits. Second, random mutation does not necessarily create the best adaptations even when those adaptations would benefit gene propagation. The adaptations observed in individuals may or may not fit with the expectations of a design engineer. Third, organisms are always best adapted to their ancestors' environment. It is the ancestors who succeeded in propagating their genes over, not the current representatives. Although rapid evolution is possible, significant change is generally dependent upon generation time and organisms with relatively long generation times – such as humans – take longer to adapt to new conditions, at least biologically. Fourth, emotions are

part of evolution and thus likely to be one method by which genes promote behaviors that result in their own propagation.

These factors generate a variety of compromises between *adaptation* – the evolution of a relatively fixed set of physiological parameters – and *adaptability* – the ability to adjust to a diverse set of environmental conditions. In predicting which strategy is likely to be favored, several factors must be considered: stability of the environment, impact of the specific environmental factor, advantage of prediction, etc. One major physiological adaptation which has evolved due to the extreme stability and impact of an environmental factor (the Earth's rotation creating day and night) is circadian rhythmicity. It is such a powerful physiological adaptation that all eukaryotic organisms on the Earth have evolved one or more circadian clocks to provide organization and scheduling of every biochemical activity, physiological and behavioral activity. It is, as the phrase goes, 'in our very DNA'.

Why is this important? It is important because humans have inherited a circadian organization from our ancestors that organizes virtually every aspect of our physiology. It is important because physiological control systems in humans – from the cardiac cycle to metabolism to brain management – all have rhythmic components whose activities are regulated by these circadian clocks. It is important because biological rhythms are so fundamental to living organisms that humans cannot eliminate those influences on health and well-being. And finally, it is important because human ingenuity has generated lighting, structures and schedules antithetical to good temporal hygiene with well-documented negative impacts on human health.

3 THE CIRCADIAN SYSTEM

3.1 What are circadian rhythms?

There are a multiple of biological rhythms in the human body, ranging from the millisecond rhythms in neural networks to the near second cycles of the heart, 20 minute glycolytic cycles, hourly pulsatile rhythms in hormone secretion through seasonal cycles in conceptions, births and psychiatric episodes. Playing a central role, both in terms of frequency and in terms of impact, are the so-called circadian rhythms. Circadian (Latin for 'about a day') rhythms are endogenous or self-generating oscillations that organize human physiology and behavior and, until recently, scheduled those activities into a temporal ecological niche. Although there are many tissues and cells that express circadian rhythms within the human body, the overall control of the circadian system lies in a small bilaterally symmetrical pair of

cell groups (called nuclei; sing. nucleus) located in an area of the human brain called the hypothalamus. This overarching circadian clock or pacemaker is found in the suprachiasmatic nuclei or SCN for short.

Like all circadian pacemakers, the SCN express oscillations with a frequency near but not exactly 24 hours. In the absence of any environmental cycles (called *constant conditions*), this endogenous oscillator is free to express its own inherent frequency, which, in humans, is about 24.5 hours. This frequency is called the *free-running frequency* and implies mechanisms that allow the internal period of the circadian clock to be adjusted so as to match the period of the day/night cycle. This ability to synchronize to an external environmental cycle is called entrainment and those environmental cycles capable of generating entrainment are called *Zeitgebers* (Ger. 'time-giver'). The most powerful of the known *Zeitgebers* is the alternating cycle of light and darkness produced by the Earth's rotation. Although there have always been other sources of light (fires, moonlight, etc.), until recently, the most powerful and consistent source of lighting input to the eye has been solar radiation.

The mechanism of entrainment to light/dark cycles is complex and need not concern us here. What is important is the observation that the lighting needed to see objects (called photopic vision) and the lighting used to entrain the SCN do not have exactly the same spectrum. The lighting which generates the highest impact on the SCN is shifted towards the blue-green end of the visual spectrum and is centered around 450 nm. Interestingly, light at the dark amber-red range of the spectrum still impacts photopic vision but is thought to have little or no effect in terms of entrainment or other effects on the SCN and thus, the overall circadian system (McEachron 2012).

3.2 *What has the circadian system evolved to expect from the external environment?*

During the solar day-night cycle, light intensity increases gradually (sunrise), then displays a powerful, sustained intensity (daylight) followed by a gradual decrease (sunset) and then a prolonged period of profound darkness (night). Combined with these intensity effects, there are also changes in wavelength, beginning and ending with red-yellow wavelengths bracketing periods of blue-white light and near blackness. Considering illuminance alone, the darkness provided by a moonless overcast night might provide only some 10^{-4} lux of lighting, while full daylight reaches 10,000-25,000 lux and direct sunlight provides 32,000-130,000 lux (http://stjarnhimlen.se/comp/_radfaq.html Hoffman 2006). The actual lighting changes in both intensity and wavelength will depend on the location of the

observer on the Earth's surface, the ecology (ex., forest cover vs. open grassland) and other variables, but clearly biological systems have evolved in environments which can provide gradual illuminance changes covering 6-9 orders of magnitude.

This evolutionary expectation has shaped the manner in which circadian systems entrain to the external environment. For example, circadian systems are typically more sensitive and react with greater levels of change when exposed to light during periods which would normally be dark than during similar times during daylight. In addition, for both evolutionary and mathematical reasons, gradually changing light/dark cycles are far more powerful *Zeitgebers* than square waves (simply turning lights on and off at regular intervals) (McEachron 2012).

3.3 *To what is the system actually exposed in modern urban environments?*

If circadian systems have evolved to expect and adapt to gradually changing lighting with varying wavelengths and intensity changes covering multiple orders of magnitude, what do human clocks actually encounter in modern urban environments?

If we focus on a well-studied environment – residential facilities for the elderly – the results are disturbing. In one study, it was reported that nursing home residents only experienced an average of 9 minutes of light over 1000 lux per 24-hour day (Ancoi-Israel 1997). In another study, sixty-six institutionalized elderly were observed over a three-day period. The average lighting exposure was only 54 lux with merely 10.5 minutes of exposure over 1000 lux (Shochat 2000). In another review of 53 nursing homes, illumination was considered scarcely adequate or insufficient in 45% of the hallways, 17% of the activity areas and 51% of the residents' rooms (Berson 2002). Thus, it is not surprising that sleep problems and disorders are often reported for nursing home residents, even when such problems were not reported prior to admittance (Clapin-French 1986, Regestein 1987).

This is not an issue isolated to such facilities. In a study on undergraduate students, Baynard and McEachron (2011) reported that students at an urban university suffered from significant sleep loss. Many undergraduates live in dormitories ill-suited for stable entrainment and adequate sleep. Shared dormitory rooms often do not isolate light and sound effects between roommates, leading to inadvertent light exposure at night. Most such accommodations require students to walk down brightly lit hallways to get to the bathroom facilities, again leading to significant light exposure if activities are undertaken at night. Additionally, the ability to block out light from the external environment is often limited, making darkness difficult to achieve even under the best of circumstances. Studies indicate that sleep deprivation

in this population is associated with poor academic performance (Lee 2015). These issues are also being noticed in hospital environments as well (Pilkington 2013), and so the questions of appropriate design for circadian stability and temporal hygiene are becoming more persuasive for architecture and architects.

3.4 *What are the consequences of circadian disruption?*

Shift work, which often results in such disruption, was reviewed in McEachron (2012). The majority of studies report negative effects associated with shift work. These effects can be broadly classified as behavioral problems, abnormal or disrupted sleep (Akerstadt 1981; Foret 1976, Knuttson 2003), reproductive issues (Fido 2008, Su 2008), gastrointestinal complaints (Caruso 2004, Pietroiusti 2008), metabolic abnormalities (Ghiasvand 2006), increased risk for cardiovascular disorders (Suwazono 2008; Tuchsén 2008) and an enhanced susceptibility for certain cancers (Davis 2006, Hansen 2006, Schernhammer 2003). The behavioral problems range from decrements in performance (Boivin 2007, Harrington 1994) to depressed mood (Healey 1993) to increases in neuropsychological problems (Costa 1981, Koller 1981). Numerous reviews have been published linking shift work with various health problems (Boivin 2007, Harrington 1994, Haus 2006).

Human studies tend to be correlational in nature and thus cannot be used to establish causality – shift work may simply be correlated with the observed results and not causal to them. Thus, it is critical to the contention that architectural designs be modified to include temporal hygiene because of the numerous animal studies that have been done which do establish causal links between circadian disruption and gastrointestinal disorders (Larson, et al. 1994; Press, et al., 2008), cardiovascular disease (Penev 1998, Roenneberg 2005), and cancer (Filipski 2003, 2004, 2005, 2006, van der Heiligenberg 1999).

3.5 *What can be done?*

Thus, disturbed or desynchronized biological rhythms carry serious consequences. It is estimated that between fifty and seventy million people in the U.S. suffer from some kind of sleep disorder or disturbance (Report from National Academy of Science). While artificial environments are often designed with multiple windows or specific “sunrooms” for institutionalized residents, it is not always possible to bring daylight to building interiors in general, leading to inadequate daytime levels of lighting. This situation can be exacerbated due to institutional lighting levels that not only do not provide residents with the biologically required full spectrum of light throughout the day, but also do not

provide total darkness at night—difficult to do when caregivers need to work throughout the night monitoring patient health and safety, as well as fulfilling administrative tasks. As a result, lighting may be too dim in the daytime and too bright at night to generate an effective timing signal for human biological rhythms, which rely on both the amplitude and waveform of the day/night differences in lighting to convey time-of-day information to the brain.

4 LIGHTING FOR A CHANGING SOCIETY

To maintain health and save energy it is important to either use or mimic *the full spectrum of natural lighting* applied with the proper amplitude, wavelength and waveform to foster circadian entrainment and temporal hygiene. This is not merely a matter of altering existing lighting but also of designing new facilities with the need for rhythm coherence in mind. Humans are not computers and do not operate in the same manner 24/7. They are the result of evolution and carry that legacy with them. In regards to time of day, buildings should adapt to the temporal requirements of their occupants to ensure the best outcomes in terms of health and quality of life.

In the meantime, what can be done with existing structures? In an attempt to find out, the study team investigated the use of nocturnal red lighting and gradually shifting solar-day mimicking LED lighting in a residential facility for homeless men.

5 RED LIGHT AT NIGHT

5.1 *Rethinking privacy for dwelling in public*

The residential program at St. Columba offers residents service coordination, personal recovery services, health care, education, and social enterprise and employment opportunities. Residents are encouraged to participate in recovery-oriented activities that lead to personal growth, well-being and self-sufficiency with a focus on moving to permanent housing. Forty homeless men live at St. Columba accommodated in a 25-bed dormitory on the first floor and fifteen single rooms on the third floor. This residential program is housed in two Philadelphia twin homes, which were joined in the 1980’s to create one united residence for homeless men. The 1980’s redesign was labyrinthical, with no views to the exterior from the community spaces and no landmarks to guide the resident through the network of spaces.

BAU Architecture was retained to redesign the interior. The first floor toilet and shower facilities were dangerous: there was only one way in and out of each of the two rooms and there was no privacy

for the private functions intended to occur there (Fig 1). While the design was compact, it was also very dangerous and the men were afraid to use the facilities. The bathroom was redesigned to provide for safety and security through exposure. While private functions could remain private and protected, there is now ease of visibility into the bathroom and within the room without increasing the square footage (Fig 2). The rest of the three-story facility was redesigned to allow views into the community spaces and views from those spaces to the exterior, which opened up the interior to provide orientation and visual landmarks while moving throughout the facility. The overall goal of the redesigned interior environment was to support the residents' transitioning to become members of the broader society.

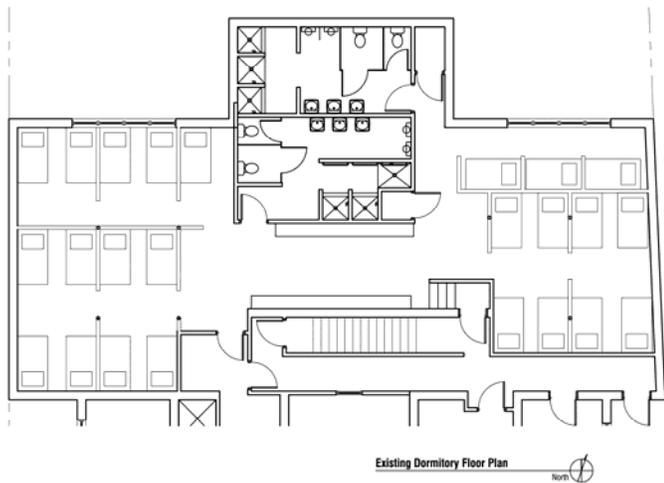


Figure 1. Existing first floor 25-Bed St. Columba dormitory. (By author).

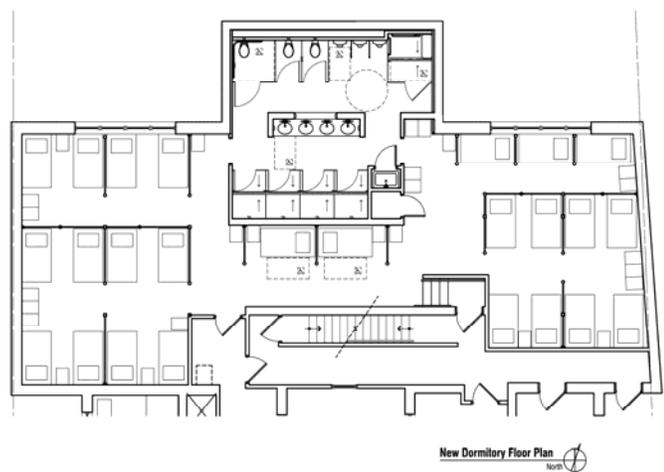


Figure 2. New first floor 25-Bed St. Columba dormitory. (By author).

5.2 A Pilot Project at a Residential Facility for Homeless Men

At the St. Columba safe haven residence for homeless men Drexel University's dLUX light lab has partnered with Project H.O.M.E. to install its solar-day mimicking LED lighting system in their 25-bed dormitory. Research has shown that LED Solid State Lighting is more energy-efficient and longer lasting with lower lifecycle costs than other light sources and that natural daylight controls the body's circadian rhythms and affects overall wellbeing. dLUX is installing a fully programmed, automatic integrated LED lighting system in the 25-bed dormitory that simulates the optimal color and intensity of natural daylight throughout the day to regulate the men's circadian rhythms (Fig 3). In lieu of complete darkness at night, the gradual onset and offset lighting dims to the red spectrum to provide light at night for general mobility and so staff can monitor the residents' wellbeing. Automatically controlled blackout shades were installed over the dormitory windows: the shades go down at 9pm and up at 6am. The goal is to prevent disrupted sleep patterns and the negative behaviors associated with sleep deprivation and to promote the residents' overall health and wellbeing.

The individuals in this study were otherwise homeless men living at St. Columba Safe Haven for Men in Philadelphia, PA. These individuals were able to come and go as they pleased but were encouraged to participate in various programs designed to promote self-sufficiency. The question can be then asked: if these individuals are exposed to environmental lighting outside of the residence, how efficacious will the solar-day mimicking lighting be for them?

The effects of lighting on circadian clocks are not uniform across twenty-four hours and there is both experimental data and a theoretical basis for the concept that a gradual onset and offset of lighting with diminished red light at night will provide a substantially more powerful synchronizing signal for circadian rhythms than current artificial lighting in the facility (McEachron, 2012). Thus, despite the residents' mobility during the daylight hours, the dawn- and dusk-simulation, combined with dim red lights at night, should provide a powerful stimulus for temporal hygiene. This was the purpose of the study – to determine if lighting cycles of this kind can have beneficial effects on residents' wellbeing and sleep.

5.3 Study protocol

The original study consisted of three phases:

5.3.1 Phase 1: Baseline

After the Institutional Review Board (IRB) at Drexel University approved the study protocol, residents who consented to be in the study completed a demographic form and two questionnaires (PANAS: Positive and Negative Affects Scale; and WEMWBS: Warwick-Edinburgh Mental Well-being Scale) at baseline.

5.3.2 Phase 2: Red light conditions

For three weeks, residents were then exposed to standard lighting during the daytime mimicking current conditions with LED lighting, but lighting at night was provided using dim red lights as shown in Fig 3. At the end of three weeks, residents who consented to be in the study completed the two questionnaires (PANAS and WEMWBS) to determine the impact of the red light conditions on residents' well-being.

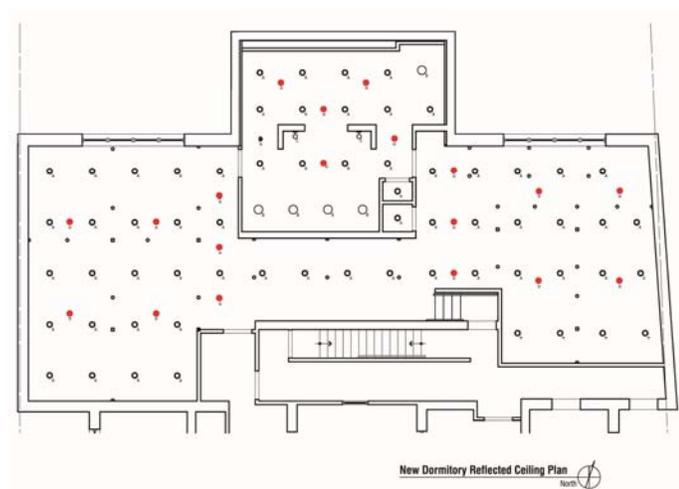


Figure 3. New lighting for 25-Bed St. Columba dormitory. (By author).

5.3.3 Phase 3: Solar day mimicking and red light conditions

Immediately after data were collected in phase 2, for the following three weeks, residents were exposed to a time-varying lighting system with intensity and wavelength variations mimicking the solar-day cycle. This was combined with red lighting at night at all the downlight locations shown in Fig 3. At 6am the lights gradually shift in color and intensity from dim red light at night to a bright 6500K daylight at 9am. The downlights remain at the daylight-corrected color and intensity until 6pm at night when they gradually dim to red at 9pm. Residents who consented to be in the study completed the demographic form and two questionnaires (PANAS and WEMWBS).

5.3.4 Initial results

Fourteen residents signed the consent form to participate in the study. Seventy-seven percent were African Americans and 23 % were Caucasians. The mean age was 51 years (SD=13.8). The mean number of years in formal education was 13 (SD=3.28). The majority were single, and 15% were married. The following challenges were encountered during the implementation of the study: attrition rate was high because participants were transient residents, lack of participant's compliance to complete the questionnaires, and technical difficulties in installation of the lighting system causing a delay in starting the study, and damage to the automatic blinds. Because of the residents' lack of adherence to complete questionnaires on Phases two and three, the research team used the staffs' documentation on residents' sleep on Phase 3, when residents were exposed to a time-varying lighting system with intensity and wave length variations mimicking the solar-day cycle to assess the residents' response to the changes in lighting.

Although a complete analysis of the staff data is still in progress, based upon staff and resident comments, red night lighting seemed to have a calming effect in the environment and improved residents' sleep. Residents indicated that they appreciated having the red lights at night. The research team plans to conduct a feasibility study and replicate the research protocol in the future to assess the effectiveness of the changes in lighting on sleep and quality of life.

6 CONCLUSION

Temporal hygiene is both an old and a new problem. It is an old problem insofar as circadian rhythms and the ability to synchronize physiological and behavioral rhythms with the solar day/night cycle is one of the oldest adaptations which evolved on Earth. It is a new problem that has arisen due to the artificial structures and indoor lighting human engineering has created, which has isolated people from the temporal ecology of the external environment. It will be up to the next generation of architects and designers to determine the best designs to retain the advantages of our artificial environments while simultaneously promoting the temporal hygiene necessary to fully enjoy the advantages brought by the new technologies we develop.

7 ACKNOWLEDGMENTS

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