The Need for Fatigue Mitigation Lighting In Naval Industrial Facilities

NSRP

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CIRCADIAN POSITIONING SYSTEMS

Outline

- What is “fatigue”
  - Extended waking
  - Too little sleep
  - Circadian Rhythm misalignment
- Consequences of fatigue
- How to mitigate fatigue using lighting
  - What is light
  - How to use light
  - How do we “standardize” light so it can be used to mitigate fatigue
- Data from shore-based Navy facilities

What is fatigue?

- Physiological state of reduced mental or physical performance capability resulting from sleep loss, extended wakefulness, circadian phase, and/or workload (US DOT, FAA, 2012).

Extended Waking, Too Little Sleep & Circadian Misalignment

- **Extended waking**
  - Cognitive impairment becomes noticeable after ~ 16 hours of continuous waking
  - Continuous waking for greater than 24 hours is comparable to a blood alcohol concentration of .10%
- **Too little sleep**
  - Sleep is critical for restoration of physical and mental performance
- **Circadian misalignment**
  - Circadian rhythms regulate daily variations in physical, mental, and behavioral processes.
  - Thus, performance is significantly worse at certain circadian phases typically during the biological night (~0200-0600)

Fatigue Impairs Safety & Performance

Sleep Loss & Circadian Misalignment: Consequences

- Performance
- Attention
- Alertness
- Mood
- Impulsivity
- Decision-making
- Learning
- Memory
- Overall physical and mental health

Fatigue Costs the US economy $411B annually

The Problem at sea & in the air:

Fatigue (Inadequate Sleep and Circadian Rhythm Misalignment) Is a Major Contributing Factor to Collisions Resulting in Loss of Life and Property

U.S. Marines F/A-18 fighter collided with a KC-130

U.S.S. John McCain

s of 10 Sailors Who Died in Navy Collision

DOCK AUG. 27, 2017

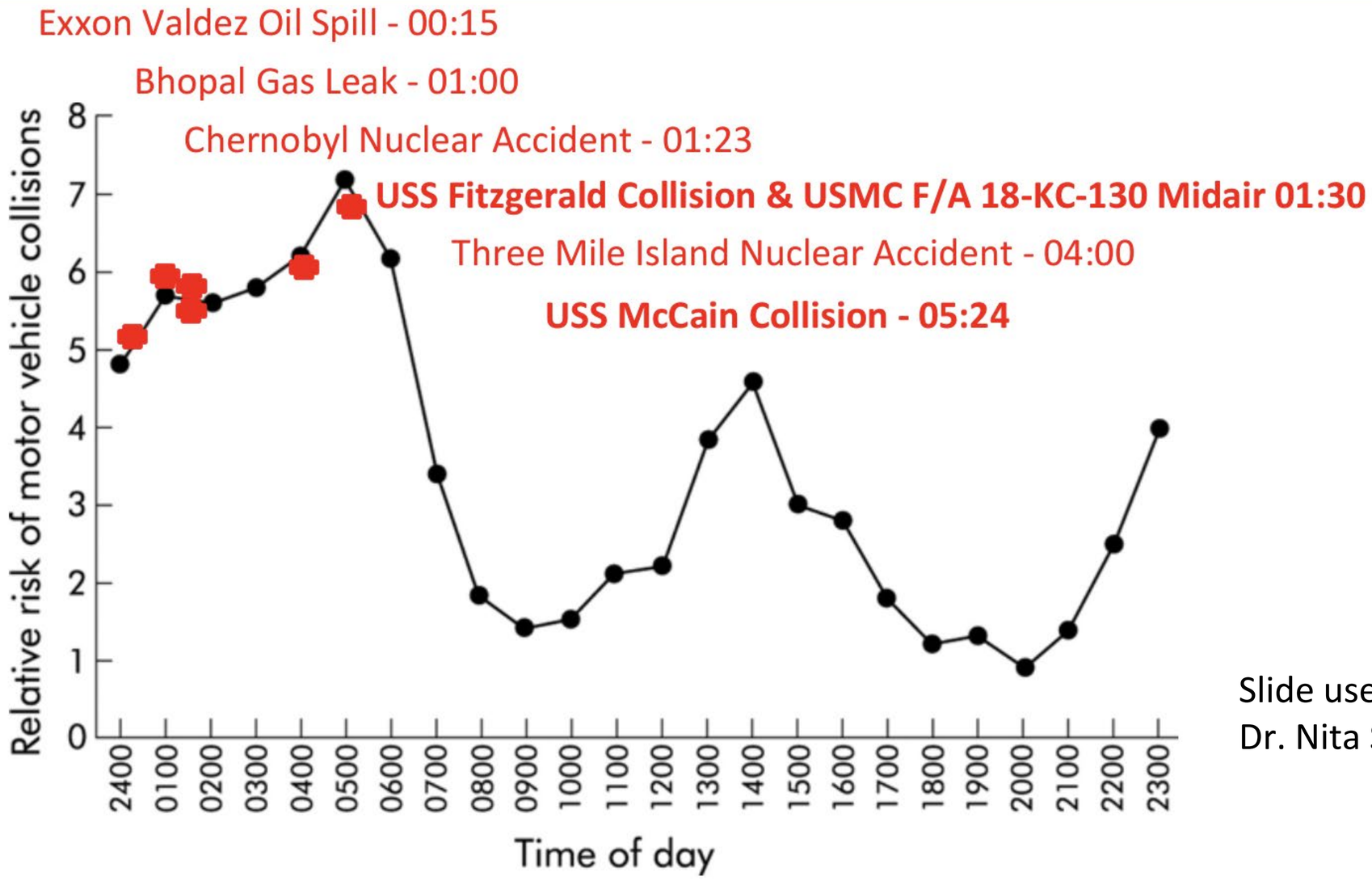
p left: Kenneth Aaron Smith, 22, from New Jersey; Logan Stephen Palmer, 23, from
ry Hoagland III, 20, from Texas; Dustin Louis Doyon, 26, from Connecticut; Jacob

USS Fitzgerald

7 sailors died aboard the USS Fitzgerald. Here are their stories.

By Avi Selk June 19, 2017 Email the author

The Problem: Real-World Accidents Happen at Adverse Circadian Phases (i.e., Biological Night)



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“Fatigue” and Workplace Safety

- 13% of workplace injuries are sleep related (Uehli et al., 2014)
- Workers with sleep problems have a 62% higher risk of sustaining a work injury compared to those without sleep problems (Uehli et al., 2014)
- Work shifts in the evening or at night are associated with increased risk of injury and increased severity of injury(Liu et al., 2020; Mustard et al., 2012)

The Solution: Circadian-targeted lighting

- "Light is radiant energy of those wavelengths that are capable of affecting the eye to produce vision."
  - DOD-HDBK-289 (SH), 1986
- Light also affects photoreceptors in the eye to "drive biological effects that powerfully regulate human ." health, performance and well-being
  - CIE Position Statement on Non-Visual Effects of Light, 2019

Photoreceptors

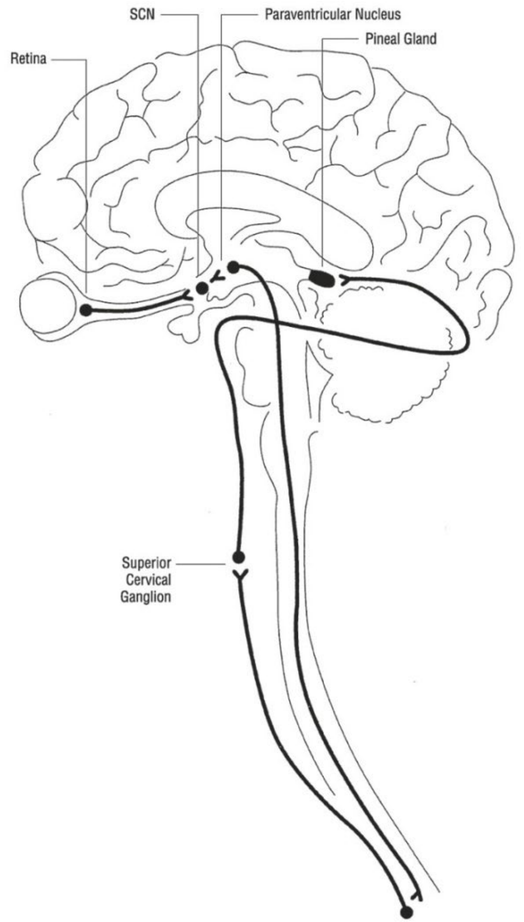
- Classical photoreceptors
  - Rods –dim light
  - Cones – color
- Intrinsically photosensitive retinal ganglion cells (ipRGCs) - late 1990's
  - Photopigment melanopsin
  - Peak spectral sensitivity ~ 480nm

Circadian Rhythms

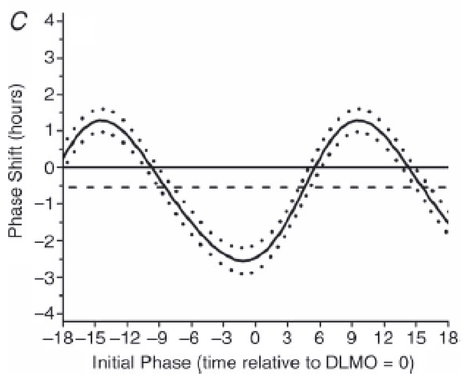
- Earth's daily axial rotation in orbit around the sun
  - Light/Dark cycle
  - Temperature cycle
- Most organisms demonstrate internal timing system with a period of ~ 24 hours
- When sleep/wake schedule is out of alignment (synch) with your internal circadian clock
  - Shift work
  - Jet lag
- Circadian misalignment results in:
  - Negative consequences to/during sleep
  - Negative consequences during waking

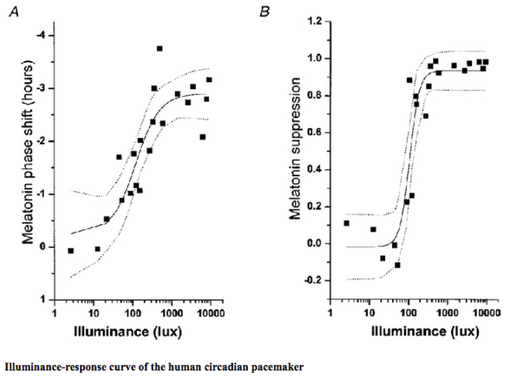
How Does Light Work to Entrain Circadian Rhythms?

- Retinohypothalamic tract (RHT)
- Photic information transmitted to the suprachiasmatic nucleus (SCN)

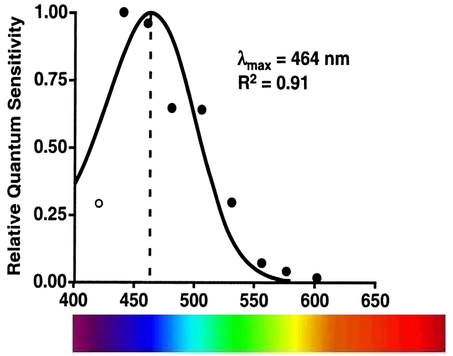


Circadian-Targeted Light: Three Critical Factors





Illuminance-response curve of the human circadian pacemaker



Timing

Intensity

Spectral Characteristics

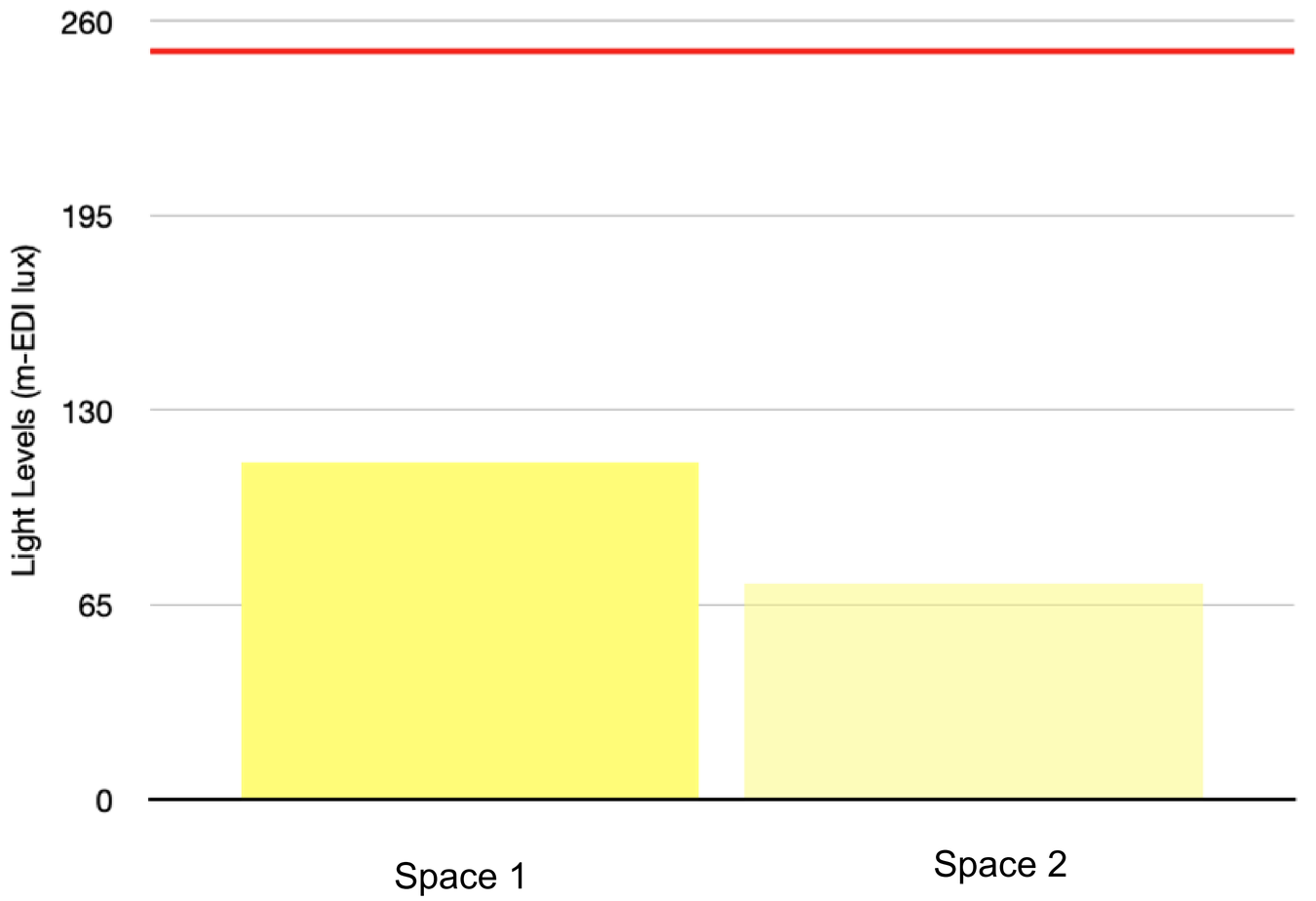
Melanopic-EDI

- High melanopic-EDI delivered at the appropriate circadian phase supportive for alertness and circadian rhythm alignment
- Low melanopic EDI delivered at the appropriate circadian phase facilitates sleep initiation, consolidation, and circadian rhythm alignment

Light Considerations Related to Circadian Rhythms

- Properties to consider
  - Intensity
  - Spectrum
  - Duration
  - Timing (clock time and circadian)
  - Light history
  - Sleep history
  - Light controller/controllability of light
- Best measured at a horizontal plane (eye-level)
- Best presented as melanopic equivalent daylight (D65) illuminance (melanopic-EDI)

Actual Lighting measurements from US Navy land-based facility



How could circadian-targeted lighting help in Naval industrial facilities

- By implementing circadian-targeted lighting in naval industrial facilities we aim to protect both personnel and mission readiness by having:
  - Fewer errors and rework cycles
  - Enhanced safety
  - Increased morale & retention
  - Enhanced productivity