THE EFFECTS OF LIGHT ON ALERTNESS:
A DRIVING SIMULATOR STUDY

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WHO ARE WE ?

Lighting Research Center Rensselaer

The Lighting Research Center (LRC), as part of Rensselaer Polytechnic Institute, Troy, NY, is the leading university-based research center devoted to lighting since 1988.

İstanbulUlaşım
www.istanbululasim.com

Istanbul Transportation Co. is the subsidiary company of Istanbul Metropolitan Municipality, and internationally provides a comprehensive range of integrated planning, management, engineering services, and operates all the railway transportation modes in Istanbul, Turkey.

FATIGUE: A matter of a second…

www.youtube.com

FATIGUE RELATED ACCIDENTS: A Growing Problem

According to a N.T.S.B. investigation, an engineer nodded off at the controls of a train in Kansas, in 1997. The train hit the side of an oncoming train at about 70 mph

The crash of a Comair flight that tried to take off from the wrong runway in Lexington, Kentucky, in 2006

Crash investigators said that driver fatigue played a key role in a bus accident in Utah in 2008

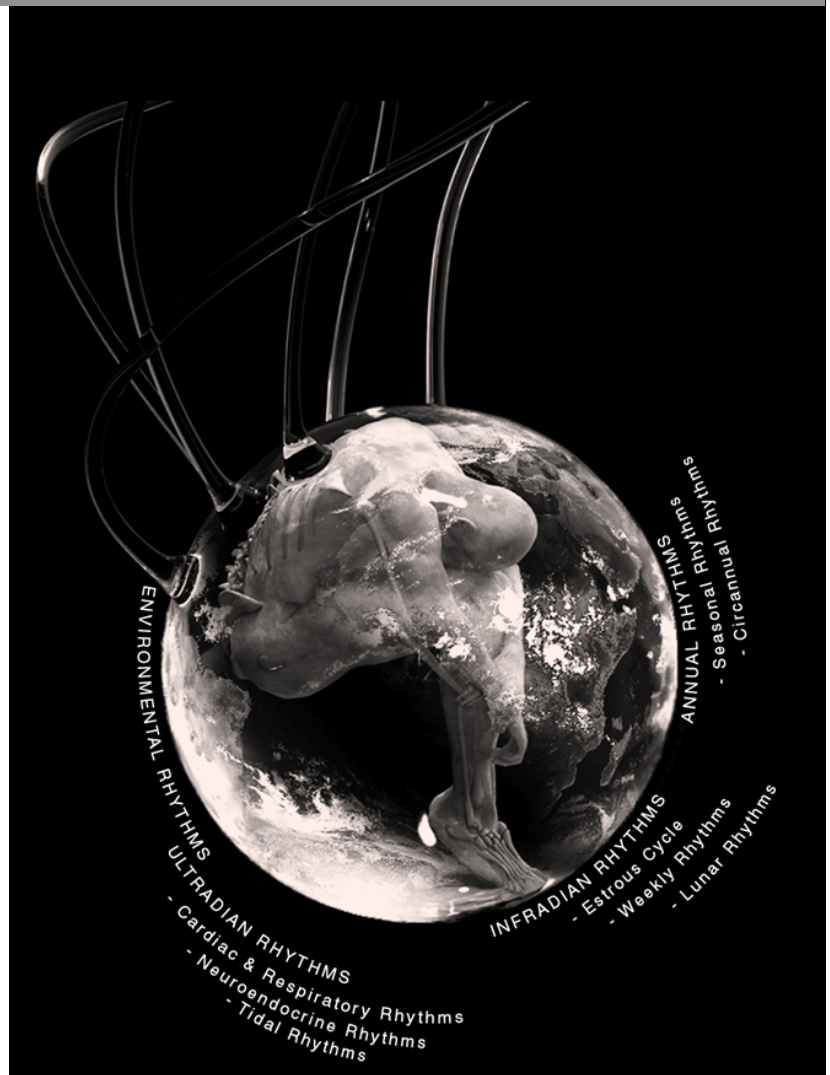
THE NATURE OF US: Circadian System

Circadian means around (*circa*) a day (*dies*).

Circadian rhythms are biological daily rhythms that repeat themselves approximately every 24 hours.

- Sleep/wake cycle
- Hormone production
- Body temperature
- Heart rate
- Blood pressure
- Gene expression

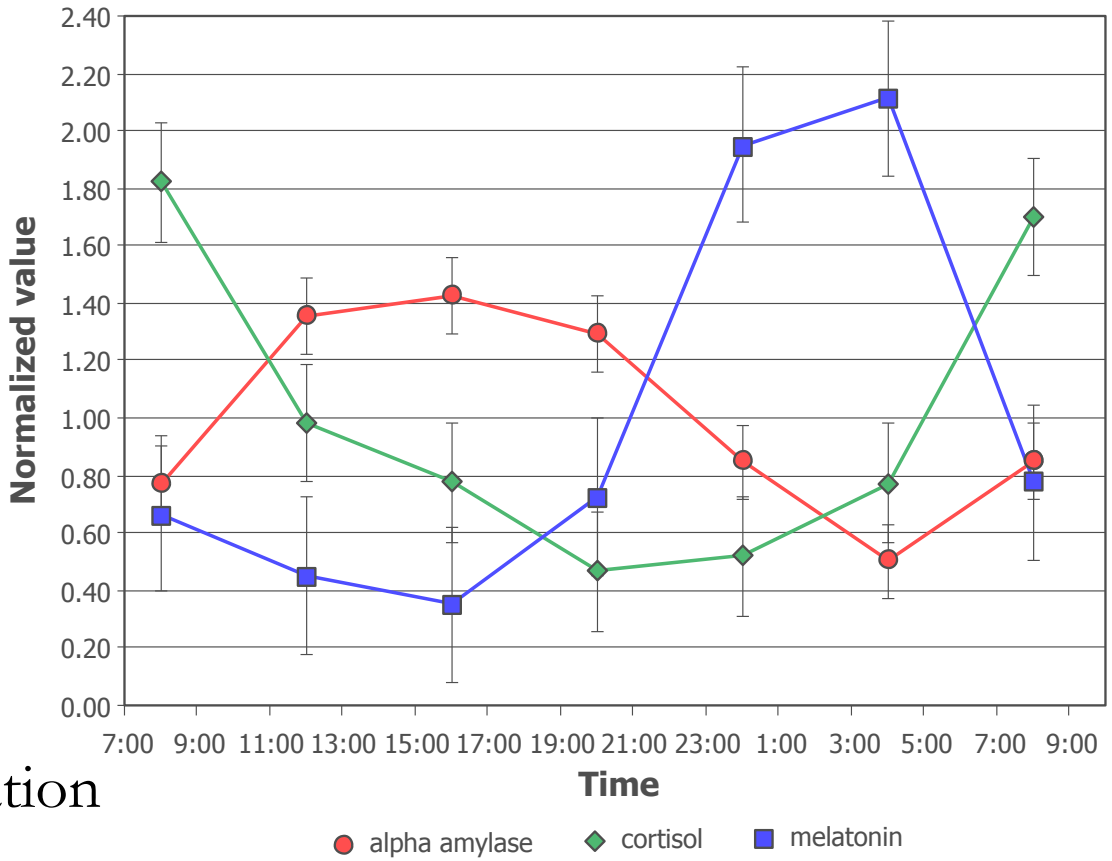
If our behaviors are desynchronized from the light and dark patterns that the outside world provides, our circadian rhythms will become disrupted.



THE NATURE OF US: Circadian System

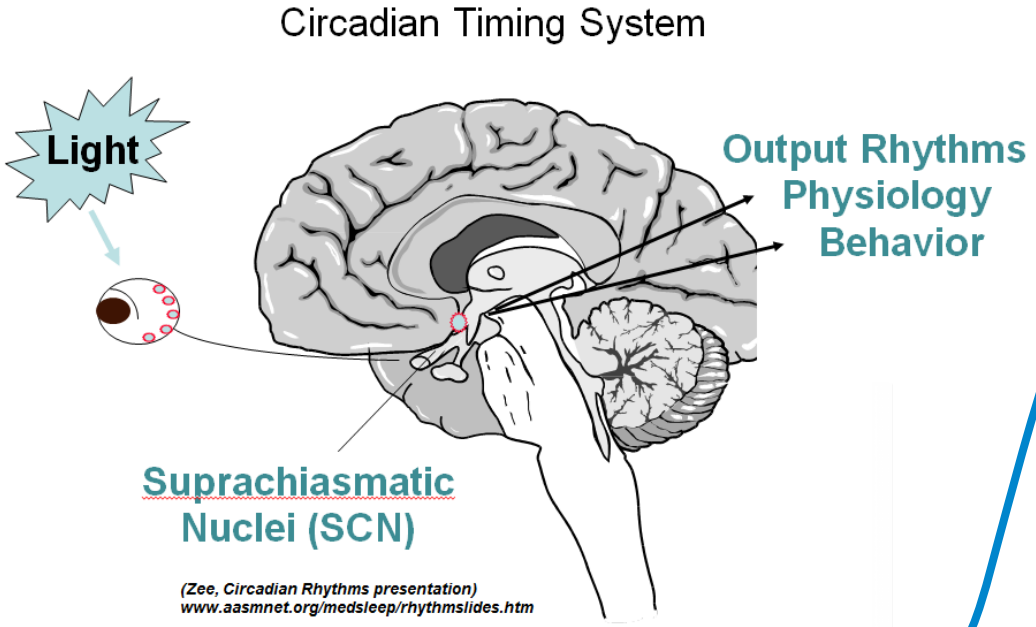
Biological (circadian) rhythms can be measured in several ways

- Sleep/wake cycle
- Core body temperature
- Melatonin concentration
- Cortisol concentration
- Alpha amylase concentration

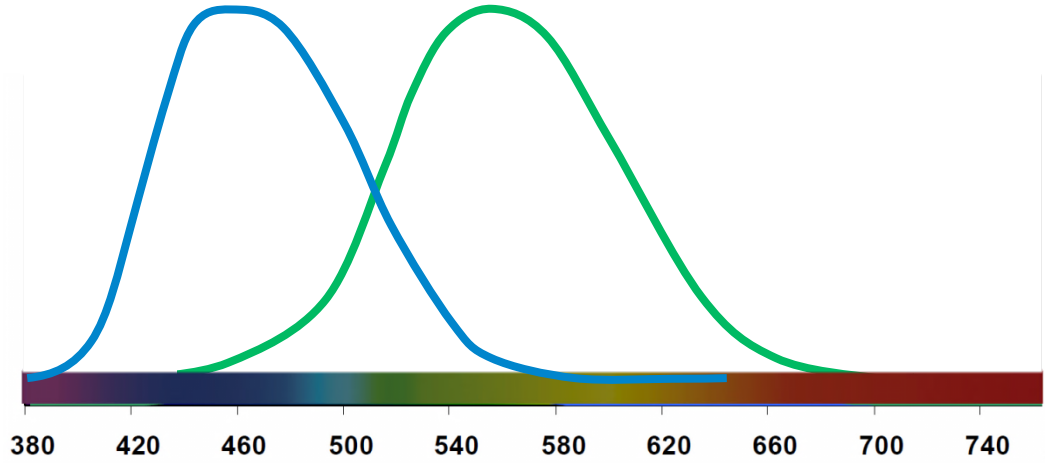


Figueiro et al., 2009
Sponsor: Office of Naval Research

THE NATURE OF US: Circadian System | Circadian Vision |

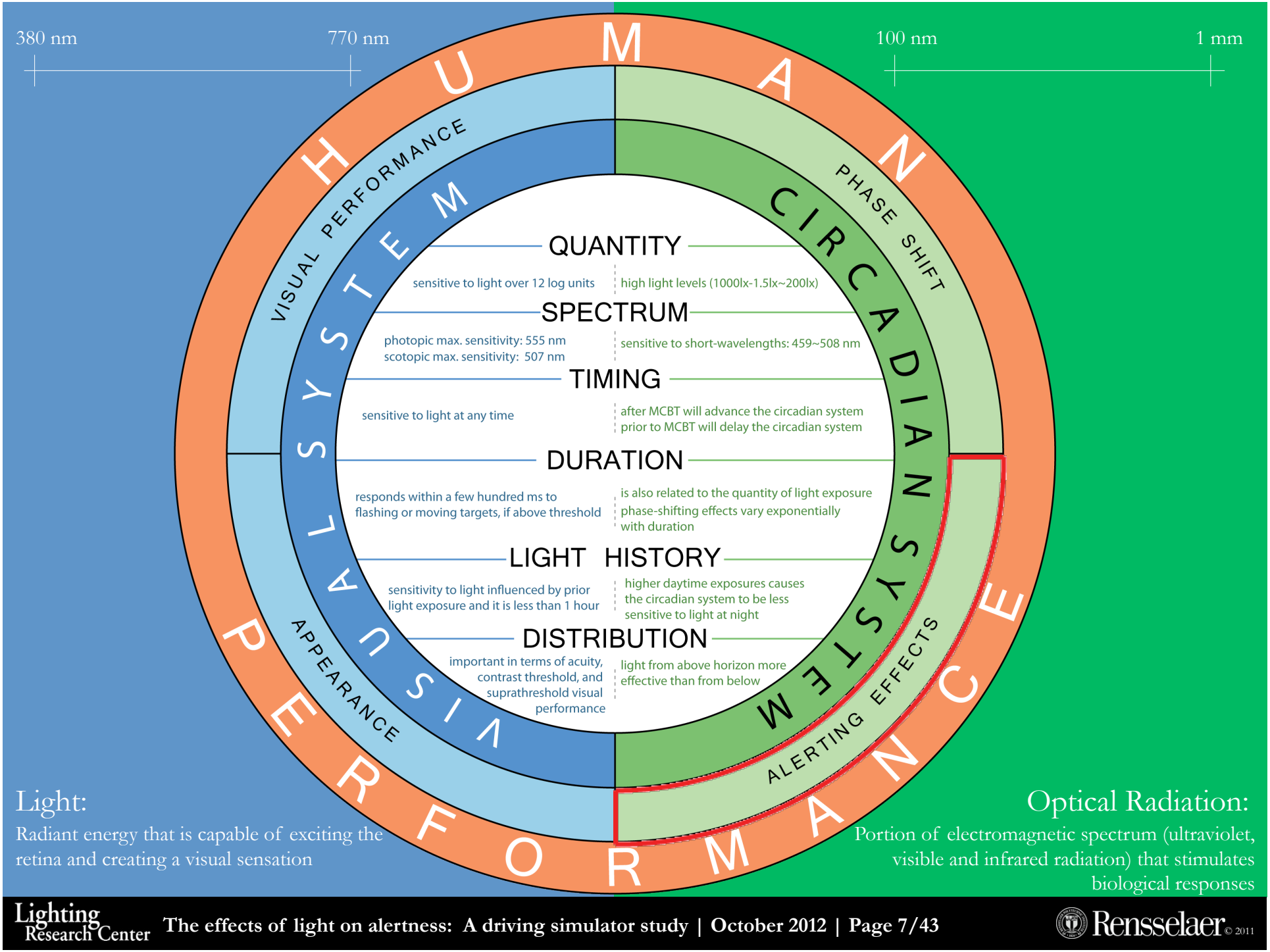


- **Visual:**
  Rods & Cones
- **Circadian:**
  IpRGCs + Rods & Cones



- A new photoreceptor (ipRGCs) was discovered in the retina in 2002 (Berson et al., 2002)
  - Slower to respond, less sensitive to light
  - Peak sensitivity at about 482 nm

- Subsequent studies showed that rods, cones and ipRGCs participate in how the retina converts light signals into neural signals for the circadian system (Hattar et al., 2003)



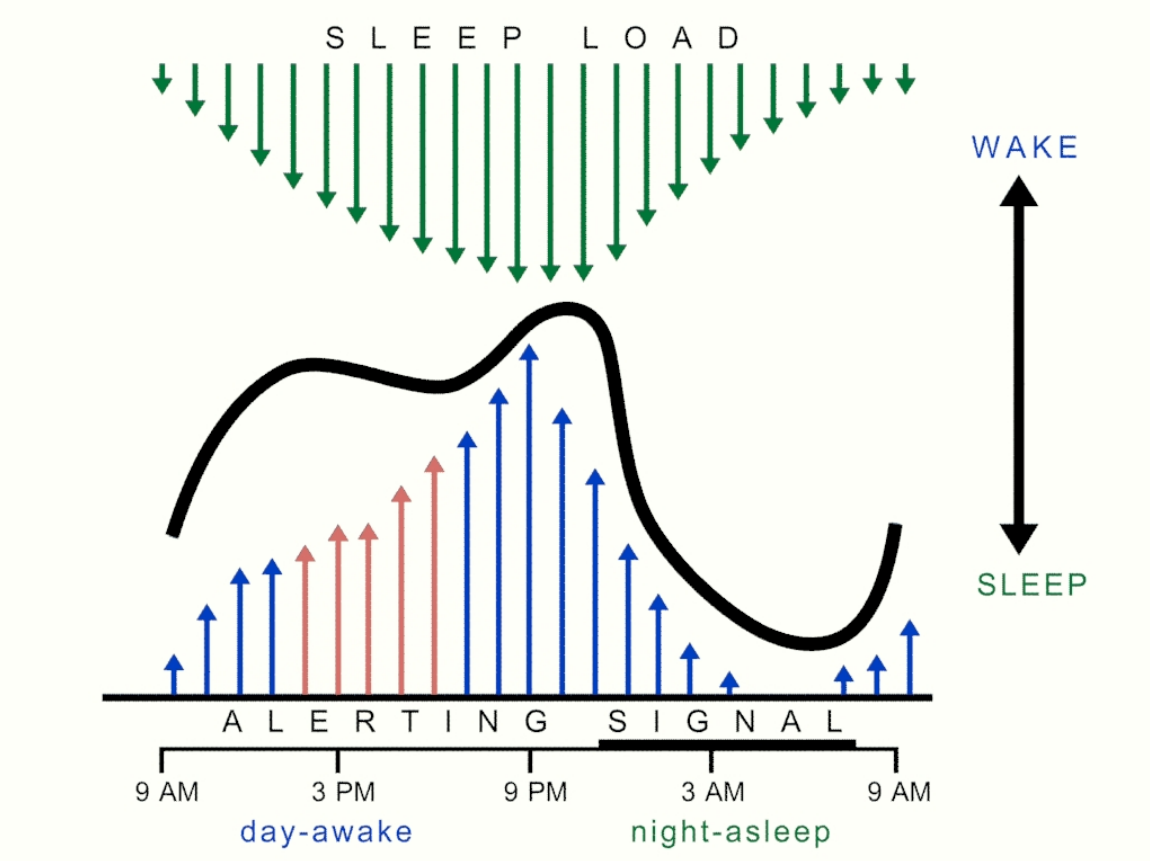
Light:

Radiant energy that is capable of exciting the retina and creating a visual sensation

Optical Radiation:

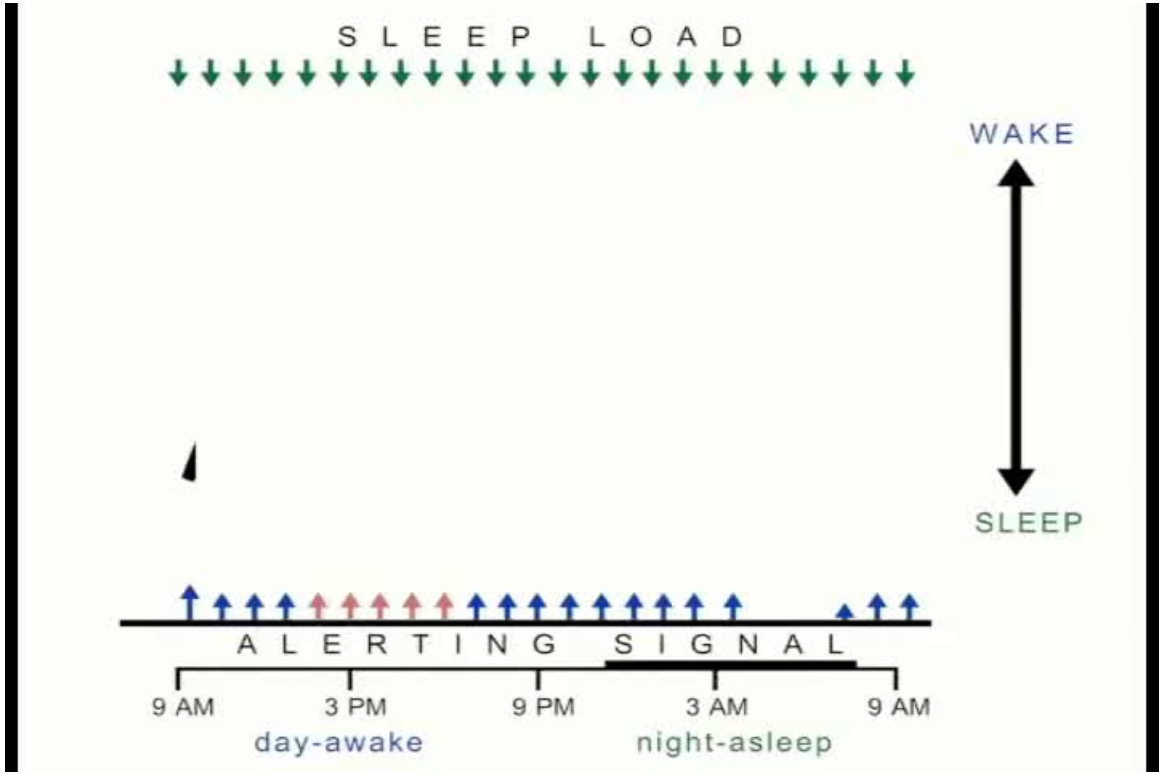
Portion of electromagnetic spectrum (ultraviolet, visible and infrared radiation) that stimulates biological responses

THE NATURE OF US: Circadian System | Opponent Process Model of Sleep |

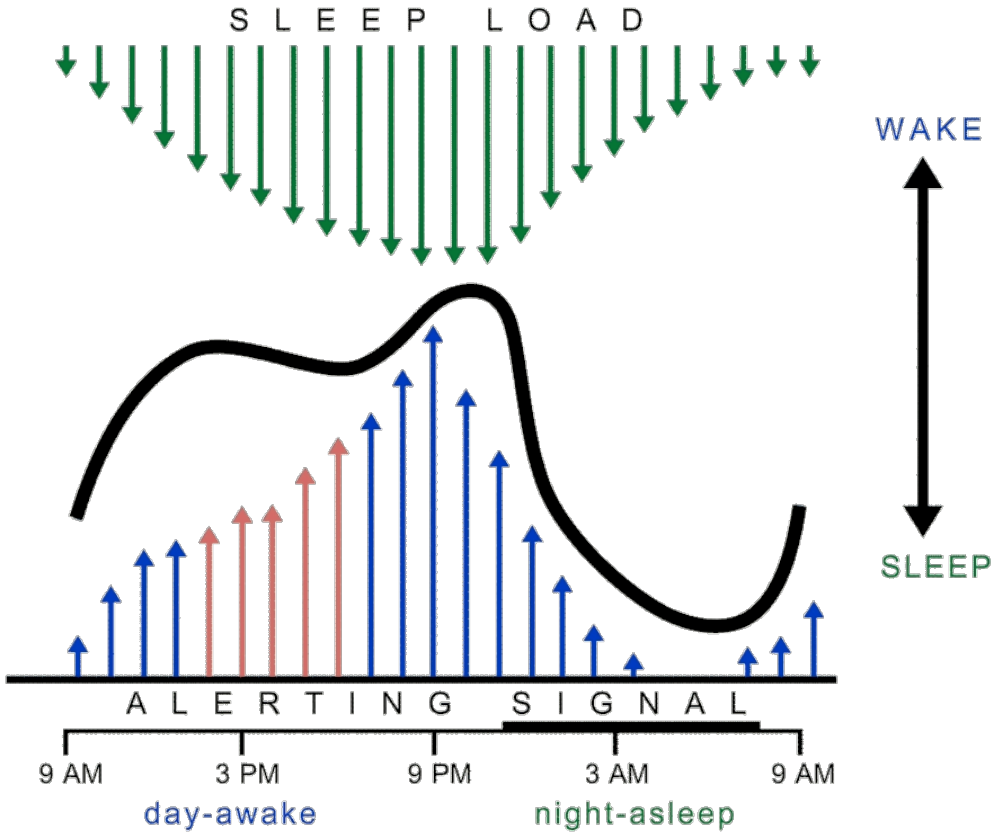


According to Edgar et al.

THE NATURE OF US: Circadian System | Opponent Process Model of Sleep |

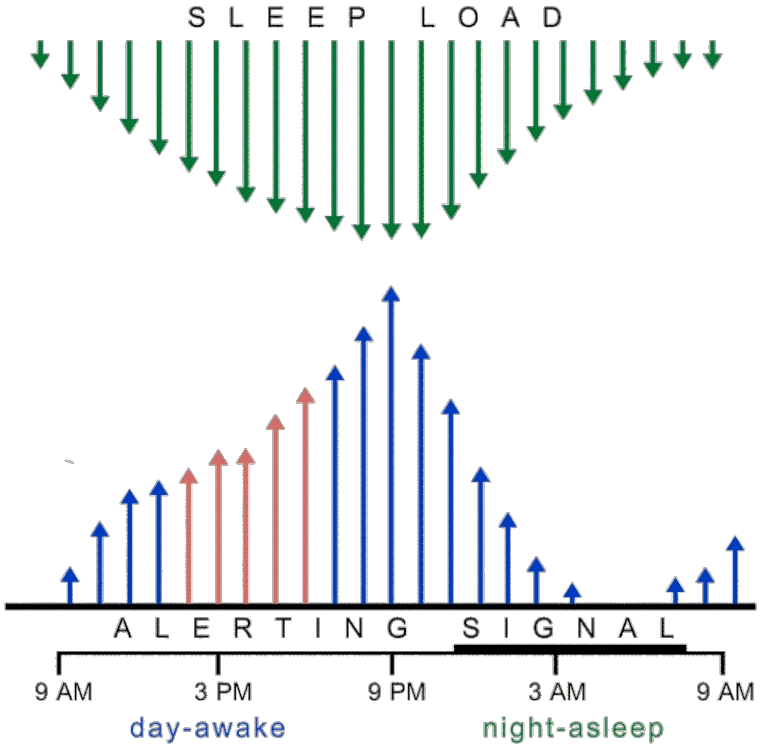


THE NATURE OF US: Circadian System | Opponent Process Model of Sleep |



According to Edgar et al.

THE NATURE OF US: In case of Desynchronized Opponent Process Model



Adapted from Akerstedt,2007

LITERATURE: Shift Work, Fatigue and Performance

- The risk for severe sleepiness was 6-14 times higher in the night shift and about twice as high in the morning shift compared with the day shift

>Harma et al. 2002

- About 25 % of train drivers dozed off while driving or waiting at the station

>Austin & Drummond 1986

- Drivers in the moderate fatigue group used 4% more, and drivers in the high group used 9% more fuel than drivers in the low fatigue group. High fatigue-group drivers used less throttle and dynamic brake and engaged in more heavy brake and maximum speed violations.

> Dorrian et al. (2006)

Light at night(> 2500 lux of white light);

- reduces subjective sleepiness
- increases task performance
- increases body temperature and heart rate
- reduces low frequency and increases high frequency EEG activity
- reduces the incidence of slow-eye movements (SEMs)
- suppresses melatonin levels compared to control conditions

>Campbell and Dawsaon 1990; Badia et al. 1991; Thessing et al. 1994; Cajochen et al. 1998; Daurat et al. 2000; Cajochen 2000; Figueiro et al. 2001; Lowden et al. 2004

LITERATURE: What else do we know? | Alerting Effects of Light |

- Blue light enhances brain responses

- Monochromatic light can affect cognitive functions almost instantaneously. However dissipates swiftly.

>Vandewalle et al. 2007

- Long wavelength light (red) also reduces alpha and increases beta activity in EEG

>Figueiro et al. 2009

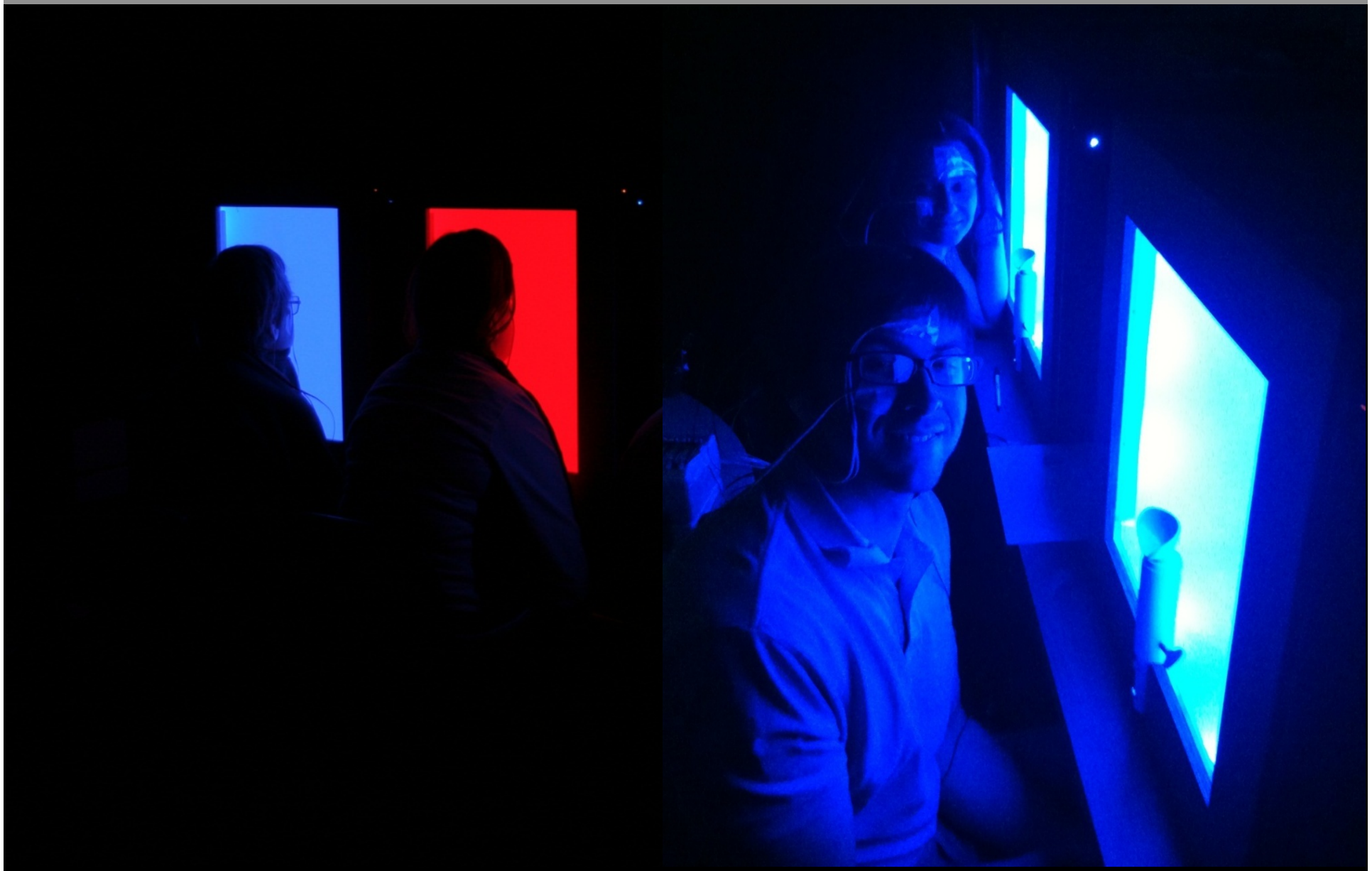
EFFECTS OF LIGHT ON ALERTNESS: Primary Goal

The **primary goal** of this study is to use light as a non-pharmacological treatment for increasing alertness of train drivers during operation , and provide scientific knowledge to initiate efforts for developing a circadian lighting scheme in the cabin interior.

EFFECTS OF LIGHT ON ALERTNESS: Benefits

- Supporting accident prevention strategies
- Reducing the impact of human errors on train accidents
- Reducing the social and economical consequences of such incidents and accidents.
- Providing essential information on driver cab design
- Recommendations for lighting standards and practices to advance driver's performance by taking the non-visual effects of light into consideration
- Applicability of the findings to other transportation types such as airlines and roadways

RECENT EXPERIMENTS: "Blue" and "red" light as alerting stimuli



RECENT EXPERIMENTS: "Blue" and "red" light as alerting stimuli | Morning |

- Morning "blue" and "red" lights significantly decreased alpha power compared to staying in darkness for 1 hour

- Lower alpha power is a sign of decreased sleepiness

α ↓

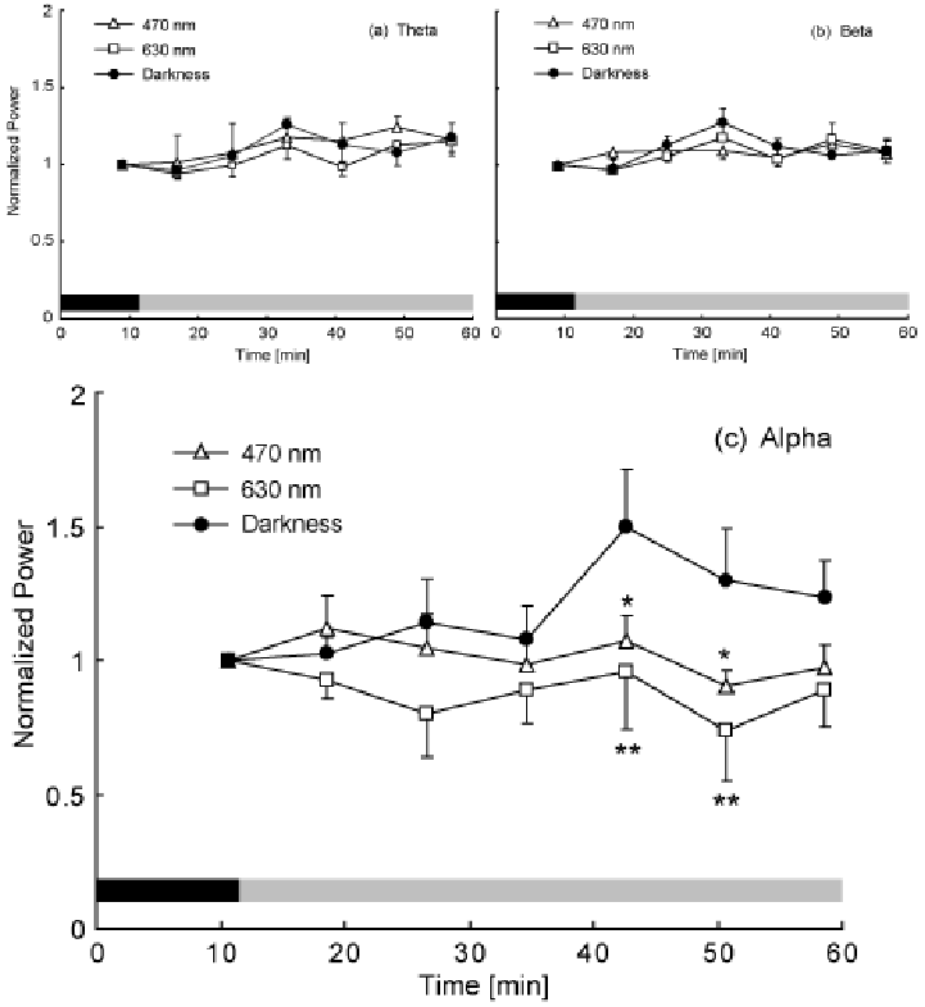
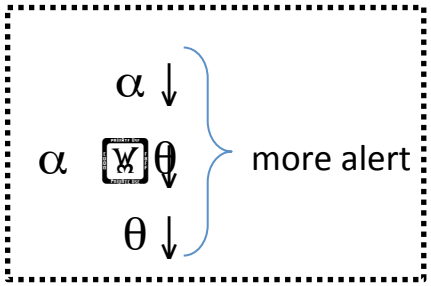
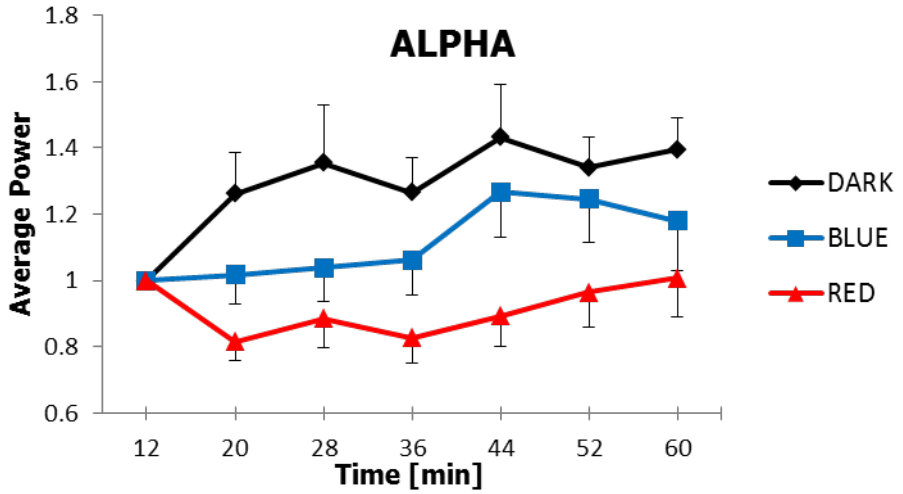


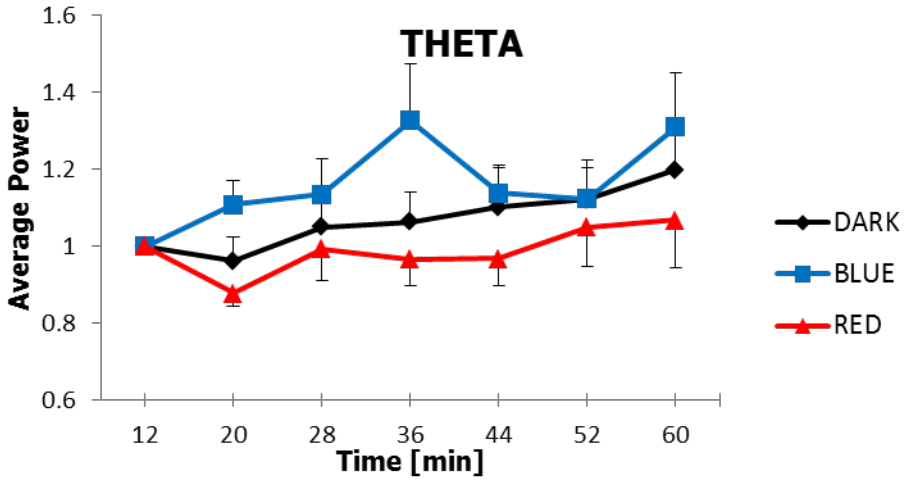
Fig. 3. Okamoto et al.

RECENT EXPERIMENTS: "Blue" and "red" light as alerting stimuli | Afternoon |

- Afternoon "red" light exposure significantly decreased alpha power, alpha-theta, and theta compared to staying in darkness for 1 hour, but blue light exposure did not reach statistical significance





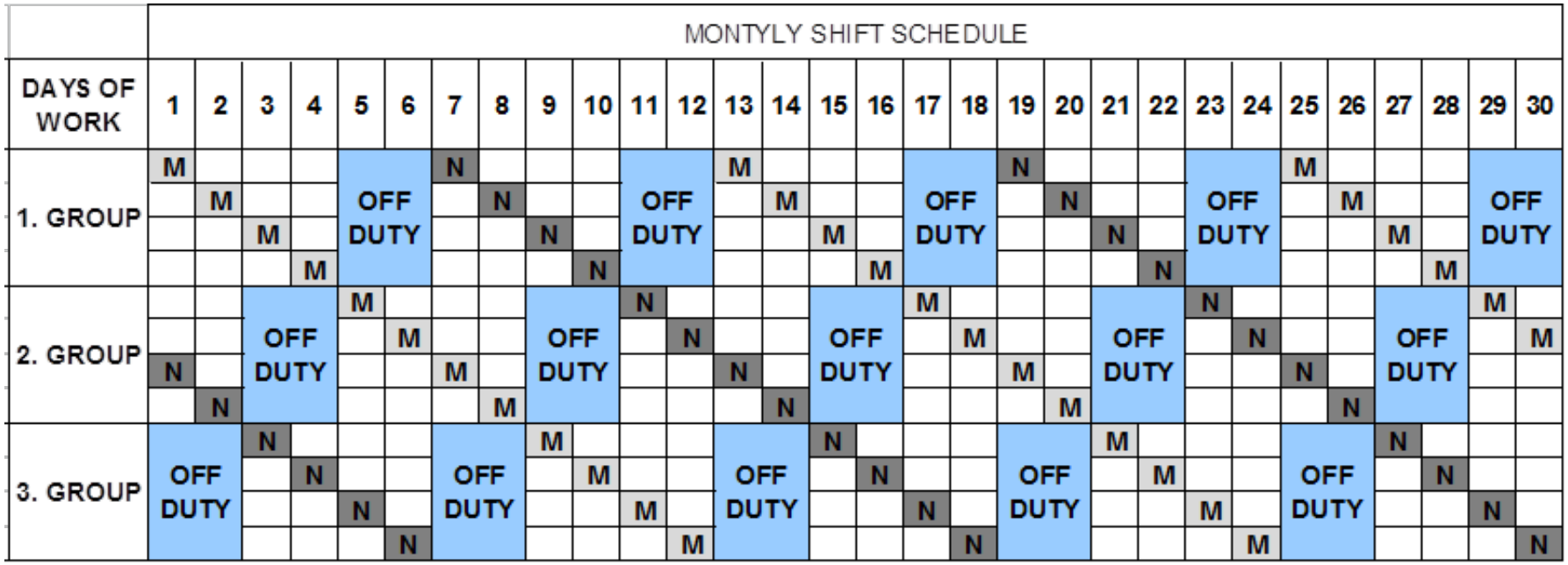


THE FIELD STUDY: Simulator Experiment

THE FIELD STUDY: **Methods** | Participants |

- 13 male volunteers, with at least 5 years of experience in train driving, were recruited among currently working train drivers in Istanbul Transportation Co. (ITC)
- Drivers were selected among those working on the Kabatas-Bagcilar tramway line, which was simulated in this study
- Each participant was screened for major health problems by the nurse of ITC, before commencing the study. Participants were asked to refrain from alcohol and caffeine for 12 hours preceding the experiment
- Mean ± SD Morningness-Eveningness scores of participants was 58.16 ± 12.21 (moderate morning type)
- Of the 13 participants, 6 (32–43 years, median=40) completed the study and their results are presented here

THE FIELD STUDY: Methods | Participants |



- Of the 6 participants, three participants were from 1st group, one was from 2nd group, and two were from 3rd group

- One subject attended to the study on the 1st days, one on the 2nd days, two on the 3rd days, and the other two on the 4th days of their shift

- Saliva Melatonin
- Karolinska Sleepiness Scale (KSS)

  ranging from 1 to 9, where 1 =very alert, 5 = neither sleepy nor alert, 7=sleepy but no effort to remain awake, and 9=very sleepy, an effort to stay awake, fighting sleep
- De Boer Glare Rating

  uses a nine-point scale (from 1 to 9) with odd-numbered values having the following equivalencies: 1=unbearable , 3=disturbing, 5=just permissible, 7=satisfactory, 9=just noticeable
- Simulator Measures

THE FIELD STUDY: **Methods** |Rail Simulator|

- The rail simulator cabin used in this study was identical to the vehicle cabin of Alstom Citadis l301 model which is currently under operation in the same tramway line, Kabatas-Bagcilar.
- The dynamic cabin platform had 6 degrees of freedom, providing real driving experience
- 3D computer generated track visuals were projected onto 6x2 cylindrical screen, providing 1420 (horizontal) and 420 (vertical) field of view (FOV).
- 3D track information consisted of buildings, motor vehicles and roads, cross walks, stations with passengers, signs and traffic lights that exist along the Kabatas -Bagcilar tramway line.

THE FIELD STUDY: **Methods** |Rail Simulator|

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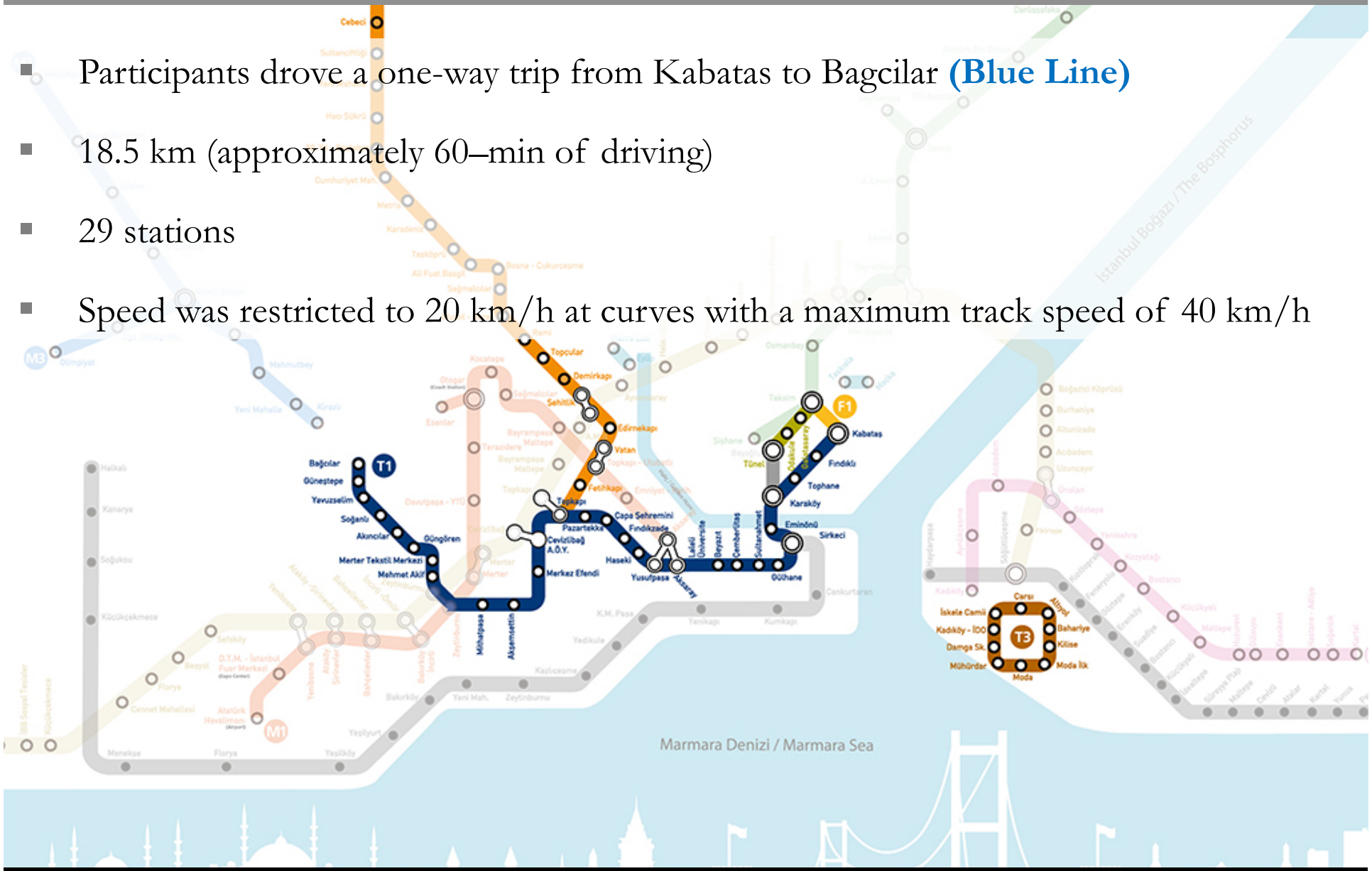
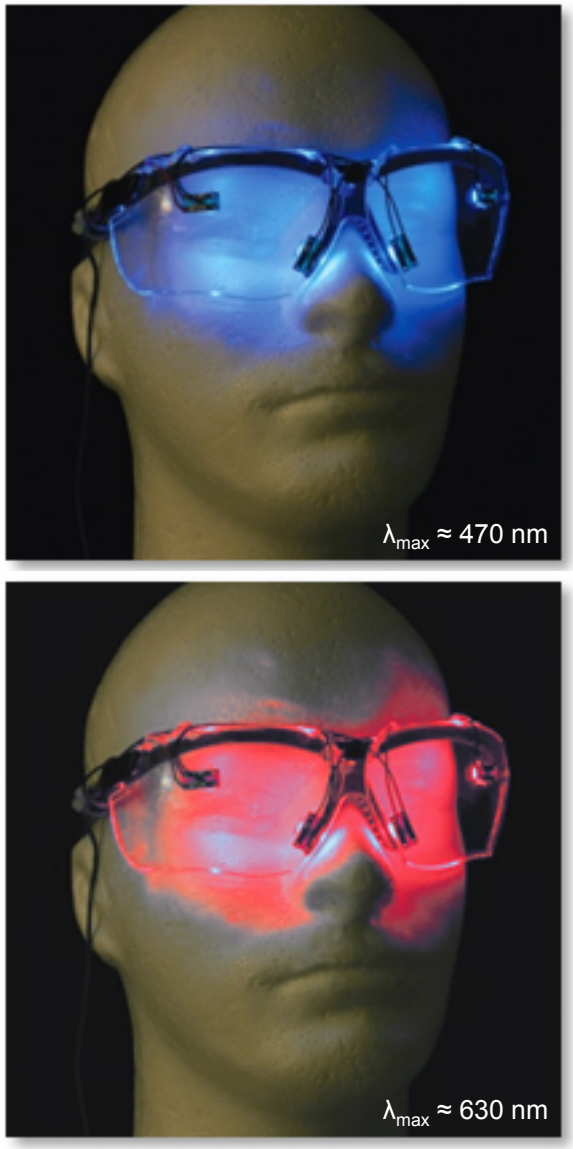
THE FIELD STUDY: Methods |Rail Simulator|

- Participants drove a one-way trip from Kabatas to Bagcilar **(Blue Line)**
- 18.5 km (approximately 60–min of driving)
- 29 stations
- Speed was restricted to 20 km/h at curves with a maximum track speed of 40 km/h



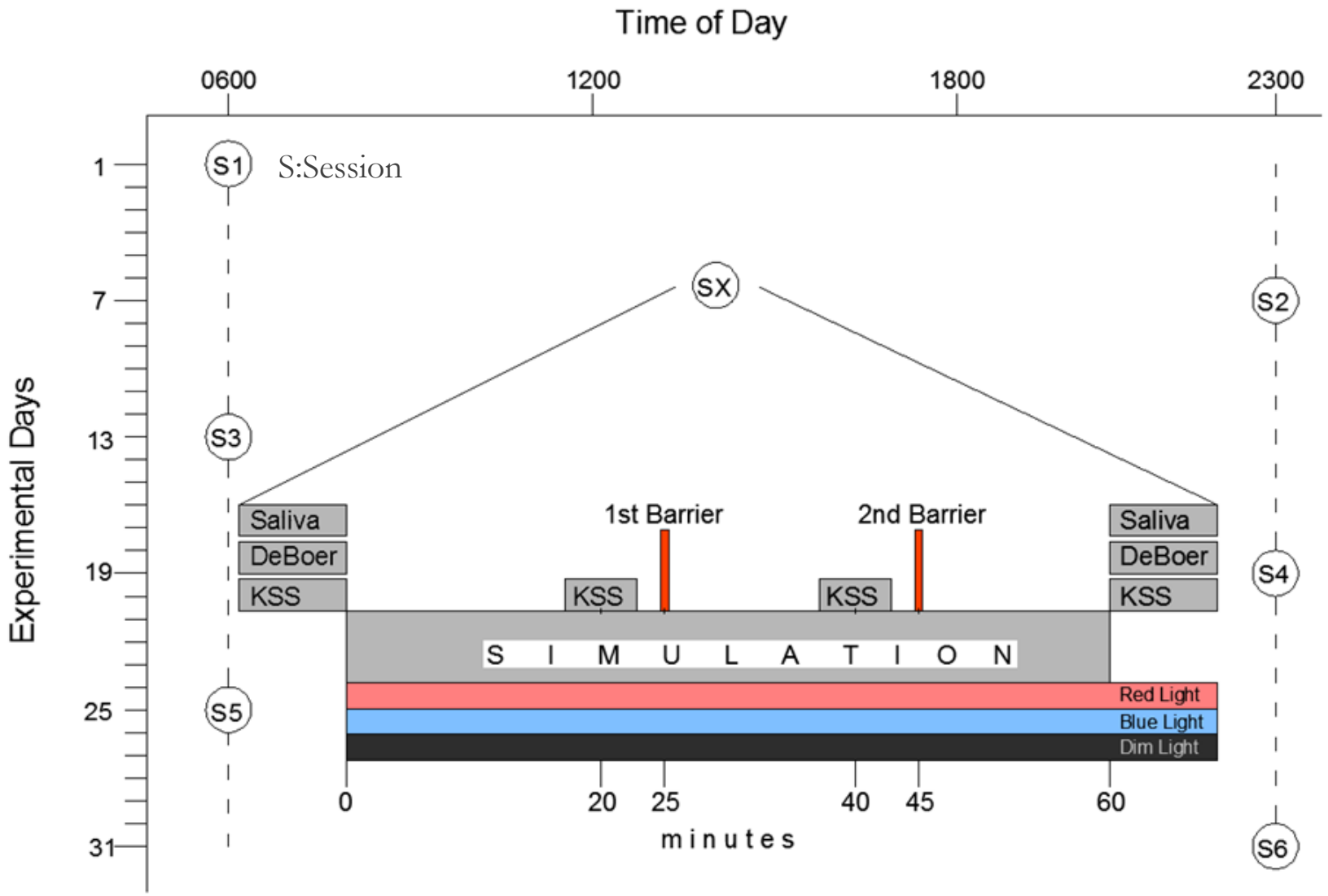
THE FIELD STUDY: **Methods** |Lighting Condition|



- Three lighting conditions; dim (<5 lux), red ($\lambda_{max} \approx 630$nm), and blue ($\lambda_{max} \approx 470$ nm) light administered during the study. Special long-wavelength (red) and short-wavelength (blue) light goggles were used for delivering light to participants' eyes

- Spectral irradiance levels were measured to reach 40 lux (0.401 W/m^2 for 470nm and 0.182 W/m^2 for 630 nm)

THE FIELD STUDY: Methods |Procedure|

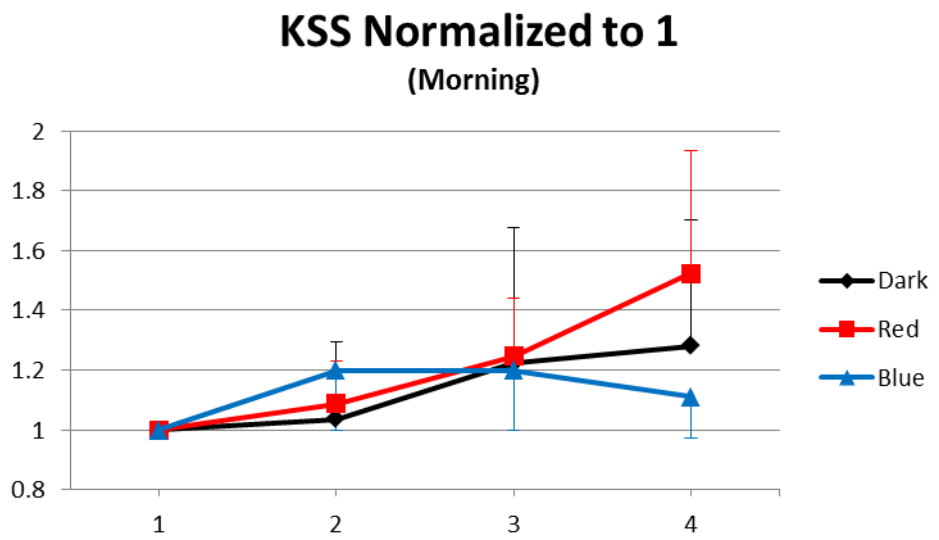


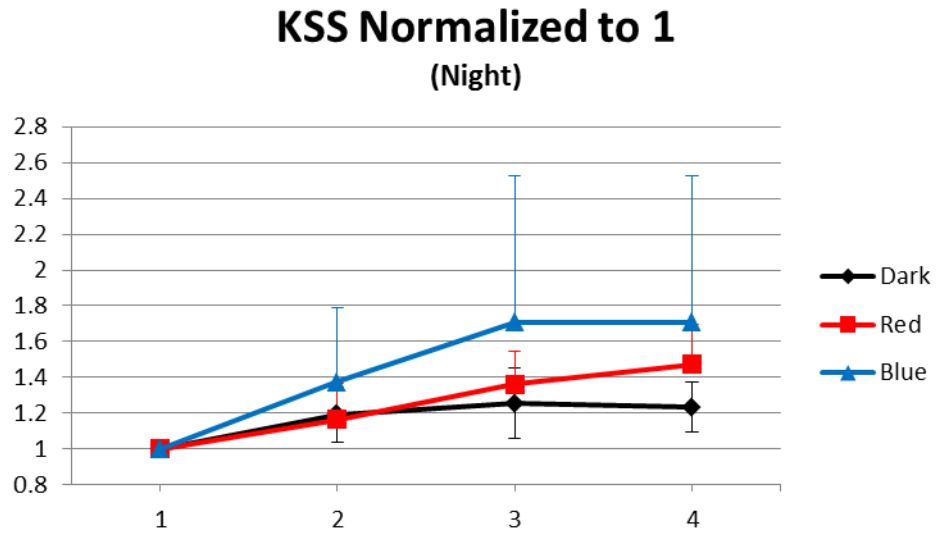
THE FIELD STUDY: **Methods** |Rail Simulator|

- Energy consumption (kWh)
- Number of red light violations
- Moderate speed violations at level crossings (≤ 22 km/h)
- Extreme speed violations at level crossings (> 22 km/h)
- Moderate speed violations (≤4 4 km/h)
- Extreme speed violation (> 44km/h)
- Detection of barriers on the rails

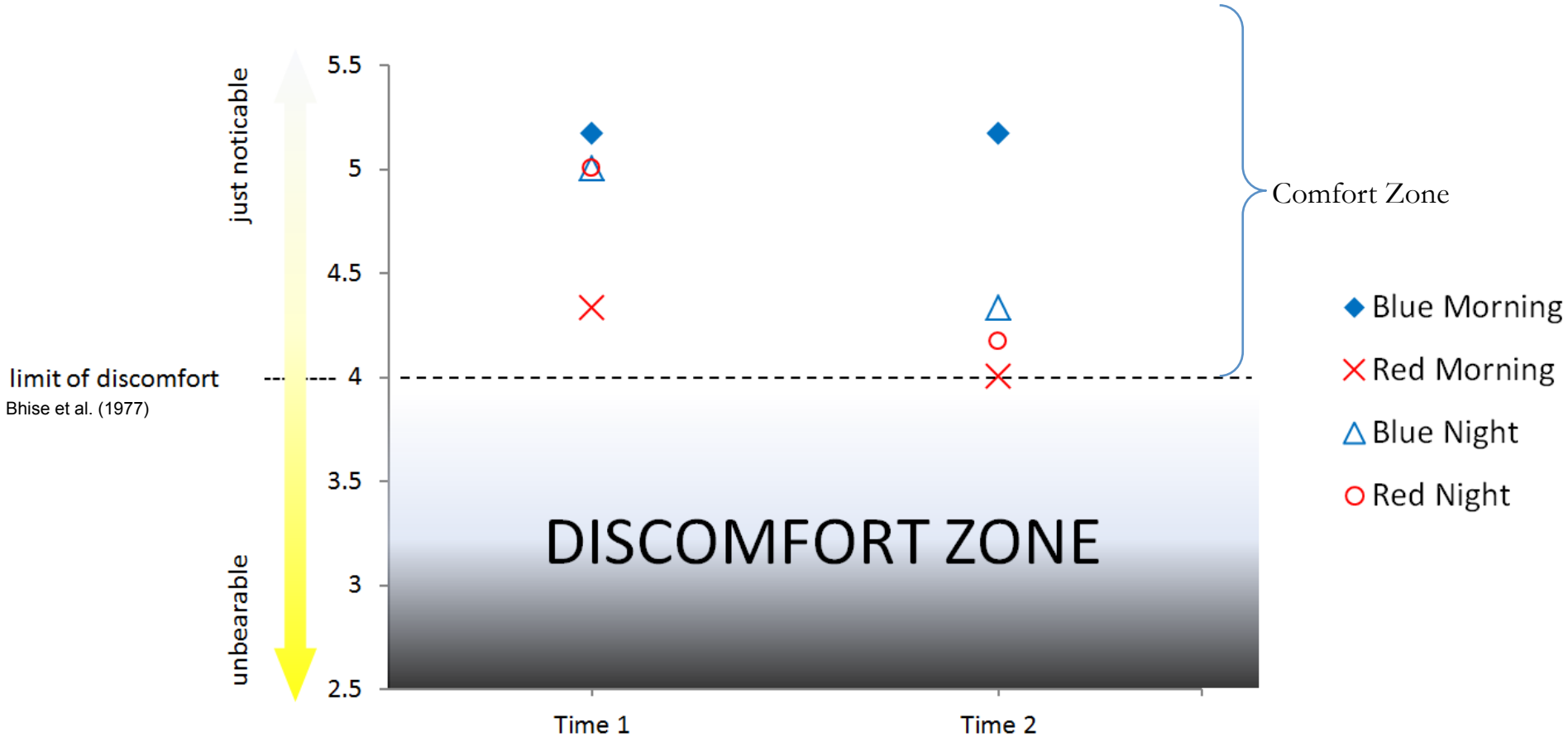
THE FIELD STUDY: Results |Karolinska Sleepiness Scale (KSS)|

- A 3 (lighting conditions) x 2 (sessions) x 3 (time) repeated-measures analysis of variance (ANOVA) revealed a significant main effect of time in the normalized KSS ratings ($F_{2,10} = 5.6$; $p=0.029$)
- Subjects reported feeling sleepier at the end of the experiment compared to the start of the experiment
- There was no significant main effect of lighting conditions ($F_{2,10} = 0.3$; $p>0.1$) and no significant interactions between the variables.



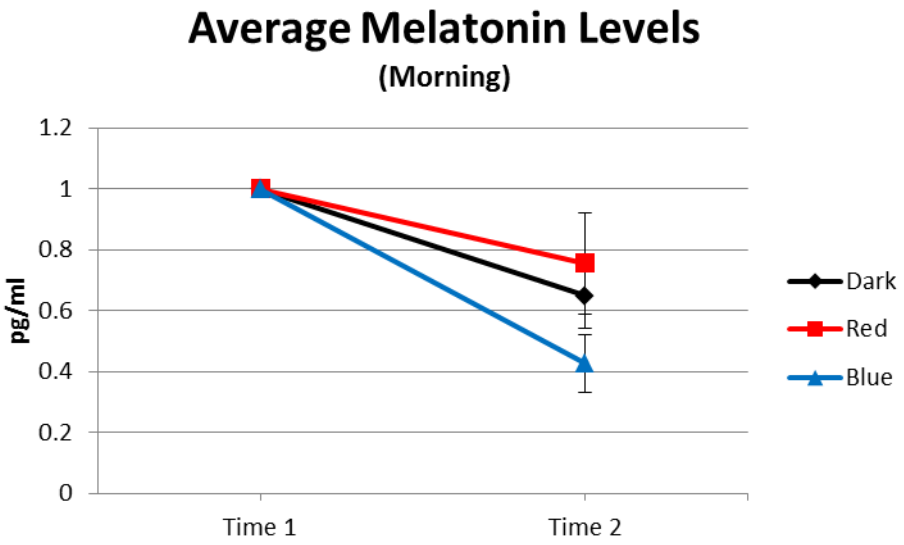


THE FIELD STUDY: Results |De Boer Glare Rating|

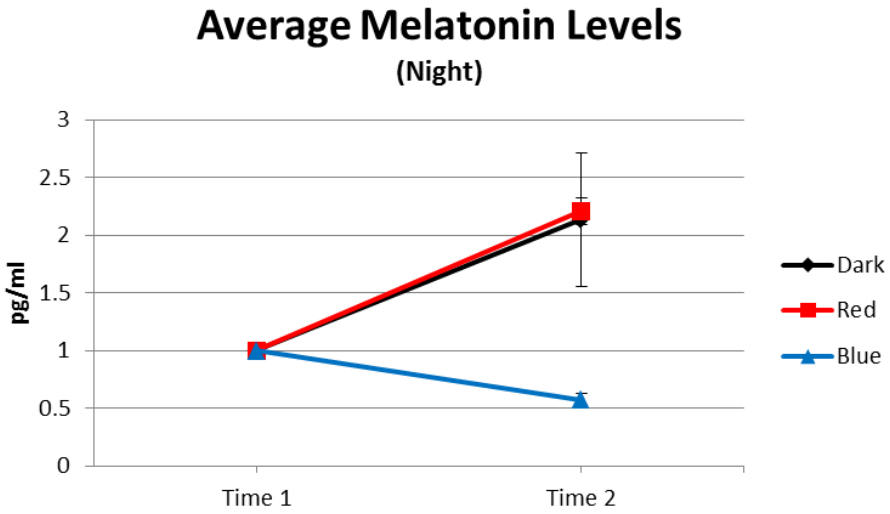


THE FIELD STUDY: Results |Melatonin Suppression|

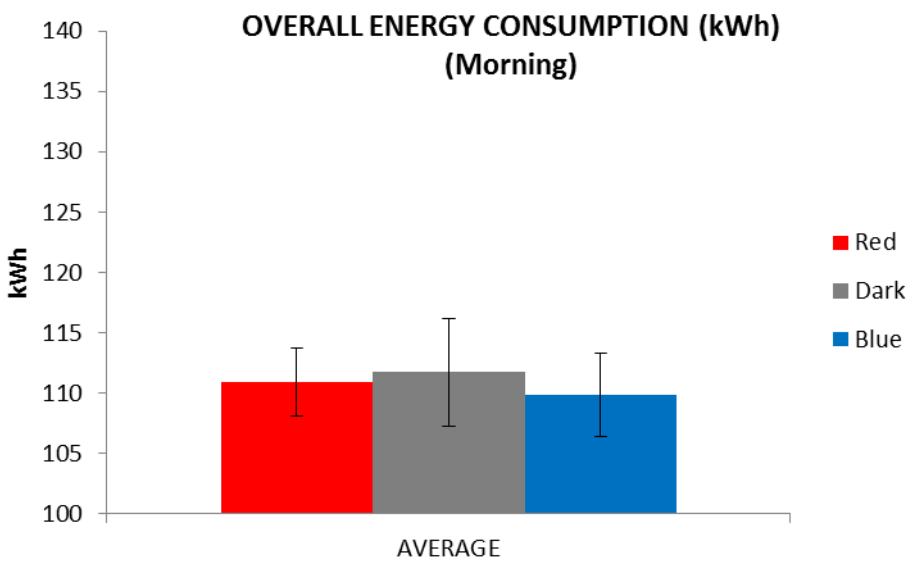
- Average melatonin level, after 1h of "red" light exposure, was significantly greater than the level after 1 hour of "blue" light exposure in the morning and at night [t(3)=3.6, p=0.038, t(3)=10, p=0.002, respectively]

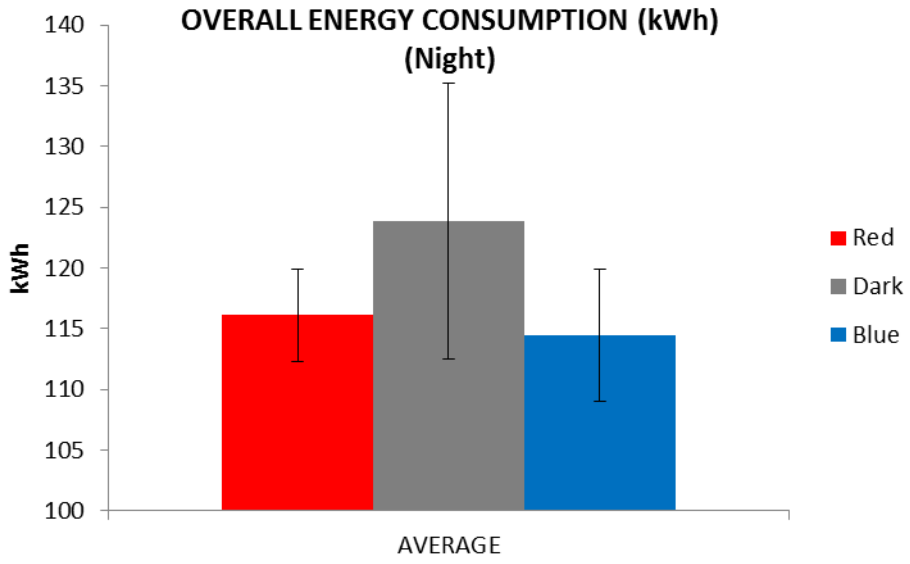


- Post hoc t-tests did not reveal significant differences between "dark" and "red" lighting conditions in the morning and at night [t(3)=0.9, p>0.1, t(3)=0.1, p>0.1, respectively]



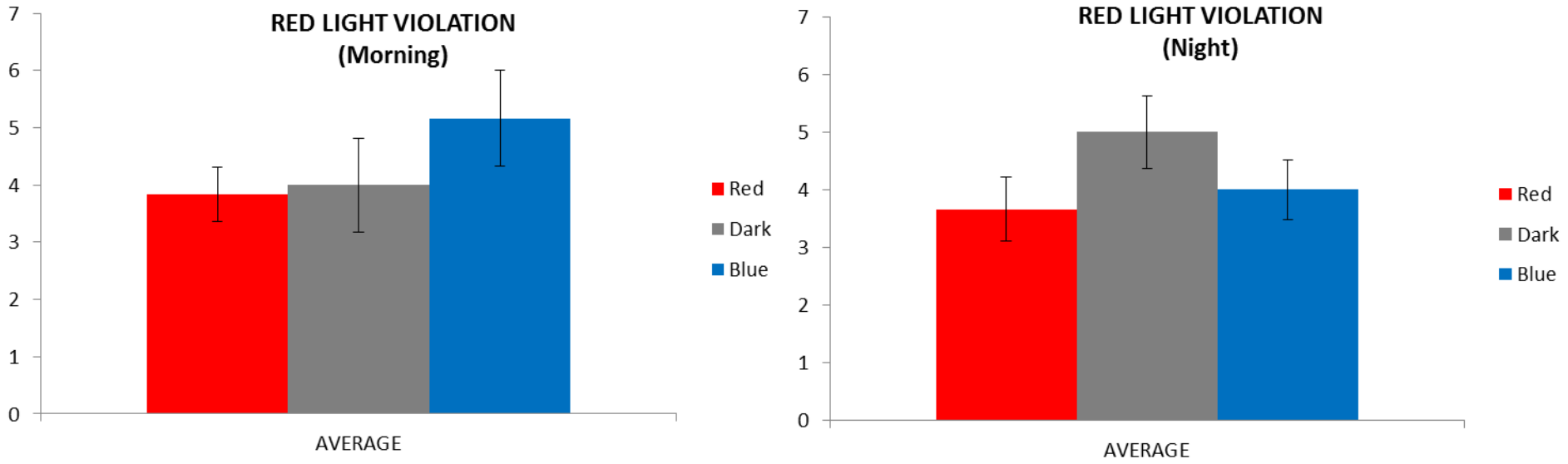
THE FIELD STUDY: Results |Energy consumption (kWh)|





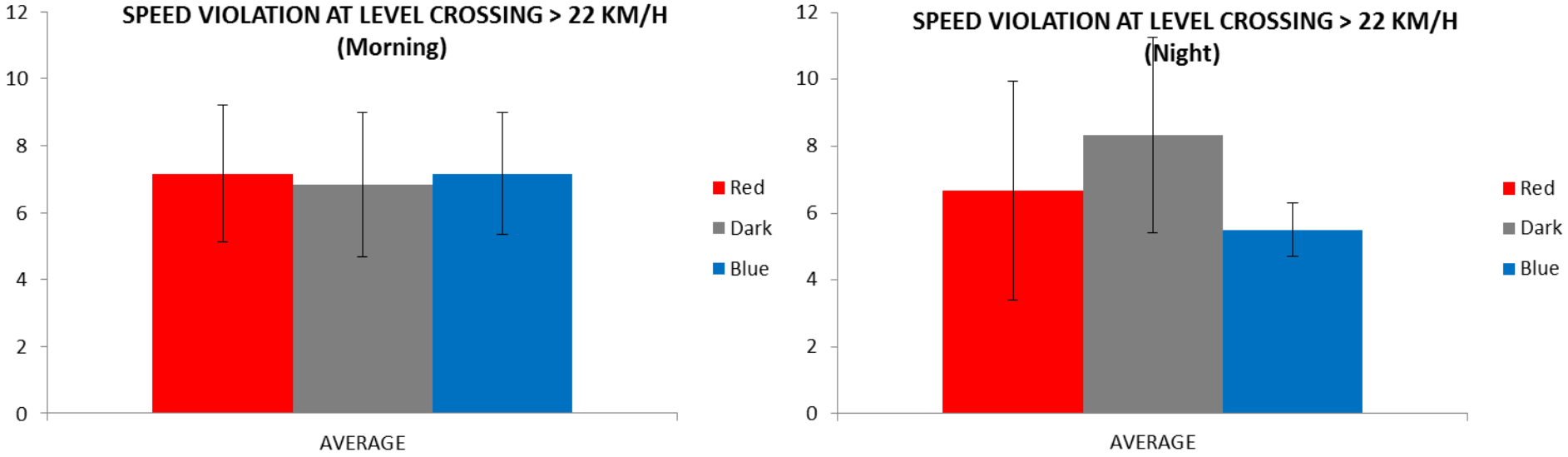
- Although the ANOVA did not show a significant main effect of light ($F_{2,10}$=0.09; p>0.1), there was a trend showing that subjects consumed less energy under "red" and "blue" light exposure than the dark condition

THE FIELD STUDY: Results |red light violation|



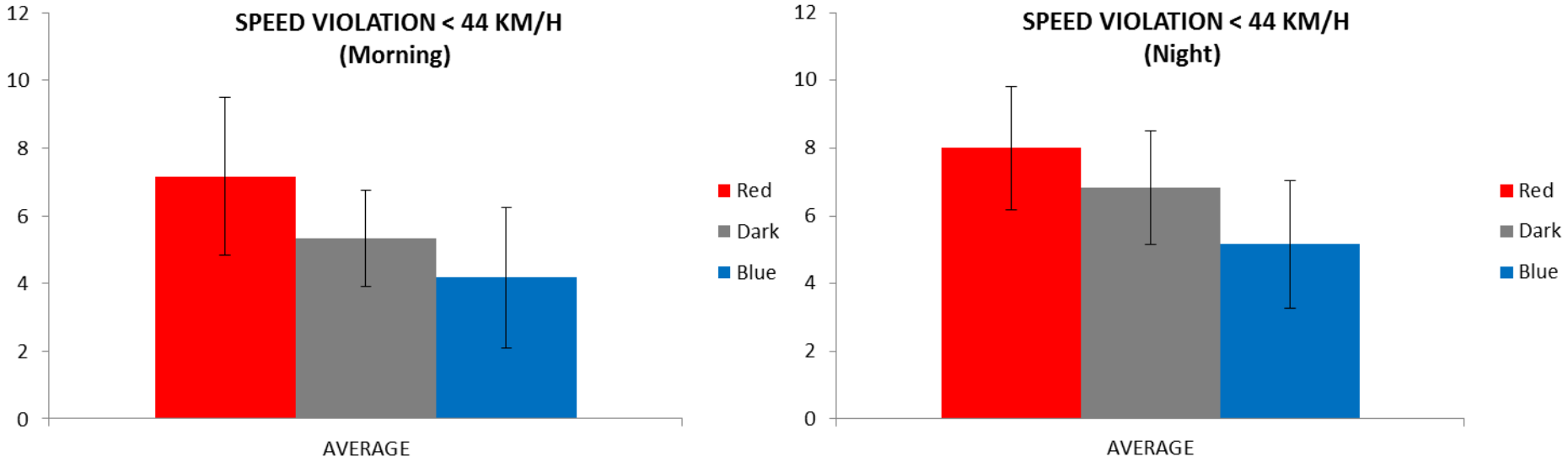
- Again, ANOVA did not show a significant main effect of light ($F_{2,10}$ = 1.07; p>0.1). However, subjects had less "red light violation" under "red" and "blue" light exposure than the "dark" condition during the night session but not in the morning session

THE FIELD STUDY: Results | Extreme speed violations at level crossings (> 22 km/h)



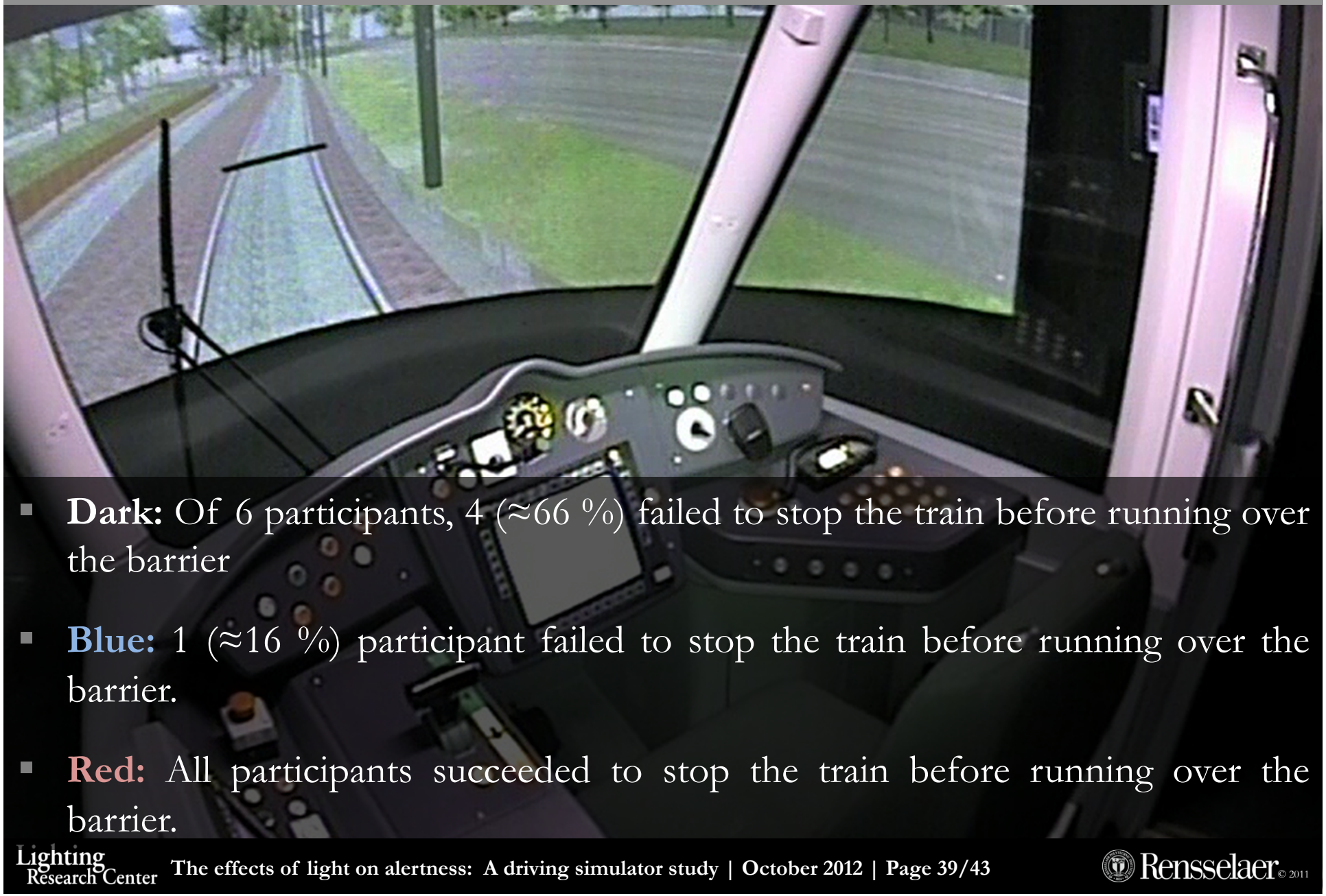
- ANOVA did not show a significant main effect of light ($F_{2,10}$=0.5; p>0.1). However, subjects had less "extreme speed violations" at level crossings under "red" and "blue" light exposure than the dark condition during the night session but not in the morning session

THE FIELD STUDY: Results | Moderate speed violations (≤ 4 4 km/h) |



- ANOVA showed a significant main effect of light ($F_{2,10}$=4.2; p=0.048). Post hoc t-test revealed a significant difference between "red" and "blue" lighting conditions, averaged across the time of day, in "moderate speed violations" [t(5)=0.9, p=0.011]

THE FIELD STUDY: Results | Detection of barriers on the rails |



- **Dark:** Of 6 participants, 4 (≈66 %) failed to stop the train before running over the barrier
- **Blue:** 1 (≈16 %) participant failed to stop the train before running over the barrier.
- **Red:** All participants succeeded to stop the train before running over the barrier.

THE FIELD STUDY: Discussion

- Phenomenon of "simulator sickness" made some participants quit the study
- We don't know at what extent the performance of a participant, who successfully finished the study, was affected by the "simulator sickness" phenomenon, even if we minimized and distributed the effect equally to participants by counter-balancing the order of the light exposures
- Statistically significant differences between some variables couldn't be achieved, maybe because of having a small sample size
- However, some promising trends that suggest a performance increase, by "red" and "blue" light exposure, could be seen in "red light violation", "energy consumption", "extreme speed violation at level crossings", and "moderate speed violation"
- Light goggles during the study were accepted by the drivers, which may encourage designers and decision makers to initiate discussions for designing "circadian" lighting schemes for cabin interiors

THE FIELD STUDY: Key Points

- Safety is inevitable and foremost quality indicator of any railway system, and fatigue is one of the leading causes of accidents in the work place
- Our circadian system works as a "blue sky detector"
- Disrupted circadian rhythm affects human performance
- Light at night suppresses "melatonin" also known as "darkness hormone"
- Not only short wavelength (blue) light but also long wavelength (red) light exposure increases alertness at night and afternoon.
- Light can affect alertness not only by mechanisms dependent on melatonin suppression, which is sensitive to short wavelength light but also on melatonin suppression-independent mechanisms
- Advancing drivers' alertness can be obtained through effective use of light without disrupting circadian rhythm

WHAT IS NEXT? Questions & Challenges

- Light may impact alertness during the day, but mechanism is still unknown
- Do we "see" color for alertness?
- Is there a change in spectral sensitivity from day to night for alertness?
- What is the pathway through which light impacts alertness?
- If light stimulus will be provided in periods, what is the optimum duration for the light intervention to keep drivers alert?
- How long the alerting effects of light remain after the removal of the stimulus?
- What is the best way to deliver alerting light stimulus to driver's eye without compromising the visual performance of the driver?

ACKNOWLEDGEMENTS

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- Office of Naval Research

  VA USA

Thank You!