CIRCADIAN® White Paper

COMBATING THE DARK SIDE OF LIGHT AT NIGHT

Performance and safety benefits of filtering out 460-480nm blue light

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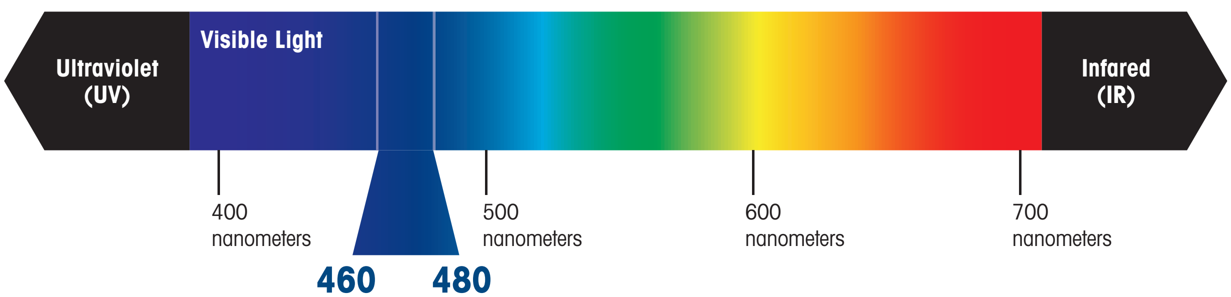
Lighting the workplace at night used to be straightforward: Provide light adequate to the job, while avoiding glare and eyestrain. Of course color temperature and color fidelity are also important for some work environments, and recent advances in lighting technology have introduced the issue of cost efficiency (lumens per watt) and capital expense into the lighting equation.

In the last ten years, however, light exposure at night has also become an important health issue, based on recent progress in understanding how the human biological clock is affected by night work. Night shift work has been linked to a number of adverse health outcomes ranging from accidents on the job, to heightened risk of heart disease and cancer. And it now appears that much of this cost to the night shift worker derives directly from the complex biological effects of exposure to light at night, at a time when human physiology is optimized for darkness. Addressing this risk to night shift work seems a daunting challenge: How is it possible to perform work at night without light?

Figure 1:
The harmful effects of exposure to white light at night can be prevented by filtering out the blue light falling in a narrow 460-480nm slice of the visual spectrum



A solution to this dilemma comes with newly published research from Professor Robert Casper's laboratory at the University of Toronto[1]. Professor Casper and his colleagues have demonstrated that the disruption caused by light at night is actually the effect of a narrow segment of the visual spectrum. These studies have shown that filtering out this narrow band of blue wavelengths in the 460-480nm range significantly prevents the biological disruptions caused by light at night, and improves the safety and performance of people working at night. This CIRCADIAN white paper summarizes the science behind the recent work reported by Professor Casper and colleagues, and looks forward to the practical implications of this work in the shift work environment.

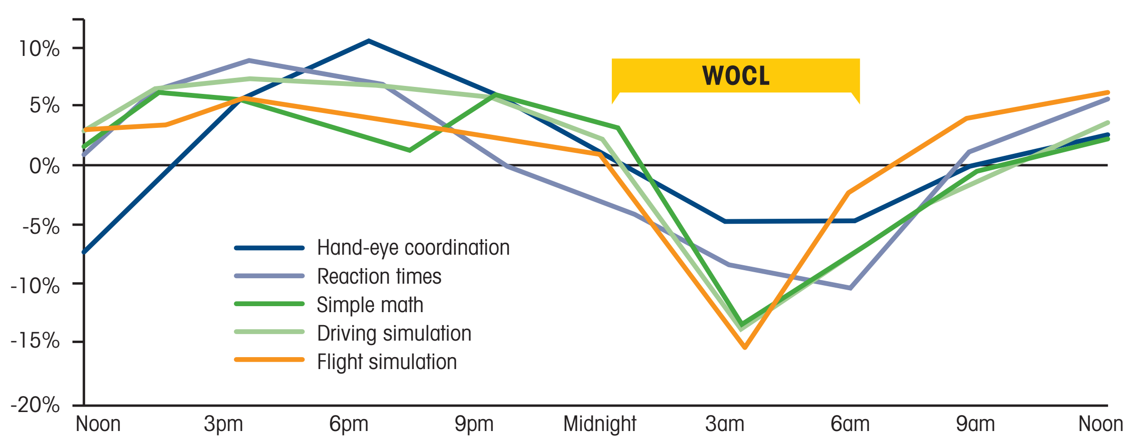
BACKGROUND

The challenge of shift work

For the first few million years of human existence, the cycle of day and night dominated our behavior. Our only exposure to light at night came from the dim illumination of the moon and stars, smoky campfires, and oil lamps. But when Thomas Edison commercialized electric light in 1890, his invention quickly found its way to the work place, where soon global workforces were being exposed to bright light at night for the first time. As the industrial economy took advantage by running business operations 24/7, an increasing fraction of employees became night workers, awake throughout the night, and losing the natural health and safety benefits of sleeping in the dark. Now, 17% of the US workforce, or approximately 26.5 million people, work between the hours of 6PM and 6 AM[2]. In Canada 2.3 million employees now work fixed night or rotating shifts,[3] and worldwide at least 100 million people work on overnight shifts.

As increasing numbers of people began working at night it soon became clear that night work comes at a cost. The rate of errors, accidents and injuries peaks during the night shift and were often several times greater than that seen during the day shift. For example, the rate of trucking accidents,[4] medication errors by nurses,[5] and industrial accidents leading to workers compensation claims[6] peaks several fold higher in the early hours of the morning (after correcting for the number of people at work at that time of day).

Figure 2:
The percent deterioration in various types of human performance that occurs during the Window of Circadian Low.



The reduction in performance by night workers appears to be due to more than one biological factor. First, all human physiology is timed by an internal biological clock, the circadian pacemaker, located near the optic nerves in the front part of the brain. The natural periodicity imposed by this clock creates a trough during the early morning hours when human performance shows a natural minimum. As Figure 2 illustrates, this is the greatest time of risk for shiftworkers, and is known as the Window of Circadian Low (WOCL). Many aspects of human performance including hand-eye coordination, reaction times and ability to do simple mathematical calculations deteriorate between the hours of midnight and 6 AM, and similar trends are found in more complex tasks such as driving a vehicle or flying a plane in a simulator.

Numerous research studies have demonstrated that substantial impairments in mood, anger and energy levels also occur in night workers during the WOCL, as compared to daytime levels. Hence this is a time of heightened risk for night shift workers.

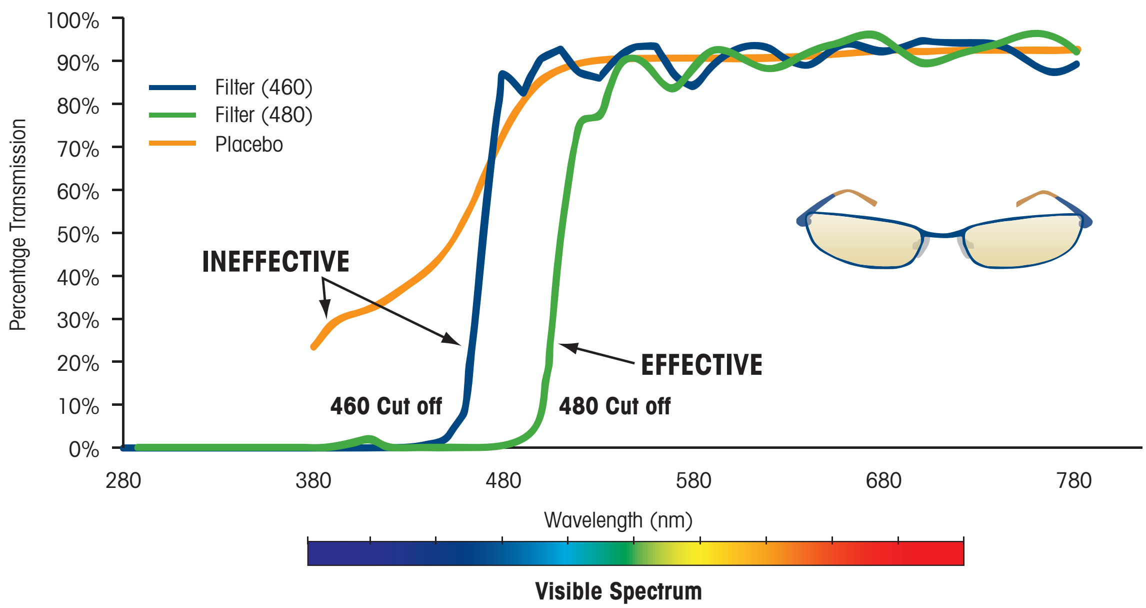
The role of light

The second major factor limiting human performance at night appears to be a direct effect of light. Recent work has shown that light falling on the human eye serves two distinct functions. The obvious function is vision, which relies on the rods and cones in the retina to project images of the physical world to the brain. Less well-known is the non-image forming connection that modulates the activity of the circadian clock, as well as other physiologic functions. This pathway involves a different set of cells in the retina with a different photopigment (melanopsin). The distinct photopigment means that this system responds to different components of the visual light spectrum. While rods and cones are most sensitive to green light, the melanopsin cells show peak response to blue light with a wavelength of 460-480nm. This difference offers a means for differentially manipulating the non-visual and visual pathways, and this is precisely the approach utilized by Professor Casper and his colleagues.

The light wavelength solution

Professor Casper and his colleagues demonstrated that many of the adverse performance and safety effects of light exposure on the night shift are attributable to exposure to this 460-480nm narrow window of blue light wavelengths in the light spectrum and appear to be mediated via these non-image forming pathways. In a recent study, Professor Casper and colleagues have demonstrated that filtering out this narrow component of the visual light spectrum, a change which minimally affects the utility of the light for vision, has an enormous effect on the non-visual pathway and the physiologic systems it innervates. The result of blue light filtration appears to be substantial reversal of much of the performance impairment seen in shiftworkers at night.

Figure 3:
Light Wavelength Transmission Curves

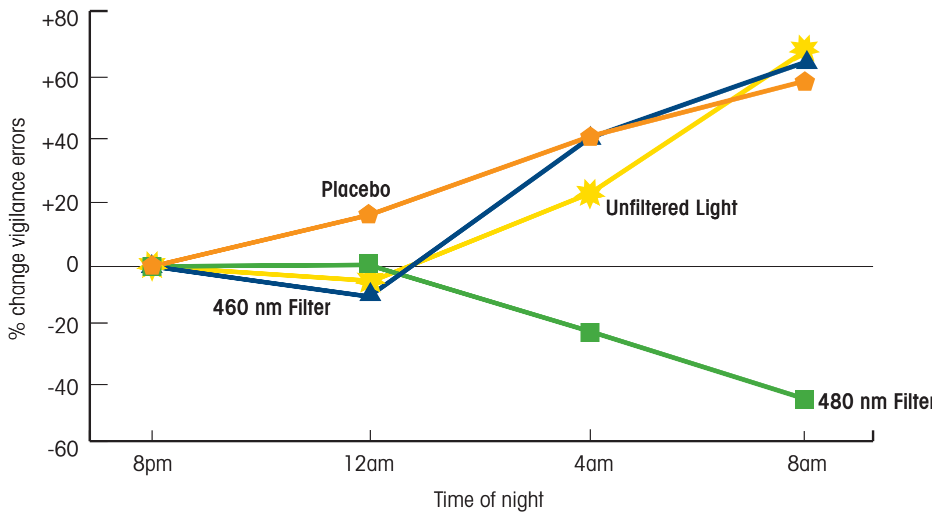


The light wavelength transmission curves of the eyewear pictured here used by the Casper laboratory study. Eyewear with full transmission above 480nm but a sharp cut-off of light wavelengths under 480nm was effective at preventing decreased performance by light, whereas two types of blue-blocking placebo eyewear with either a 460nm sharp cut-off or gradual low wavelength cut-off had no effect. (Based on Rahman et al 2011[1])

The new study, reported in the *American Journal of Physiology – Endocrinology and Metabolism*, was performed using eyewear with optical lenses coated with a 19-layered filter that provided a sharp cut-off of all wavelengths below 480nm. Two types of blue-blocking placebo eyewear were studied. One had a sharp cut-off at 460nm and the other has a gradual cut-off of low wavelength light. Neither placebo eyewear had any effect

Figure 4 shows that when volunteers wore the 460nm cut-off placebo eyewear or the partial blue-blocking placebo eyewear, their errors showed the normal night shift pattern of progressively increasing vigilance error rates as the simulated night shift went on, with up to 80% more errors at the end of the night shift at 8am as compared to the 8 pm beginning of the shift. In contrast, subjects who wore the 480nm cut-off eyewear had a substantial decrease in errors of vigilance during night shifts. Comparing the 460 to the 480 result identifies that the active window of light wavelengths is between 460 and 480nm. In other studies using sharp cut-off notch filters and laboratory rodents, the Casper team, showed that the actual active window is most likely even narrower, between 470-480nm.

Figure 4:
Percent change in vigilance errors



Percent change in vigilance errors from people spending a night either in unfiltered bright light (✸), bright light with <480nm filtered eyewear (■), bright light with placebo <460nm filtered eyewear (▲) or partial blue-blocking placebo eyewear (⬟) The normal decrease in performance during the WOCL caused by light was only prevented by the eyewear filtering out all light wavelengths below 480nm (Replotted from Rahman et al, 2011[1]).

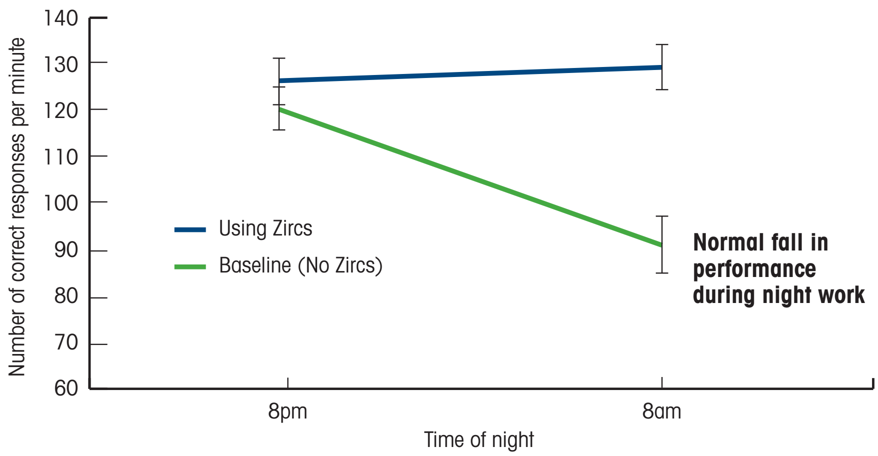
Similar results were found for the normal mood decrease during the final hours of the night shift, which was prevented with the 480nm cut off filter eyewear but not with the placebo eyewear.

The Casper team's finding that the deterioration of human performance during the Window of Circadian Low is a result of nocturnal light exposure to blue light wavelengths between 460-480nm provides a practical solution to the problem of night shift safety and performance. By filtering out this narrow band of wavelengths, and leaving sufficient illumination for normal night work activities, the decrease in shiftworker energy and performance normally seen during the night shift can be prevented.

From laboratory to real world

Next the University of Toronto team conducted workplace trials to see if these effects could be confirmed in real-world shiftwork operations. They set up two workplace trials, one in hospital nurses working rotating 12-hour shifts at the Toronto Western and Toronto General Hospitals and the other in control room operators working rotating 12-hour shifts at a power plant in Canada. Each study compared night shifts during which shiftworkers wore the <480nm cut-off eyewear with night shifts without the light-filtering eyewear. Specially-designed <480nm cut-off eyewear called "Zircs™" were used in these studies..

Figure 5:
Nurse Performance
(Accuracy & Rate = "Thruput")



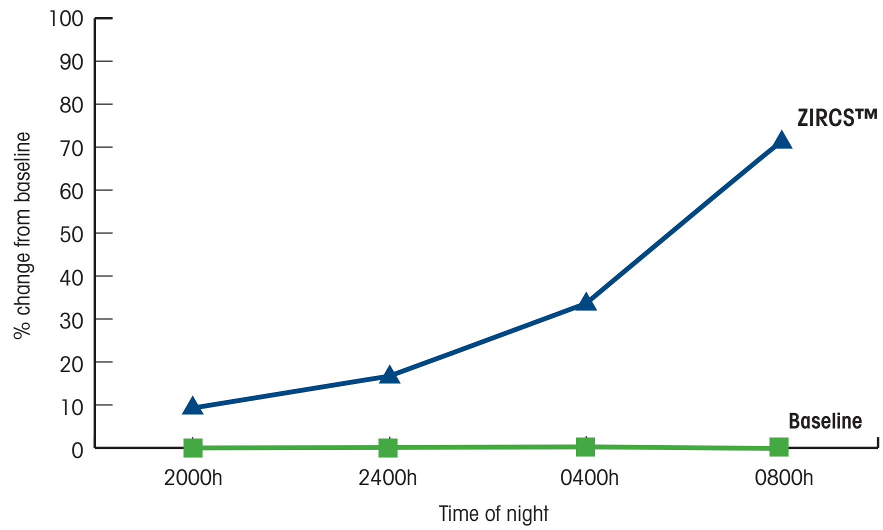
Performance of nurses working the night shift with and without 480 nm cut off eyewear showing the number of correct responses per minute on a vigilance task was improved by wearing the 480nm filtering eyewear.

Figure 5 shows that the nurses working on the regular hospital patient floors at night and exposed to relatively dim lighting (30-50 lux) showed the typical drop off in performance as the night shift progressed when they were not wearing the light filtering eyewear. However when they wore the 480nm filtering Zircs™ eyewear this fall of performance during the WOCL did not occur.

Similar findings were obtained with a group of control room operators at the power plant. One of the measures to track the response of the power plant operators was to track their level of self-reported energy, which normally lags as the night shift progresses. As Figure 6 shows when wearing Zircs they experienced a significant elevated energy as the night shift progressed.

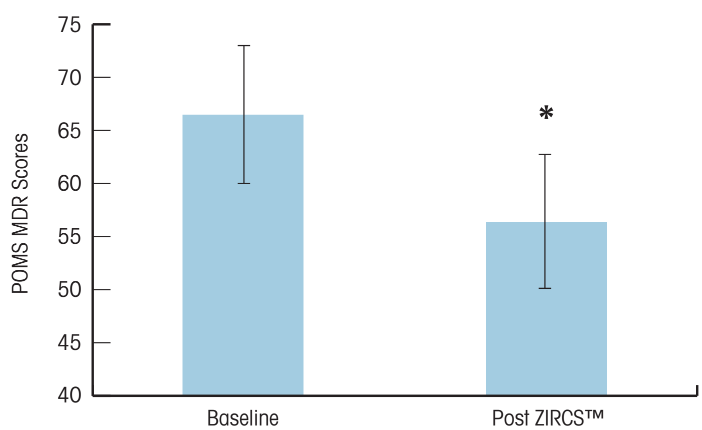
At the same time their mood and tendency to have feelings of anger or restlessness (See Figure 7) was significantly reduced by wearing the 480nm cut-off eyewear.

Figure 6:
Shiftworker Reported Energy Level on Night Shift



Relative to baseline, power plant operators reported up to 70% increase in energy during the final hours of their night shift.

Figure 7:
Mood Disturbance Rate



Zircs™ improved the control room operators' mood and reduced anger & restlessness.

Summary

The results of these workplace trials with <480nm cut-off eyewear were clear-cut and impressive:

- Up to a 70% increase in energy and vigor
- Prevention of the typical fall in performance during WOCL
- Prevention of increase in reaction time during WOCL
- Errors between 4 and 8am decreased by 78%.
- Up to 38% improvement in subjective mood scores (POMS)

From these real-world trials, it appears that filtering out 460-480nm wavelengths from the light in the night workplace using Zircs™ filter-coated eyewear has considerable benefits for shiftworker productivity, energy and mood. By filtering out the problematic piece of the light spectrum, shiftworkers feel and perform better during their most at-risk hours.

Disclosure

CIRCADIAN® is now distributing Zircs™ eyewear to 24/7 business operations under an exclusive global license from the manufacturer, ZircLight Inc., as a consumer product. Zircs™ are classified as a low risk medical device (like other prescription eyewear or non-prescription sunglasses) and Zircs™ safety glasses are CSA and ANSI certified.

Zircs™ are not currently indicated for therapeutic purposes, but are currently limited to the following indications for use by nighttime shift workers:

- Improved energy
- Improved performance
- Reduced errors
- Improved mood

Any other use, including any uses or results described in the Rahman et 2011 American Journal of Physiology paper[1] cited in this white paper have not been cleared or approved by the U.S. Food and Drug Administration (FDA).

CIRCADIAN® is currently working with companies and organizations operating night shifts to conduct controlled trials of other potential applications of Zircs™ eyewear, and other applications of 460-480nm light filtering technology. 460-480 nm light-filtering is a proprietary patent-protected technology owned by ZircLight Inc.

Moore-Ede and some of the authors of the cited American Journal of Physiology article[1] (Casper, Rahman & Shapiro) have a shareholder interest in ZircLight Inc. Moore-Ede has a majority shareholder interest in the CIRCADIAN® companies.

Frequently asked questions

- **Can Zircs™ be worn during daytime?**

  Zircs™ are not designed for use during daylight. 460-480nm light is only proven to be harmful during nighttime light exposure. Other research indicates that exposure to blue light may be beneficial during daylight hours.

- **Bright light exposure at night has been reported to have alerting effects, and as a result scientists have recommended that light intensity levels should be increased at night. How can blocking the 460-480 narrow band of blue wavelengths be so effective?**

  Research published in the 1990's showed that is possible to increase human performance and alertness by turning up light intensities at night, but recent research studies over the last ten years (since 2000) have shown that this performance benefit from bright light at night comes with significant health risks and costs (as discussed above). Selectively blocking the 460-480 nm blue wavelength band appears to provide the same performance-enhancing benefits while avoiding the harmful effects of nocturnal light exposure.

- **How can people who wear prescription eyewear part-time, such as for reading, use Zircs™ during their night shifts?**

  Progressive lenses are ideal for users such as these. If a user only wears a prescription to see at distances, the top of the lens will be fitted with their prescription, while the bottom is left without a prescription. If they only wear prescriptions for reading, the reverse applies. In this way the removal of 460-480 nm light can be continuously achieved by wearing Zircs™ throughout the night shift.

- **Exposure to blue light is claimed to have alerting effects and there are now devices on the market to provide blue light for this purpose. How can removing blue light be effective?**

  Prior research probed the <u>additive</u> effects of light wavelength on circadian rhythms and human performance, using monochromatic (one color) light, typically delivered in short pulses. The effects of polychromatic white light, as is normally used in the workplace, appear to be quite different. Furthermore the Casper research studied the <u>subtractive</u> effects of <u>removing</u> specific blue wavelengths from the normal workplace scenario of continuous nighttime exposure to white light. It is in that condition (which is the normal workplace condition) that the blocking of 460-480nm light has the dramatic effects seen in the Casper studies.

- **Can shiftworkers safely drive home after the night shift after using the Zircs™ all night? What happens if they don't use the Zircs™ glasses during the drive home?**

  Driving home after the night shift is a significant risk for all shiftworkers especially those who have reached a low level of alertness because of being awake all night and the timing of their circadian rhythms. In contrast shiftworkers using Zircs™ all night have been shown to be operating at peak levels at the end of the night shift and they report maintaining that state on the drive home even though they have left their Zircs™ at their workplace.

- **What happens if the glasses are removed during the night shift?**

  While the impact of removing the glasses for short periods of time during the night shift has not been systematically studied, it is assumed that brief periods of light exposure during the night will attenuate the benefit of the Zircs™ in a dose-dependent way: the longer the light exposure, and/or the brighter the light, the greater the return to the normal adverse impact of light exposure at night.

- **The published spectral sensitivity curves for the melanopsin non-visual image pathways have a broader distribution than the narrow 460-480nm band identified in the Casper group research. How can blocking that narrow band be effective?**

  Removing all light at the peak sensitivity 460-480 wavelengths of melanopsin appears to be the key. Furthermore the spectral curves for the subtractive effects of light wavelength out of white light may be different than the additive effects of monochromatic light pulses, as discussed above.

References Cited

1 Rahman SA, Marcu S, Shapiro CM, Brown TJ, Casper RF. Spectral modulation attenuates molecular, endocrine and neurobehavioral disruption induced by nocturnal light exposure. Am J Physiol Endocrinol Metab. 2011; 300:E518-E527.

2 Beers TM. Flexible schedules and shift work: Replacing the "9-to-5 workday? Monthly Labor Review. 2000; 23(6):33-40. Note: Current total US civilian and military employed workforce is 156.2 million x 17% = 26.5 million http://wiki.answers.com/Q/What_is_total_number_of_people_in_US_workforce

3 http://www.carexcanada.ca/en/shiftwork.pdf

4 Mitler,M.M., Carskadon, M.A., Czeisler,C.A. Dement,W.C., Dinges,D.F. and Graeber,R.C. (1988) Catastrophes, Sleep, and Public Policy: Consensus Report. Sleep. 11(1): 100–109.

5 Gold, D.R., Rogacz, S., Bock.N, Tosteson T.D, BaumT.M, Speizer, F.E and C A Czeisler, C.A. (1992) Rotating shift work, sleep, and accidents related to sleepiness in hospital nurses. American Journal of Public Health, Vol. 82, Issue 7 1011-1014

6 Fathallah, F.A., Brogmus, G.E. (2001) Hourly trends in workers' compensation claims Ergonomics 42: 196 - 207

ABOUT THE AUTHORS

Dr. Martin Moore-Ede has been a leading expert for over 30 years on managing the risks of human fatigue in businesses that operate 24/7. After experiencing the challenges of fatigue as a surgeon-in-training required to work 36-hour shifts, Dr. Moore-Ede was one of the first to define the challenges of living, working and sleeping in a 24 hour a day, 7-day a week world. As a professor at Harvard Medical School (1975 – 1998), he led the team that located the biological clock in the human brain that controls the timing of sleep and wake, and pioneered research on how the human body can safely adapt to working around the clock and sustain optimum physical and mental performance. In 1983 Dr. Moore-Ede founded Circadian Technologies, Inc. (www.circadian.com), a research and consulting firm dedicated to reducing the costs and liabilities of managing a 24/7 workforce. As Chairman and CEO, he has guided the growth of the international network of CIRCADIAN® companies which now advises over half of the Fortune 500 on 24/7 work schedules and employee fatigue risk management. Dr. Moore-Ede graduated with a First Class Honors degree in Physiology from the University of London, and received his medical degrees from Guy's Hospital Medical School, and his Ph.D. in Physiology from Harvard University. He has published 10 books, and more than 145 scientific papers on human fatigue, errors and accidents and the physiology of sleep deprivation and circadian rhythms. He has served on multiple national and international committees, and has received numerous awards including the Bowditch Lectureship of the American Physiological Society.

Dr. Gary S. Richardson is a leading expert on sleep, sleep disorders and fatigue in 24/7 operations and is a Senior Scientific Consultant at CIRCADIAN working in fatigue risk management applications in 24/7 industries. His research interests have focused on the neuroendocrine pathways triggered by circadian light exposure and applications to protecting for health and safety of 24/7 workplace employees. He is currently responsible for overseeing the design and conduct of industry trials of the 460-480nm light filtering technologies described in this white paper. Dr. Richardson received his B.S. in Biology from Stanford University and his M.D., with Honors for Achievement in Medical Research from Stanford University School of Medicine. He has held faculty positions at Harvard Medical School, Brown University and Henry Ford Hospital and has authored a wide range of published books and monographs, and hundreds of original reports, on circadian neuroendocrinology and sleep medicine. He has served as a consultant to leading pharmaceutical companies and medical device companies on the application of circadian science to their markets, and has been a committee member and study section reviewer for the National Sleep Foundation, the National Institute of Mental Health/National Institute of Health and the National Center for Sleep Disorder Research/National Heart, Lung & Blood Institute.

Becca Chacko is CIRCADIAN's Project Coordinator for the transition of 460-480nm wavelength science from laboratory into industry and for managing the regulatory affairs for the international introduction of this technology into 24/7 markets worldwide. She coordinates industry workplace trials in North America, Europe and Australia. Ms Chacko graduated from Bates College and has been accepted into the Harvard Business School MBA program.

ABOUT CIRCADIAN®

CIRCADIAN® is the global leader in providing fatigue risk management solutions for the 24/7 workforce for businesses that operate around the clock. Through a unique combination of consulting expertise, research, software tools, fatigue management technology and informative publications, CIRCADIAN® helps organizations in the 24-hour economy optimize employee performance and reduce the inherent risks and costs of their extended-hours operations.

Working from offices in North America, Europe, Australia, South America and Asia, CIRCADIAN® experts ensure that over half the Fortune 500, and other leading international companies, improve their competitiveness in the global 24/7 economy. CIRCADIAN®'s core expertise is the staffing, scheduling, training and risk management of their most vital asset: the 24/7 workforce.

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