
Society of Light and Lighting
Light & Sleep
Learn how light can effect our sleep, and suggestions on possible rectification.

Light & Sleep

Peter Raynham (UCL)
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1. Context recap: the direct and indirect NIF effects of light
2. Light for NIF effects: metrics and recommendations
3. Current workspace lighting practice
4. How to improve workspace lighting: a discussion on general and task lighting options
5. Research into task lighting and NIF effects

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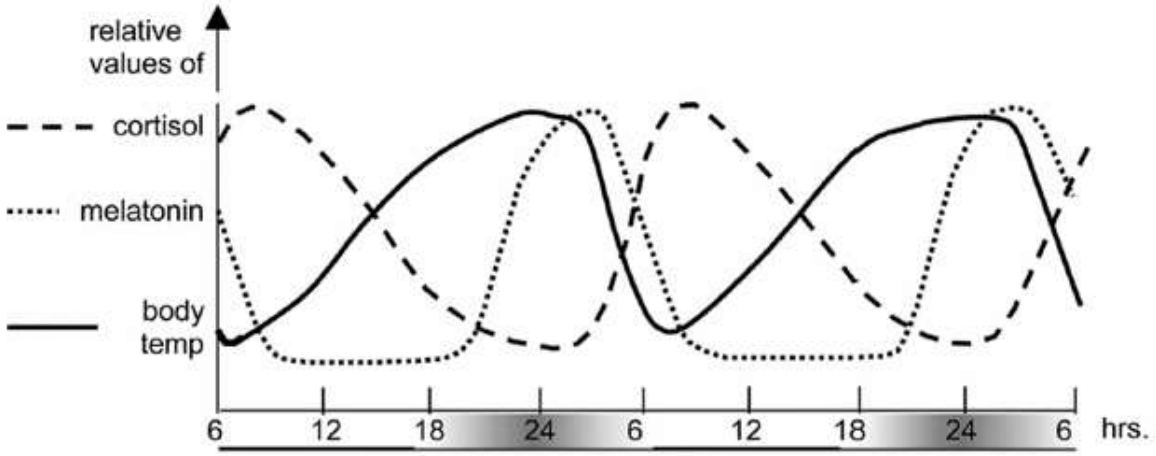
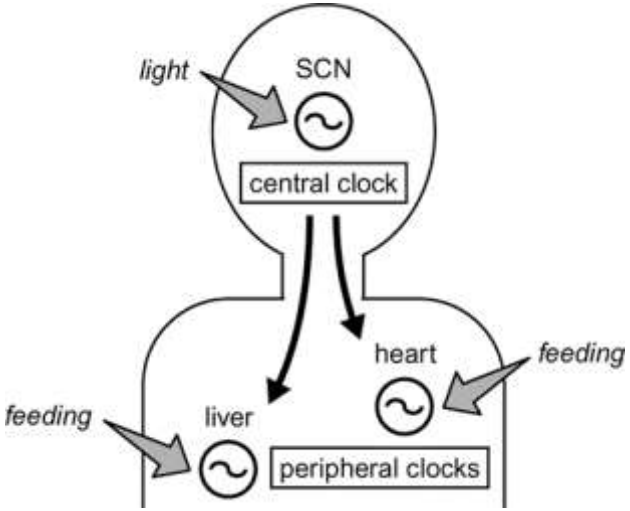
Circadian System



From: 'Lighting for work: a review of visual and biological effect', Wout Van Bommel and Gerrit van den Beld. LR&T vol 36 (2004)



From 'Resetting Mechanism of Central and Peripheral Circadian Clocks in Mammals', Tsuyoshi Hirota and Yoshitaka Fukada. ZOOLOGICAL SCIENCE 21 (2004)

Having the right chemical cocktail inside us throughout the day not only defines our daily personality, but also the quality of our life, health and how we sleep. Getting this is right is a matter of survival.

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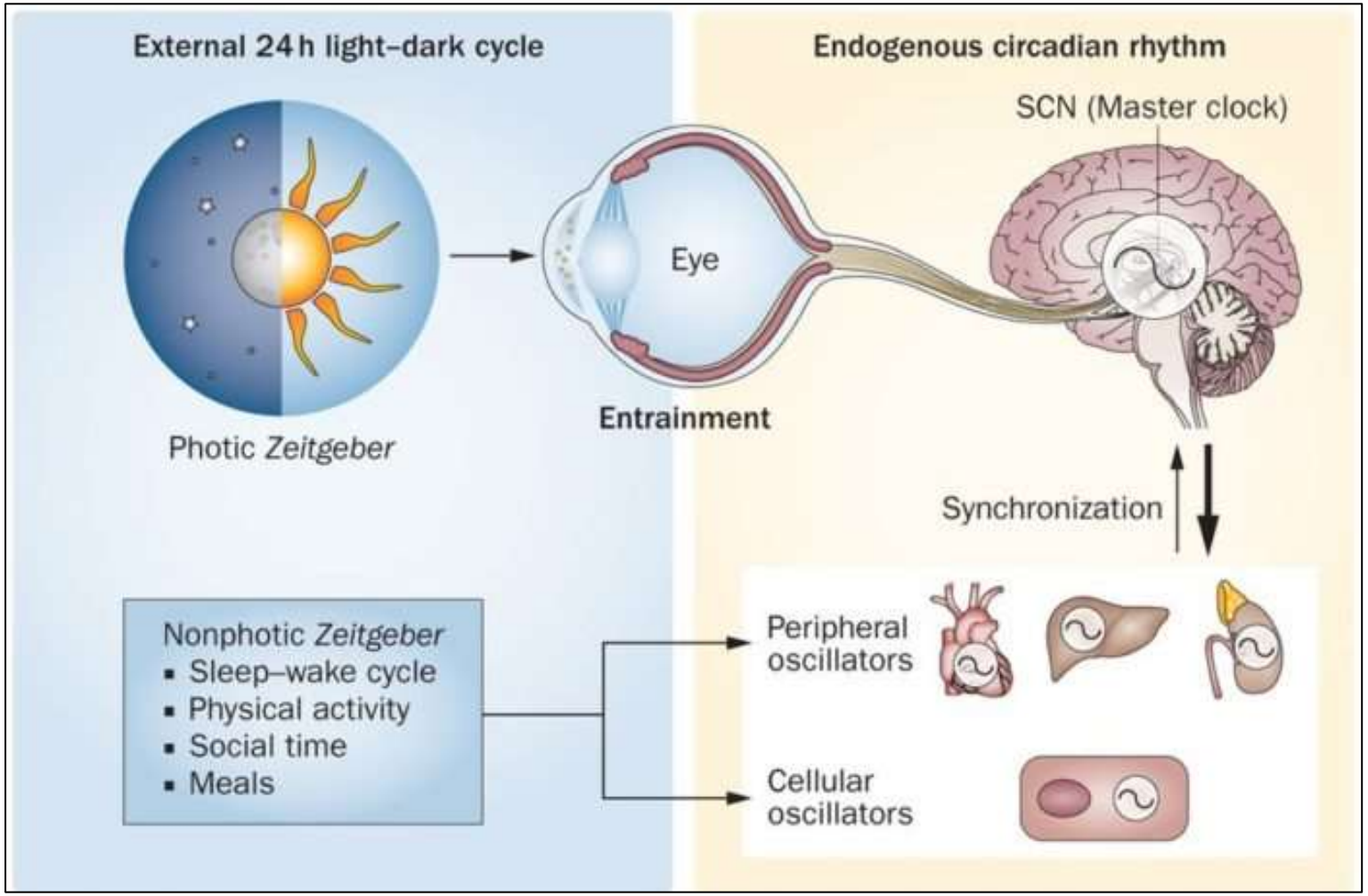
Light and Entrainment

What cues synchronise / throw off our body clock. Most importantly: good light and bad light.



From: Clocking in: chronobiology in rheumatoid arthritis, 2015, Buttgereit et al

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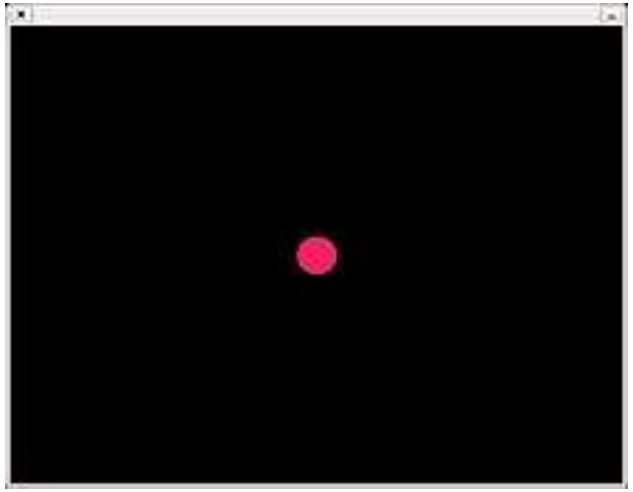
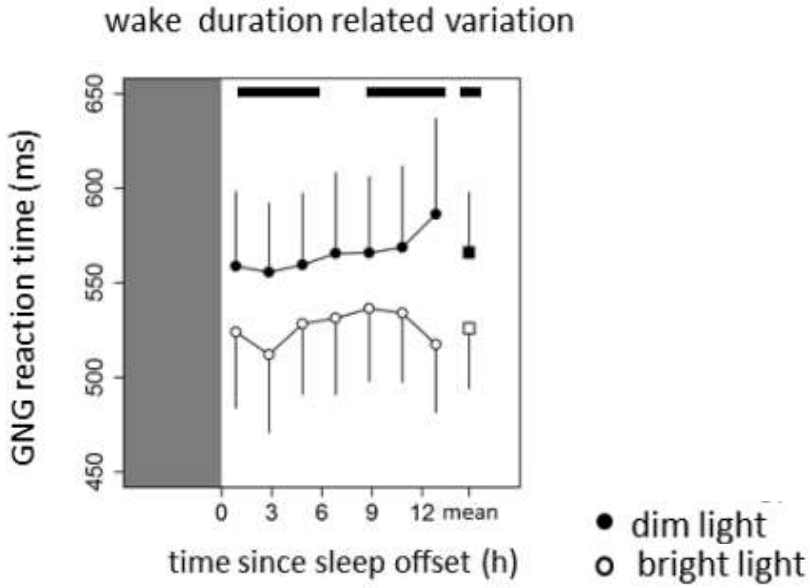
The Direct (Acute) Alerting Effect of Light

- The direct alerting effect of light refers to the immediate psychological and physiological response that a person experiences upon exposure to light.
- Neuroendocrine system
- Cognitive functions (neurobehavioural)



Psychomotor Vigilance Task test example



Forced desynchrony testing
From: Light effects on circadian and homeostatic regulation: alertness increases independent of time awake, 2020, Lok et al

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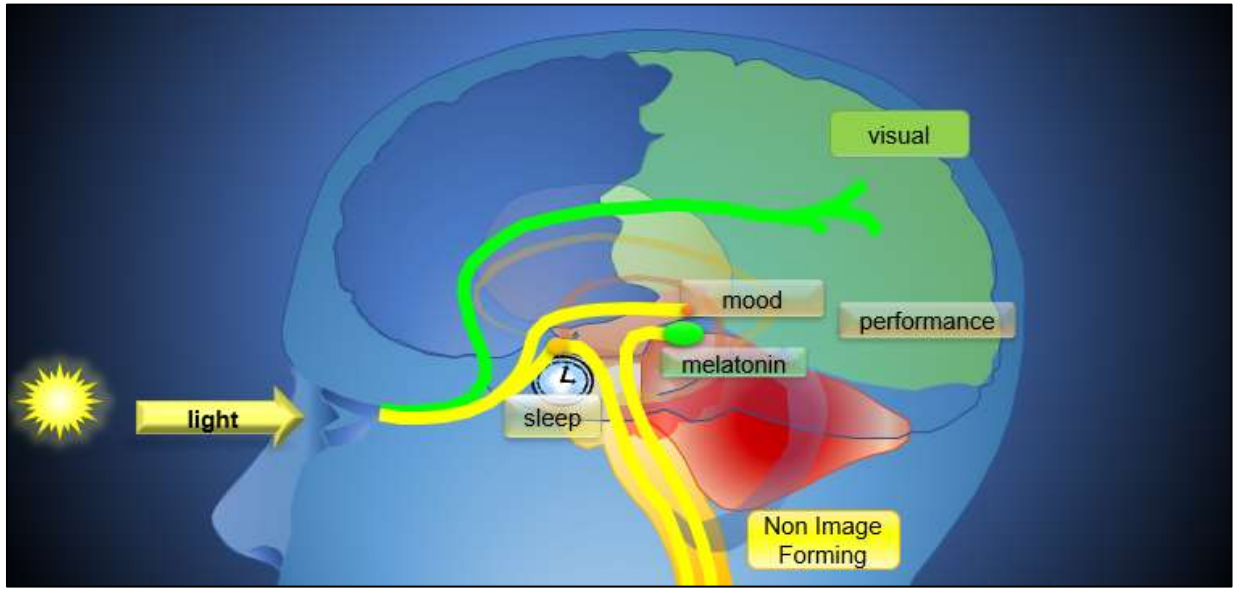
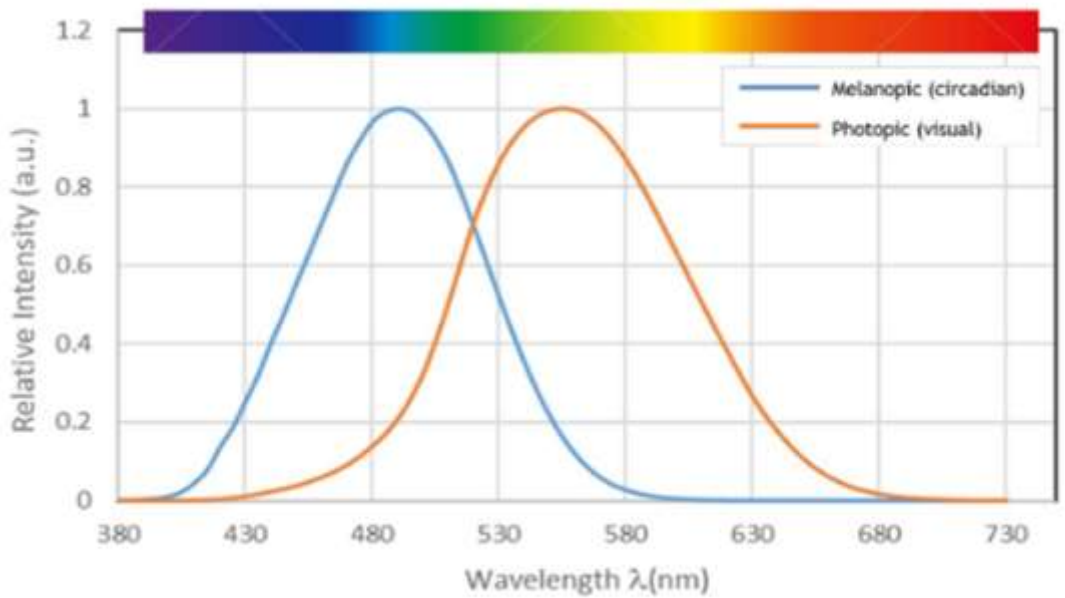
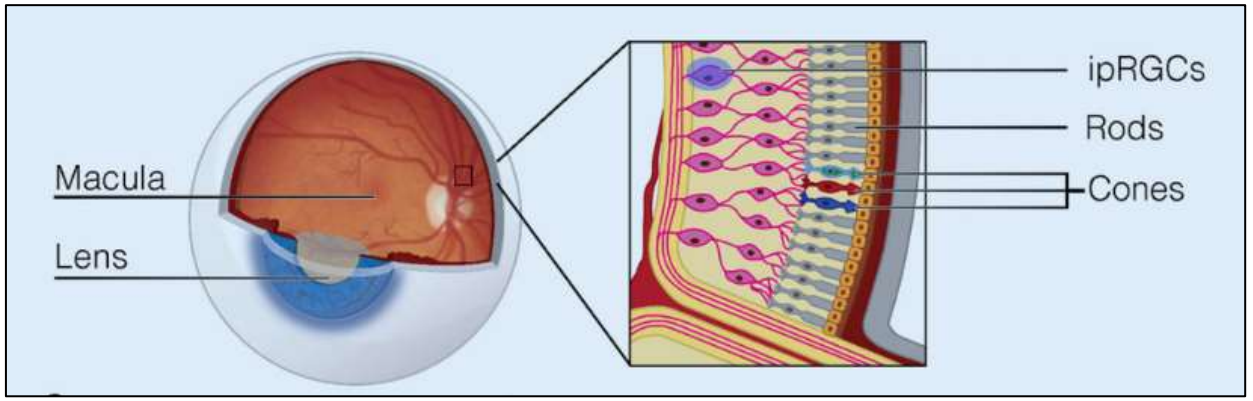
Light for NIF effects, 1
Neural Pathways





Graphic by Marijke Gordijn, Chrono@Work. Shown with permission.



From ‘Effects of light on human circadian rhythms, sleep and mood’, 2019, by Blume et al

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Light for NIF effects, 2

The International Standard CIE S 026/E:2018
MELANOPIC EQUIVALENT DAYLIGHT ILLUMINANCE (m-EDI)

DEMO

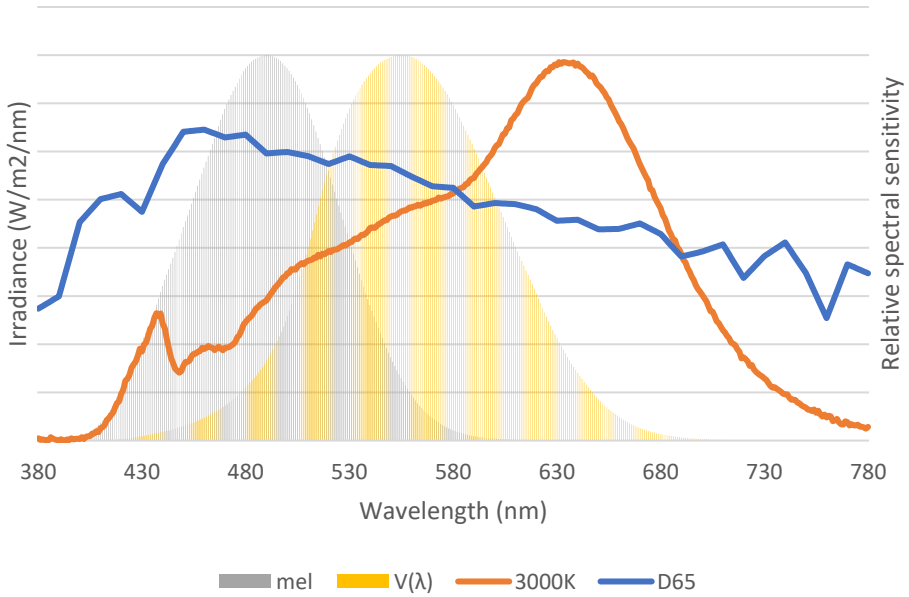
Chronobiologists give healthy lighting advice related to daylight.

How to think about outputs from electric light sources?

MELANOPIC EQUIVALENT DAYLIGHT ILLUMINANCE (m-EDI) represents the illuminance produced by radiation conforming to standard daylight that provides an equal melanopic irradiance as a given electric light source.

BIOLOGICALLY speaking electric light sources should have as high a melanopic content as possible. Two other considerations:

- Psychological
- Energy consumption



CCT = 3000K
CRI = 96.8
m-DER (melanopic Daylight Efficiency Ratio) = 0.5407

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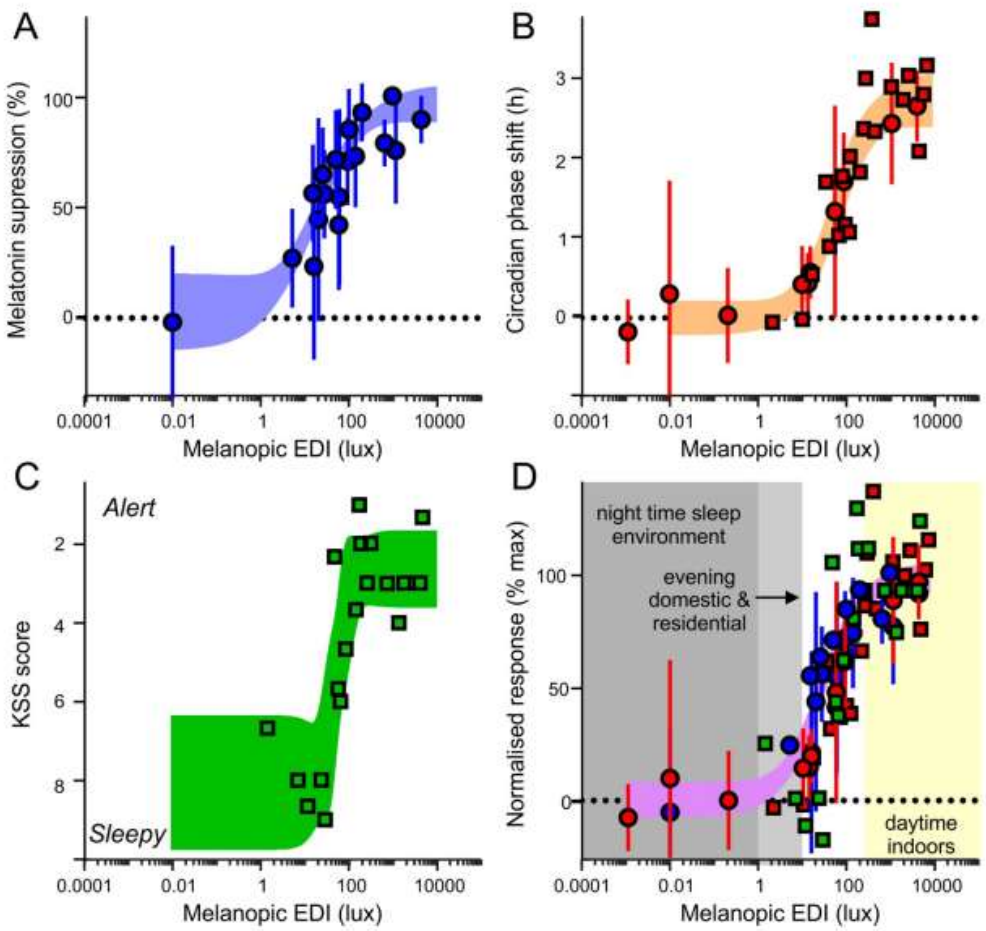
Light for NIF effects, 3

‘CONSENSUS VIEW. Recommendations for daytime, evening, and nighttime indoor light exposure to best support physiology, sleep, and wakefulness in healthy adults’ (Brown et al, 2022).’



- Throughout the daytime: 250 m-EDI lux vertical, minimum
- During the evening, starting at least three hours before bedtime: 10 m-EDI lux vertical, maximum
- The sleep environment should be as dark as possible: 1 m-EDI lux maximum

From: Consensus view. Recommendations for daytime, evening, and nighttime indoor light exposure to best support physiology, sleep, and wakefulness in healthy adults. 2022. Brown et al

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Light for NIF effects, 4

“Integrative Lighting” Example From The Well Standard

WELL v2, Q1-Q2 2023

Imperial 中文 Sign in

Light

Overview

- P L01 Light Exposure
- P L02 Visual Lighting Design
- 3 Pts L03 Circadian Lighting Design
- 2 Pts L04 Electric Light Glare Control
- 4 Pts L05 Daylight Design Strategies
- 2 Pts L06 Daylight Simulation
- 1 Pt L07 Visual Balance
- 3 Pts L08 Electric Light Quality
- 3 Pts L09 Occupant Lighting Control

REQUIREMENTS

WELL Core — Collapse All

Part 1

Meet Lighting For Day-Active People (Max: 3 Points)

For All Spaces Except Dwelling Units | For Dwelling Units

For workstations used during the daytime, electric lighting is used to achieve the following thresholds:

a. The following light levels are achieved for at least four hours (beginning by noon at the latest) at a height of 18 in above the work-plane for all workstations in regularly occupied spaces:

Tier	Threshold		Threshold for Projects with Enhanced Daylight	Points
1	At least 150 EML [136 M-EDI(D65)]	OR	The project achieves at least 120 EML [109 M-EDI(D65)] and L05 Part 1 or L06 Part 1	1
2	At least 275 EML [250 lux M-EDI(D65)][11]	OR	The project achieves at least 180 EML [163 M-EDI(D65)] and L05 Part 1 or L06 Part 1	3

b. The light levels are achieved on the vertical plane at eye level to simulate the light entering the eye of the occupant.

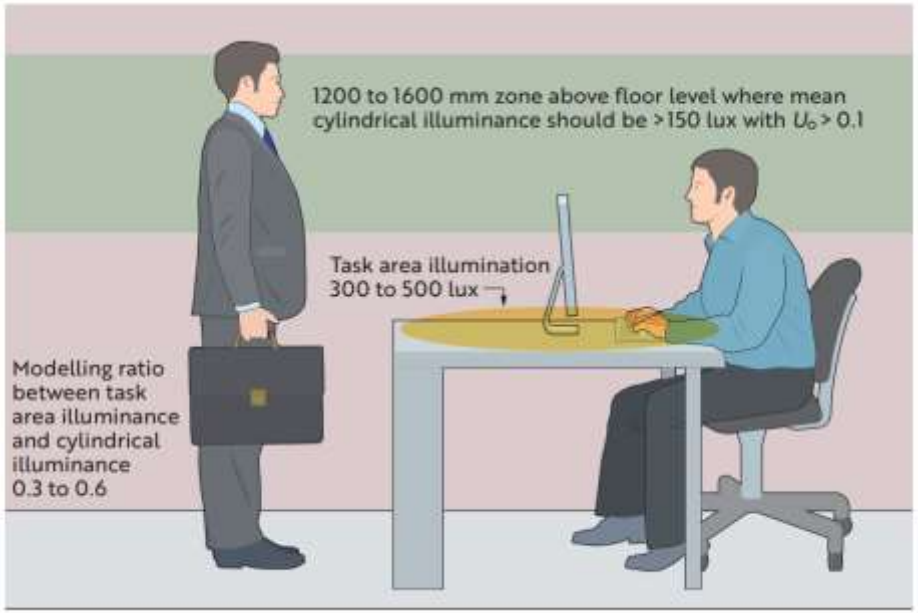
Verified by Performance Test

Note:
Refer to the Performance Verification Guidebook for information on sensor/testing requirements, required testing duration and compliance calculations.

References

1. Figueiro MG. Disruption of Circadian Rhythms by Light During Day and Night. Curr Sleep Med Reports. 2017;3(2):76-84. doi:10.1007/s40675-017-0069-0

Current office lighting – biological twilight



From SLL's Lighting Guide 7: Lighting for offices, 2023

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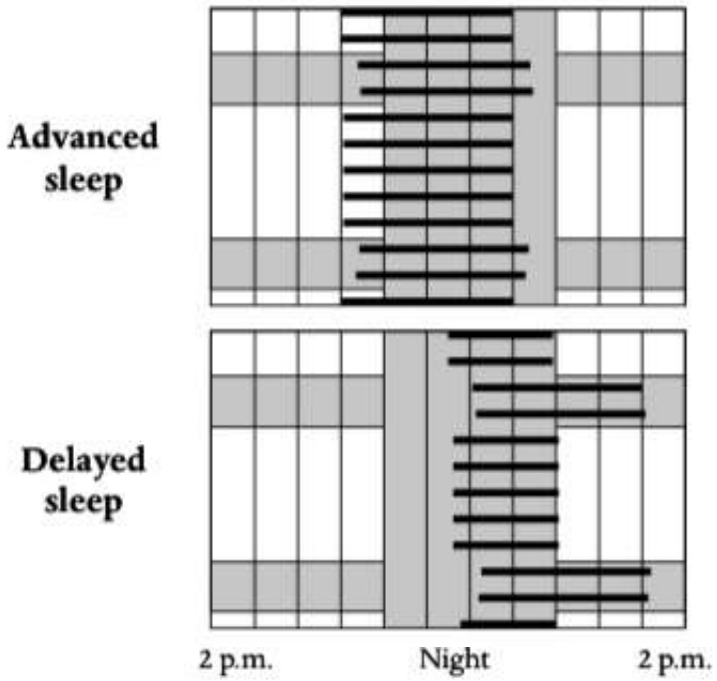
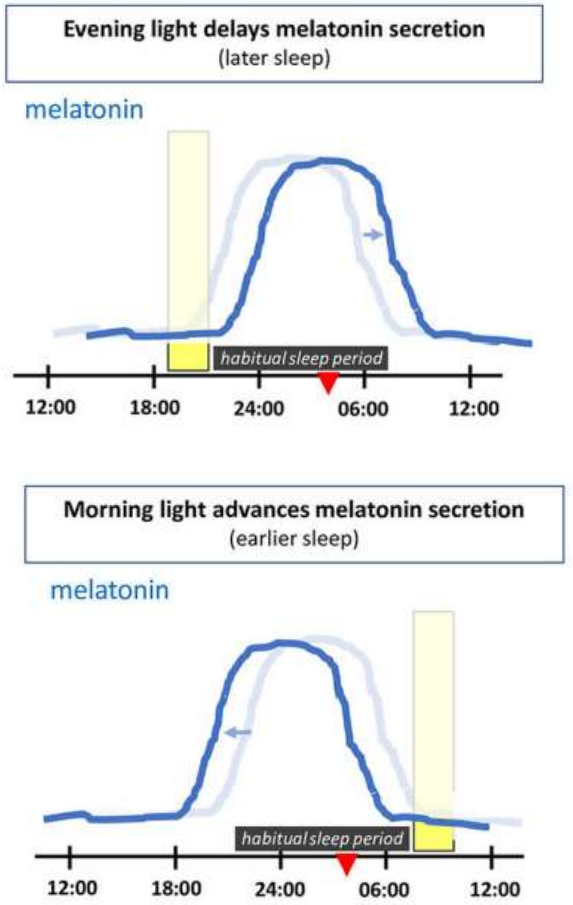
Need to provide more light in work environment, 1



Advanced and Delayed Sleep Phase Disorder
From: 'Life Time' by Russell Foster, 2022



From: The Lighting Environment, Its Metrology, and Non-visual Responses, Luc J. M. Schlangen and Luke L. A. Price, 2021

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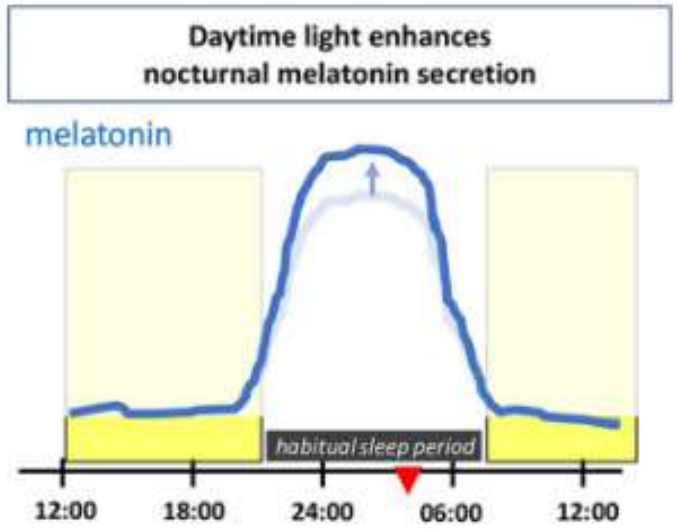
Need to provide more light in work environment, 2



The Lighting Environment, Its Metrology, and Non-visual Responses, Luc J. M. Schlangen and Luke L. A. Price, 2021

The effects on nighttime sleep of extremes in daytime EDI levels were compared in a study by Geerdink et al.

Higher Equivalent Daylight Illumination levels led to:

- Earlier Dim Light Melatonin Onset
- Higher sleep efficiency
- Higher percentage Rapid Eye Movement sleep
- Higher accumulation rate of slow wave activity during sleep

‘The influence of daytime light on nighttime sleep’
Moniek Geerdink, Tom Woelders, Domien D.G.M. Beersma, Marijke C.M. Gordijn, 2017

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Hard to do with general lighting systems…

Assumptions		
Horizontal Illuminance	500	lx
Ratio Vert/Hor	0.4	
m-DER	0.7	
UF (AxE/ϕ)	1	
Maintenance Factor	0.8	
Efficacy	115	lmw^{-1}
Results		
m-EDI	**140**	
Power Density	**5.43**	wm^{-2}

Using the typical light technical figures above for a design to 500lux horizontal on the working plane, to increase to 250m-EDI lux vertical would mean the capital and operational expense of increasing flux by 80%, and:

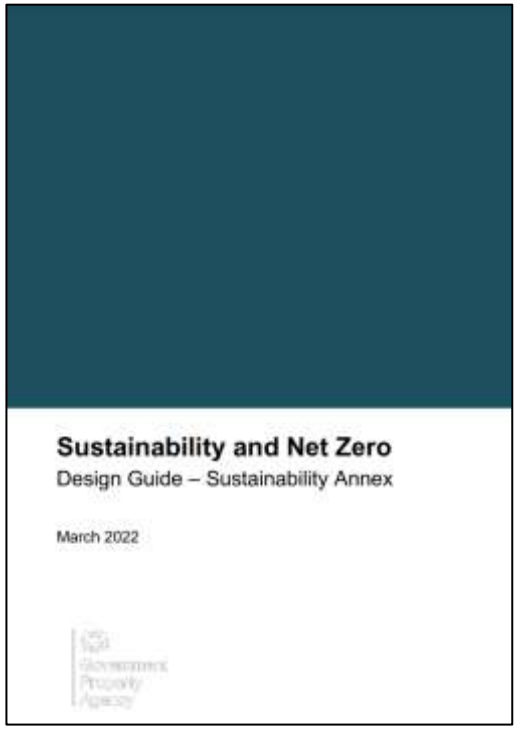
- **Horizontal Illuminance to 900lux**
- **LPD to 9.77 W/m²**

A comparison with **local task lighting**, assuming 6m2 per person and 13W per task light.

5.43 W/m² general + 13/6 W/m² task = 7.6 W/m²
> 25% less.

As an example LPD threshold the Government Property Agency cites **4.5W/m²** for the Net Internal Area among its 'Supporting Targets'

(This guide sets standards for Sustainability and Net Zero for the Government Workplace Design Guide to be applied to all Government Estates buildings.)



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Attention to source SPD

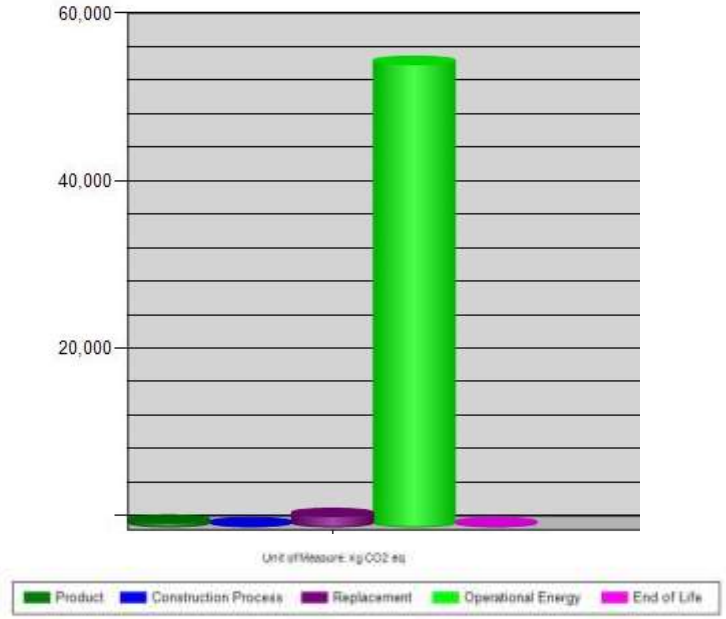
1. Melanopic content at least sufficient to meet NIF recommendations for healthy light – physiological
2. The CCT the client wants – psychological
3. Lowest possible energy consumption

There will have to be trade-offs to find the best fit.

There should be no trade-off with 1.

Comparison of a colour appearance with CCT 3000K and 5000K, CRI equal

Comparison of a building's Global Warming Potential by life cycle stages (per m^2)



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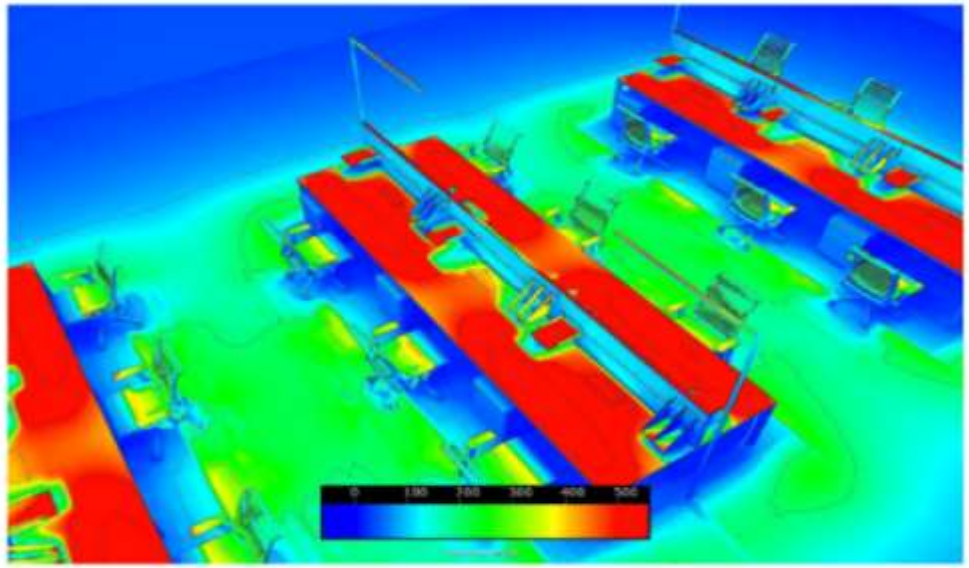
Can localised lighting work?



Avoid unwanted light: consider task / ambient layers.
From: BDP Ideas. The Lighting Circular Economy, 2022.
https://www.bdp.com/globalassets/ideas/lighting-the-way-to-a-circular-economy/bdp-ideas-the-lighting-circular-economy.pdf?fr=sNGRlNDQwMjA2MTU

- Comfortable for worker / coworkers?
- Any adaptation issues connected to ratio of task and general surround illumination?
- m-EDI lux recommendations can be obtained but static? Effect of varying:
  - Daylight?
  - Task in hand?
  - User mood / health?
- Visual intrusion on desk?

And most of all ….

- Will it have an impact?

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Will it have an impact?

1. There is much evidence for nighttime light-induced alertness improvements but less research indicating the direct alerting effect of light during the day.

2. Research has mostly been carried out in laboratory conditions (isolating variables) and extreme light levels. What would be the outcome in a real world setting with:

    a. Normal artificial light levels in normal workspaces
    b. Varying distances from a window;
    c. Varying participant age, sex and chronotypes;
    d. Varying participant light-related experiences outside of the working day;
    e. Varying participant all zeitgeber experiences,
    f. Differing daytime practical tasks within and between participants rather than standardised alertness tests.
    g. Progress of the seasons
    h. Schedule? 100% office based or office / home hybrid? Time in office / time on site?

With all these variables is it possible to demonstrate a real impact?

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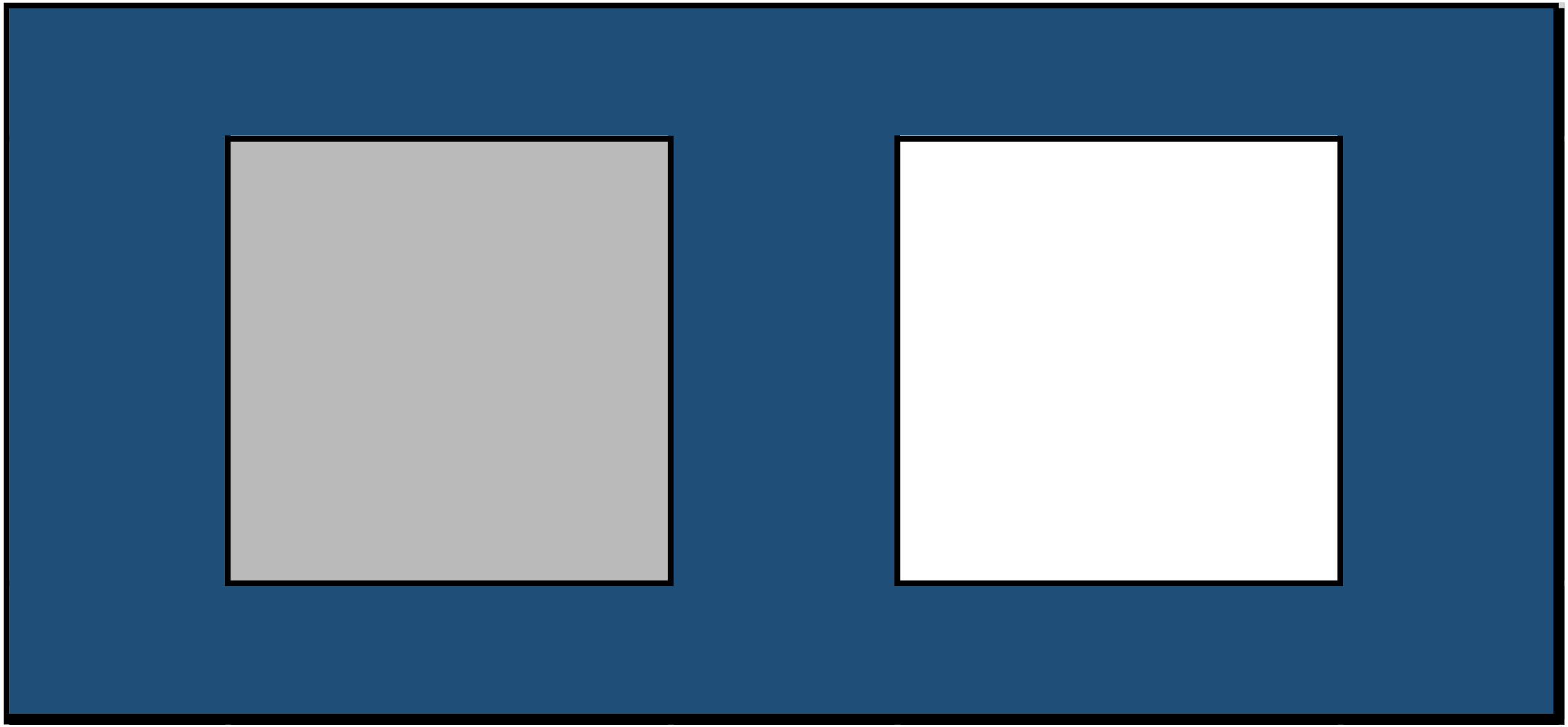
Designing the Experiment

- What is being assessed?
- What needs to be avoided?

Matching Perceptions



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Limits on the Experiment

- Screen luminance limits
- Maximum ratio between test and control luminance
- Slow changes in luminance
- Common subject questions each day

Subjects should not know if they have Test or Control conditions

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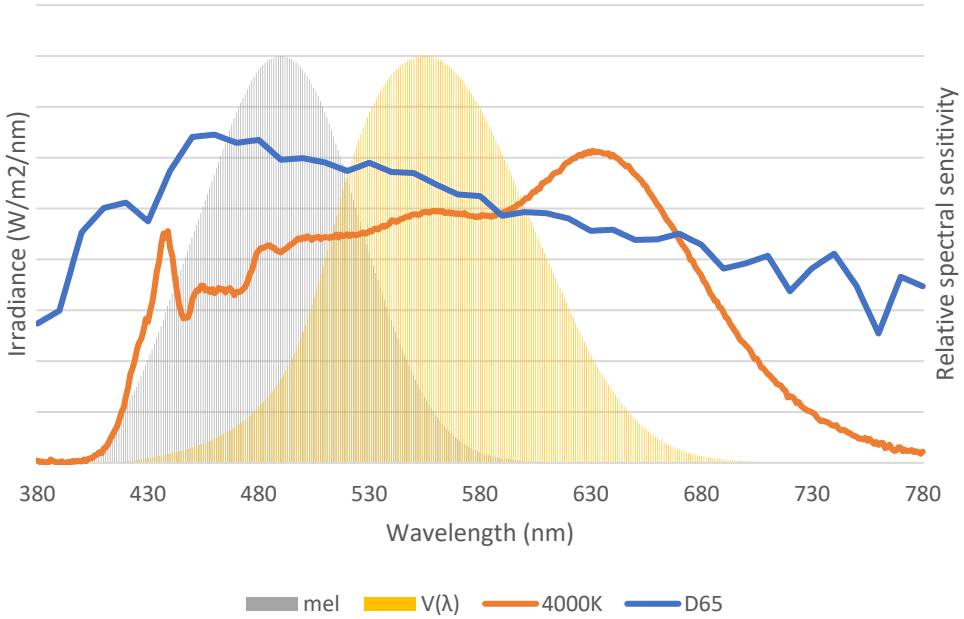
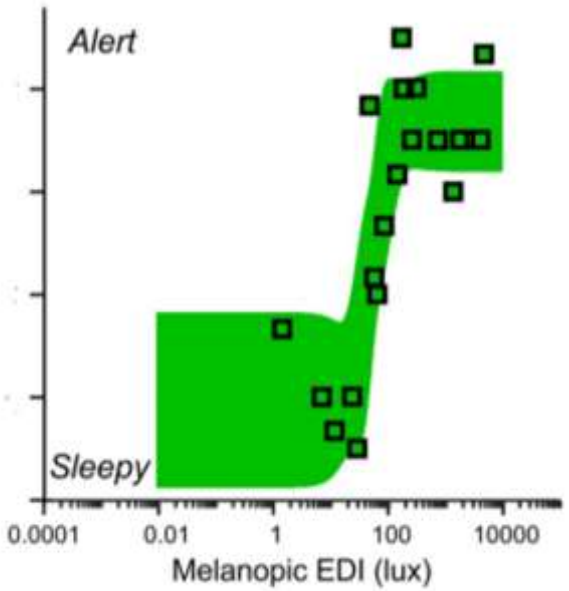
Task Light

Tile size: 25x30cm
Height and tilt adjustable to suit participant

Control	~ 125 m-EDI lux
Test	~ 250 m-EDI lux





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Data Collection

- Previous night's sleep
- Sleepiness
- Mood
- Comments

← Collected morning and afternoon

Data collected via web page following reminder email

End of test feedback interview

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Mood

alarmed	calm	frustrated	sad
angry	content	gloomy	satisfied
annoyed	delighted	happy	serene
aroused	depressed	miserable	sleepy
astonished	distressed	pleased	tense
at ease	droopy	relaxed	tired
bored	excited		

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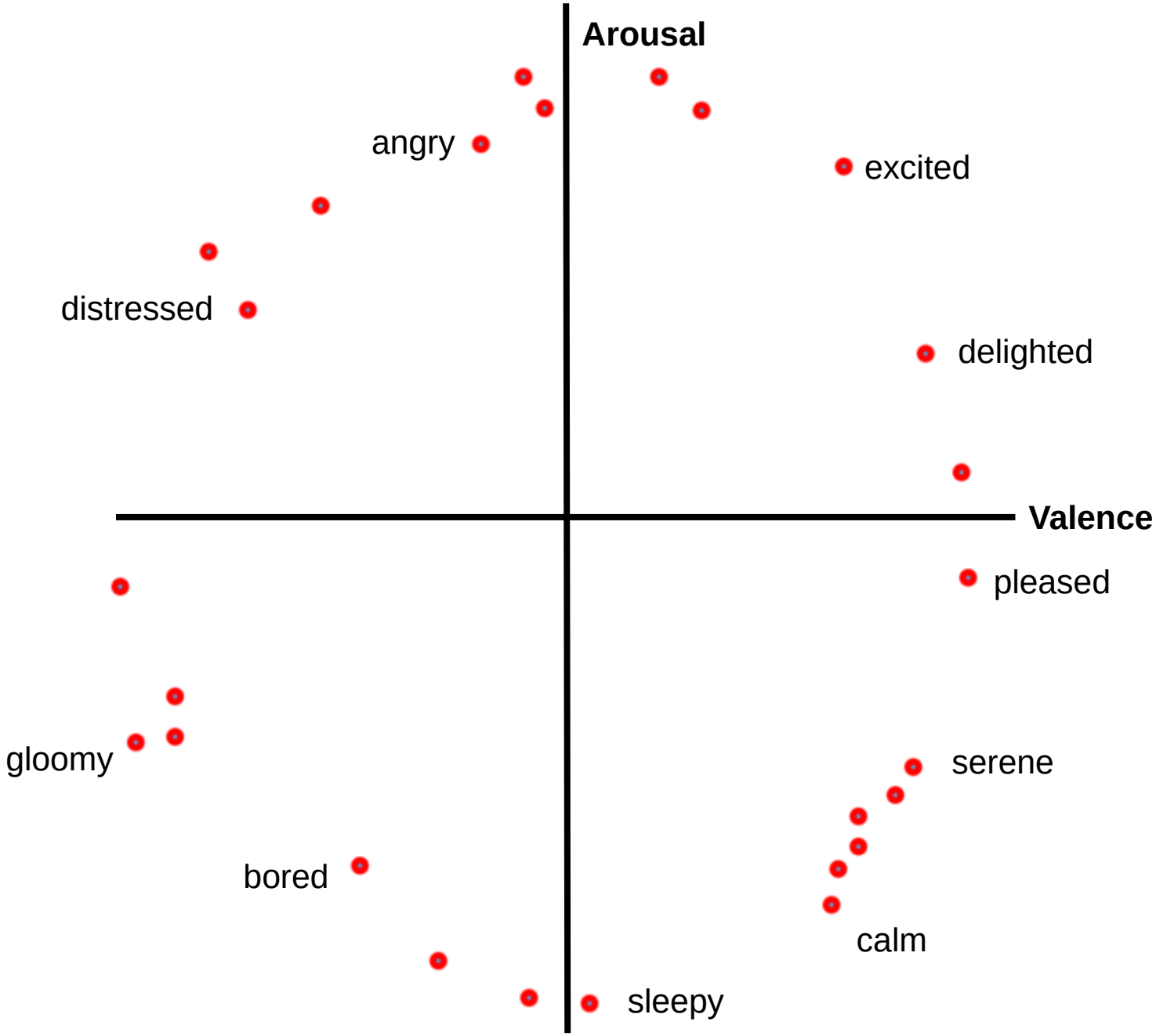

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Sleepiness

1 2 3 4 5

Karolinska Sleepiness Scale

Daily Test Routine

Initial switch on light is assigned to a particular scene and set itself slowly.

Questions	
Morning	**Afternoon**
How did you sleep (comments)	Karolinska Sleepiness question
Karolinska Sleepiness question	Mood Words
Mood Words	How was the day (comments)

Expected Results

- Relatively small change in stimulus
- Time in office only part of day

Daily use of light source should reveal if it is accepted

Difference in mood a sleep assessment between Test and Control expected to be small

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Data Cleaning – Mood Question

Word list checked for antonyms

Examples

at ease	alarmed
bored	aroused, astonished
calm	alarmed, aroused,
content	alarmed, angry, annoyed
delighted	alarmed, angry, annoyed
depressed	delighted,
distressed	at ease, calm, content, delighted
droopy	alarmed, aroused, astonished
excited	calm, sleepy
gloomy	delighted
happy	angry, annoyed, sleepy, tense
miserable	delighted
pleased	angry, annoyed, tense

Data Cleaning – Minimum Days +

- Requirement each subject to have a minimum 3 days under each lighting condition

- 1 subject was removed when it was noticed that they always used the same set of mood adjectives.

After all cleaning there were 491 records from 28 different subjects

Mood Results - Calculation

Word	Valence	Activation		Word	Valence	Activation
alarmed	-0.08	0.92		excited	0.60	0.74
angry	-0.17	0.78		frustrated	-0.65	0.44
annoyed	-0.50	0.65		gloomy	-0.89	-0.46
aroused	0.21	0.92		happy	0.84	0.10
astonished	0.30	0.85		miserable	-0.92	-0.13
at ease	0.63	-0.61		pleased	0.86	-0.11
bored	-0.42	-0.71		relaxed	0.58	-0.72
calm	0.57	-0.79		sad	-0.81	-0.36
content	0.71	-0.57		satisfied	0.63	-0.67
delighted	0.77	0.35		serene	0.74	-0.51
depressed	-0.81	-0.44		sleepy	0.06	-1.00
distressed	-0.74	0.56		tense	-0.03	0.86
droopy	-0.25	-0.91		tired	-0.06	-0.98

Example

relaxed, content, calm

relaxed	0.58	-0.72
content	0.71	-0.57
calm	0.57	-0.79
Average	**0.62**	**-0.69**

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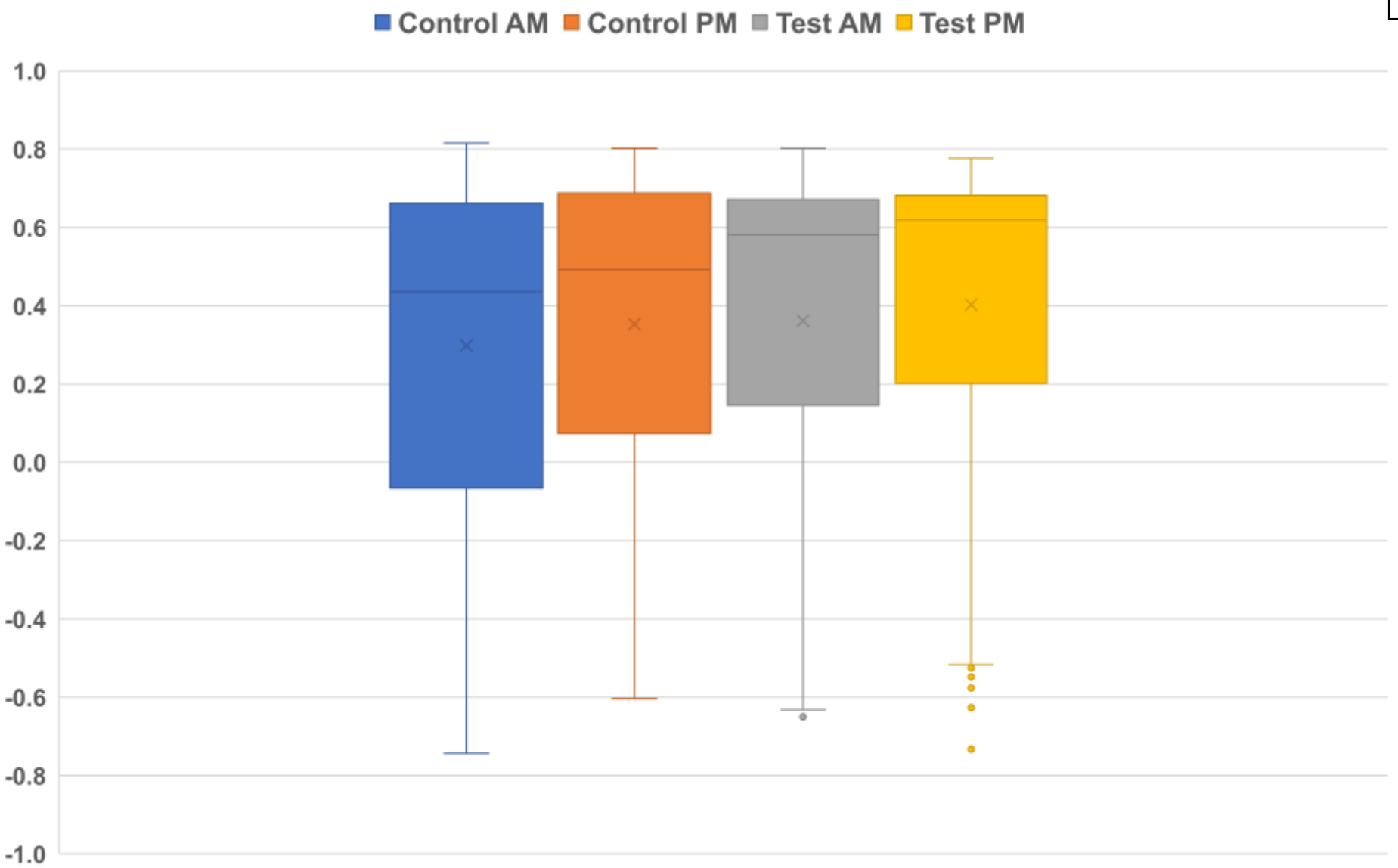
Valence

	AM Valence	PM Valence
Control (N=231)	0.30	0.35
Test (N=260)	0.36	0.41



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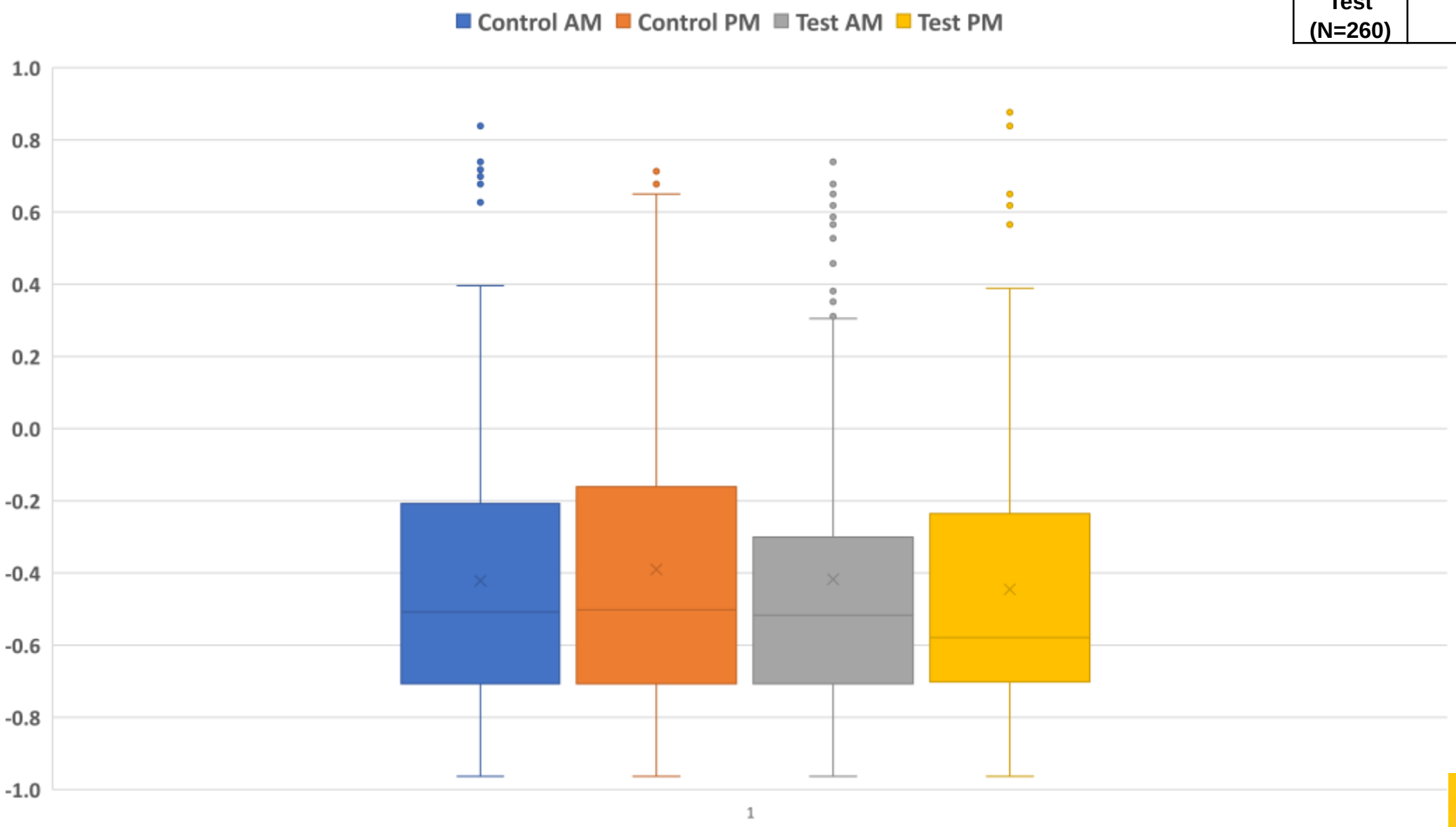
Arousal

	AM Arousal	PM Arousal
Control (N=231)	-0.42	-0.39
Test (N=260)	-0.42	-0.45



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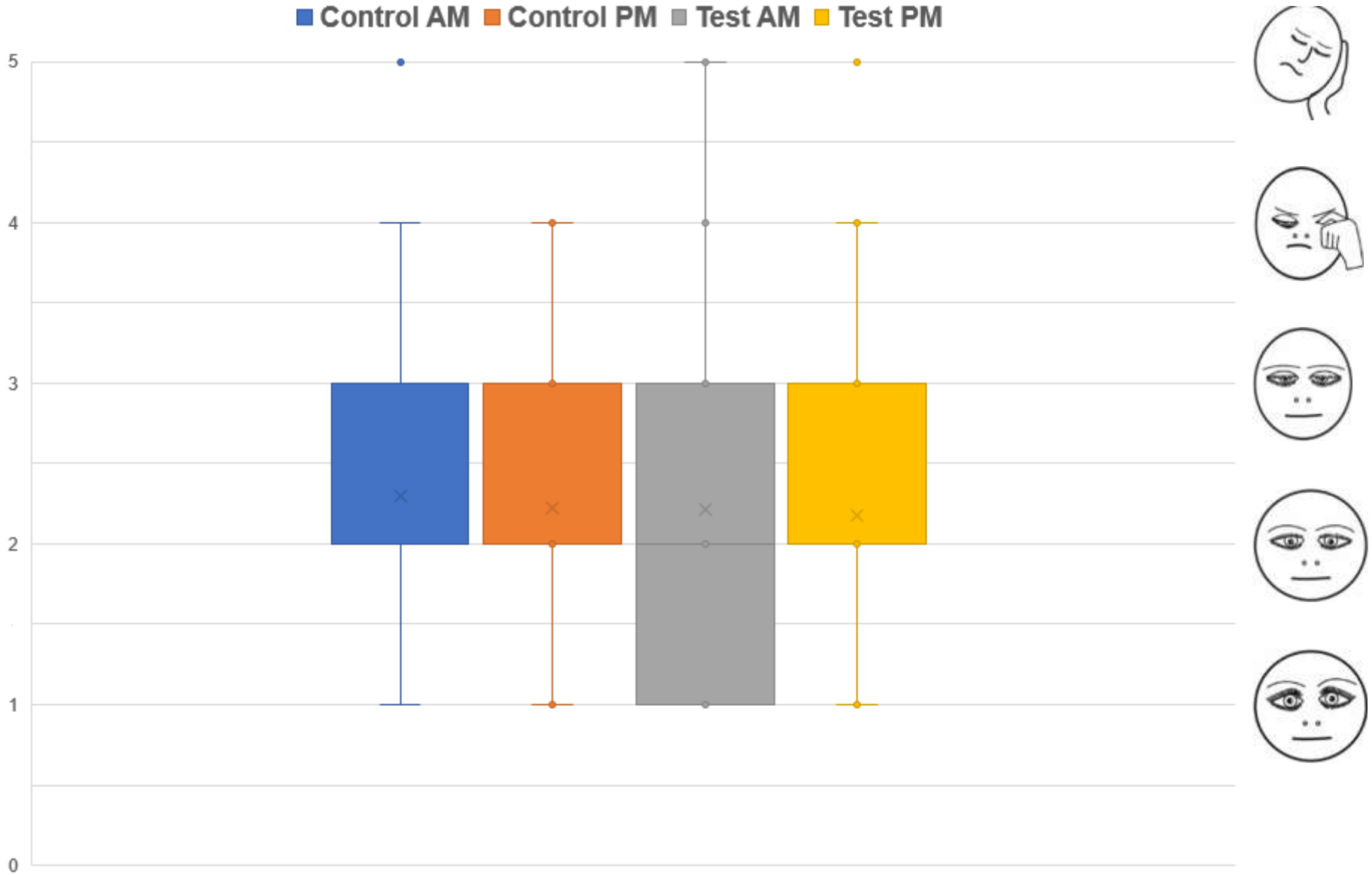
Sleepiness

	AM Sleepiness	PM Sleepiness
Control (N=231)	2.29	2.225
Test (N=260)	2.212	2.177



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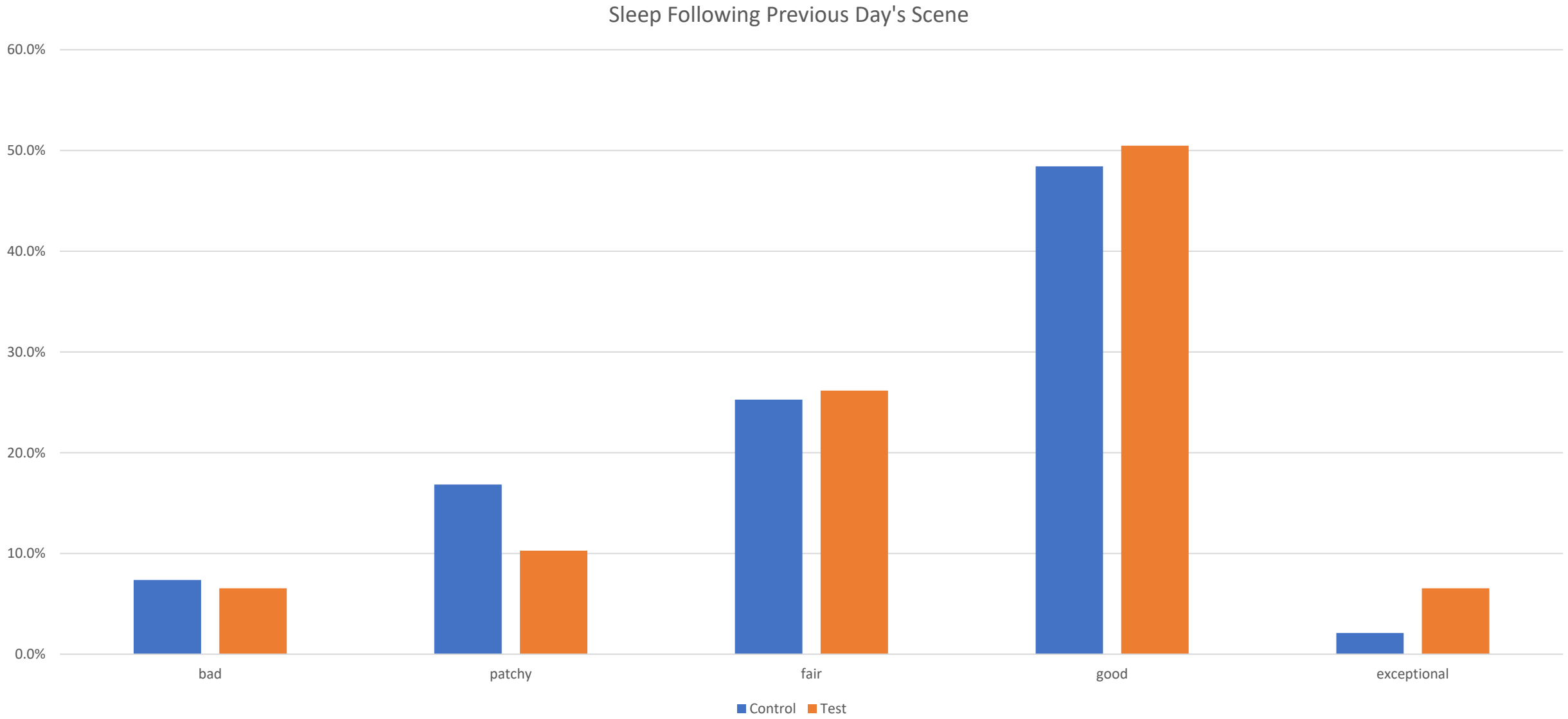
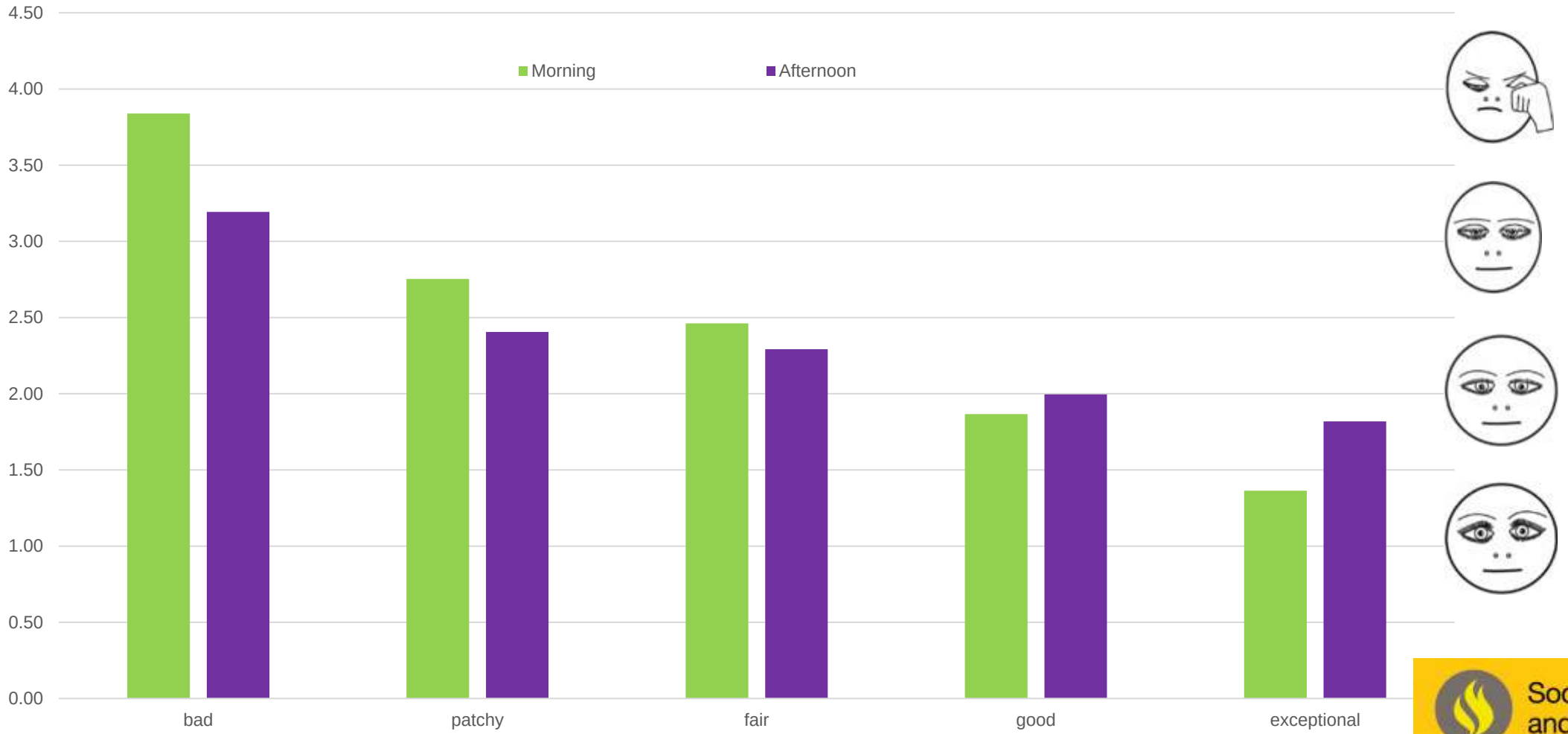
Scene and Next Night's Sleep

Previous Day	Number	bad	patchy	fair	good	exceptional
Control	95	7.4%	16.8%	25.3%	48.4%	2.1%
Test	107	6.5%	10.3%	26.2%	50.5%	6.5%



Impact of Previous Night's Sleep on Sleepiness

Reported sleep	bad	patchy	fair	good	exceptional
N	31	69	130	239	22
Morning Sleepiness	3.84	2.75	2.46	1.87	1.36
Afternoon Sleepiness	3.19	2.41	2.29	2.00	1.82



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Results – Diary Comments

Positive

- Comfortable (16 comments from 15 subjects)
- Felt more alert (11 comments from 10 subjects)
- Improved mood (9 comments from 9 subjects)

Negative

- Irritating/Lack of control/too bright (14 from 13) subjects

Results – Post Study Interview

Positive

- About the light (30 comments from 23 participants)
- Alertness (24 comments from 22 subjects)

Negative

- About the light (9 from 9) subjects
- Alertness (0)

Note: most of the negative comments about the light would be resolved if the users could adjust the light

Results – Post Study Interview – Sleep

20 participants commented on sleep

- Positive effect 10
- Negative effect 0
- No noticeable effect 10

Conclusion

- Most subjects found the additional light acceptable and a majority found benefits from its use.
- The were some negative comments but most of these would be resolved if the subjects could control the light
- Results tend to show that the use of the light improve valence and sleep the following night and reduced sleepiness during the day.
    - However due to the number of competing variables the size of the impact is small
- 10 subjects reported improved sleep during the trial.

Questions?

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