



The Physiological Impact of Lighting

Effects of light beyond visual perception

Visual effects

Intensity
Shape
Motion

Image
Contrast
Perception



Biological effects

Hormones
Chronobiology
Circadian Rhythm

Concentration
Inner Clock
Alertness



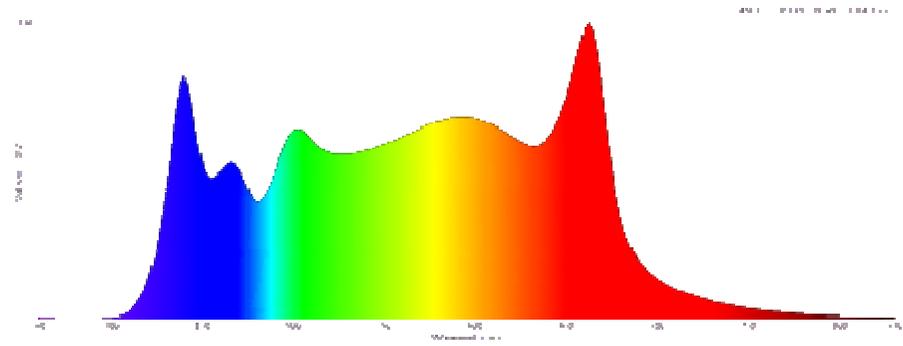
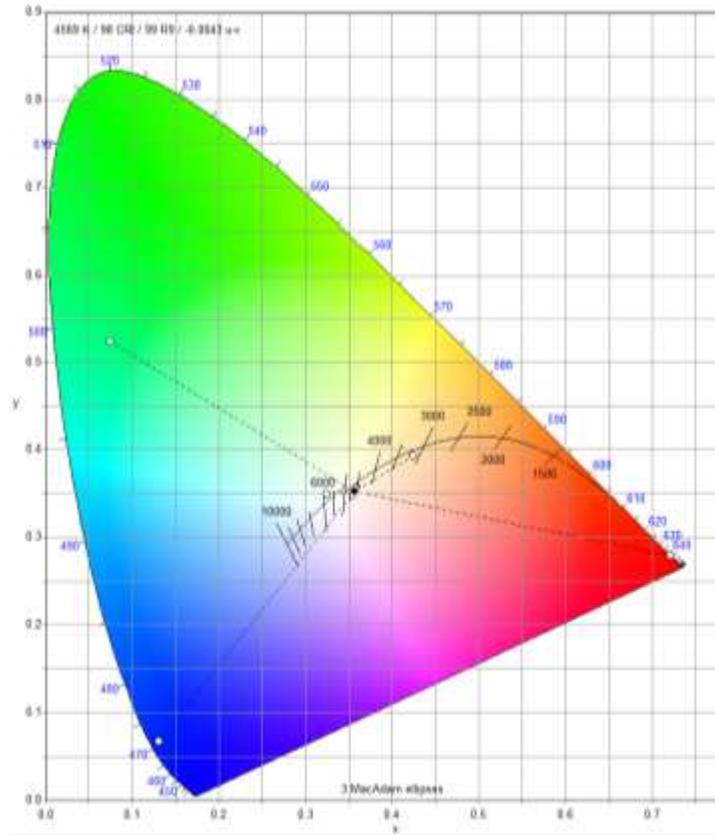
Psychological effects

Wellbeing
Mood

Comfort
Relax



LED Combinations - Arranged to Achieve Excellent Color Rendering



CRI Points	Ra	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14
100															
90	98	99	99	99	98	99	97	98	98	99	97	95	97	99	100
80															
70															
60															
50															
40															
30															
20															
10															
0															

Why should we consider biological effects in lighting?

Visual effects

Intensity
Shape
Motion

Image
Contrast
Perception



Biological effects

Hormones
Chronobiology
Circadian Rhythm

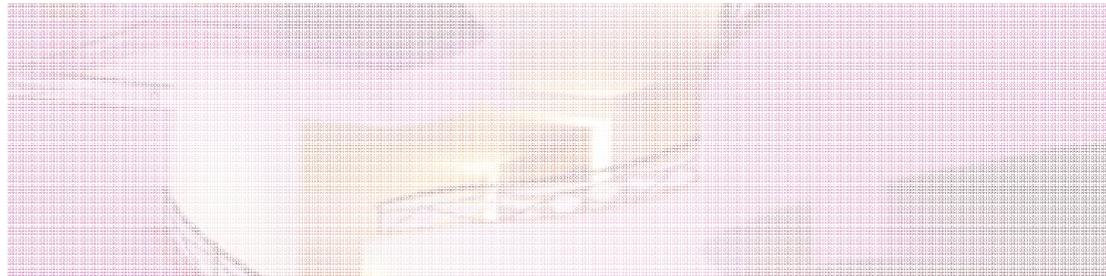
Concentration
Inner Clock
Alertness



Psychological effects

Wellbeing
Mood

Comfort
Relax



Biological Effects by Light bring Benefits

Positive effects that have been shown in studies include:

Function:

Established effects:

Sleep:



- shortened sleep onset
- increase in deep sleep

Well-being:



- improvements in mood
- stabilization of rhythm
- decreased depression scores
- positive judgement of performance

Cognition:



- activation
- increased performance
- shortening of reaction time

DOE: Fact Sheet on Biological Effects of Light 2014

U.S. DEPARTMENT OF **ENERGY** | Energy Efficiency & Renewable Energy

Solid-State Lighting Technology Fact Sheet

Lighting for Health: LEDs in the New Age of Illumination

Key messages:

- **Non-visual effects of light are clearly shown**
- **Light impacts on health and wellbeing**
- **Effects are not comprehensively understood**
- **positive as well as negative effects are possible**

however: the lighting industry cannot ignore nonvisual needs indefinitely.

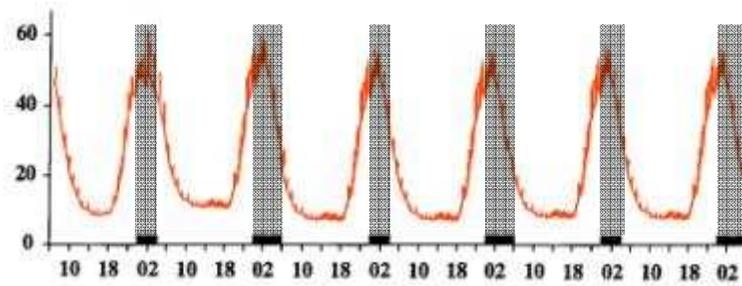
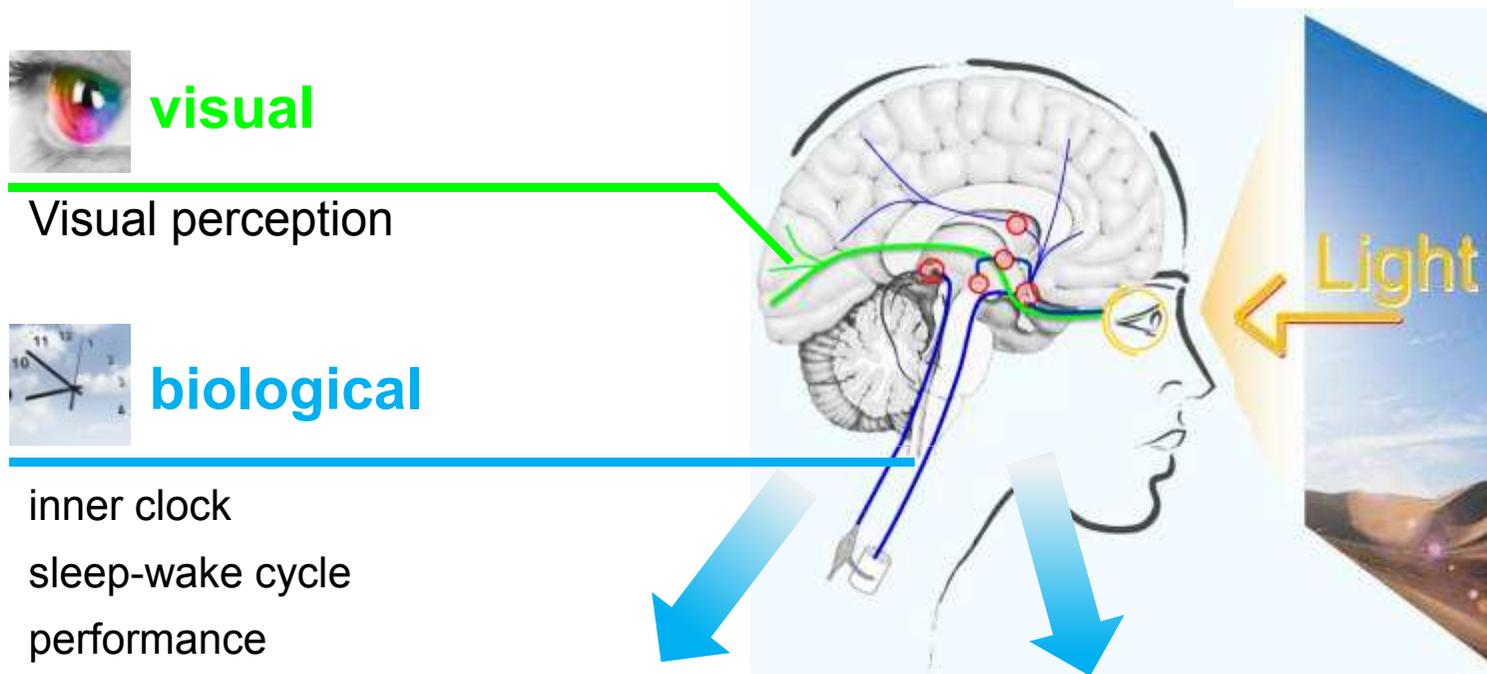
alertness, and melatonin suppression. Light has been shown to be an effective clinical treatment for a variety of conditions, such as Seasonal Affective Disorder (SAD), but also plays an important role in maintaining daily physiological function. Importantly, the non-image-forming photoreceptor system in our eyes is different from our visual system. Although it shares some of the same photoreceptors, it has its own unique spectral and temporal response to light stimuli. This is one of the reasons traditional measures of lighting quantity, such as illuminance, do not accurately quantify the nonvisual effect of a lighting stimulus.

In the past two decades, much has been learned about the sensitivity of the nonvisual photoreceptor system. Most notably, intrinsically photosensitive retinal ganglion cells (ipRGCs) were identified, as was the spectral sensitivity of melanopsin, the photopigment they contain. The ipRGCs have peak

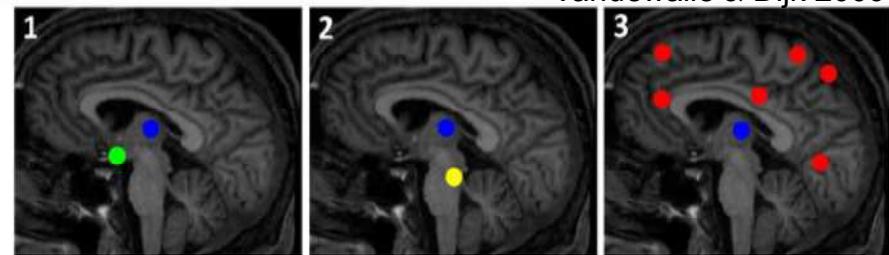
One thing is for certain, and we cannot ignore the nonvisual effects of light.



Visual and non-visual information is processed in different central nervous pathways



Rhythm of sleep hormone melatonin



sofort 30 sec 15 min

PET/fMRI Scans show brain activation

Vandewalle & Dijk 2009

Visual and biological effects of light rely on separate receptor cell systems.



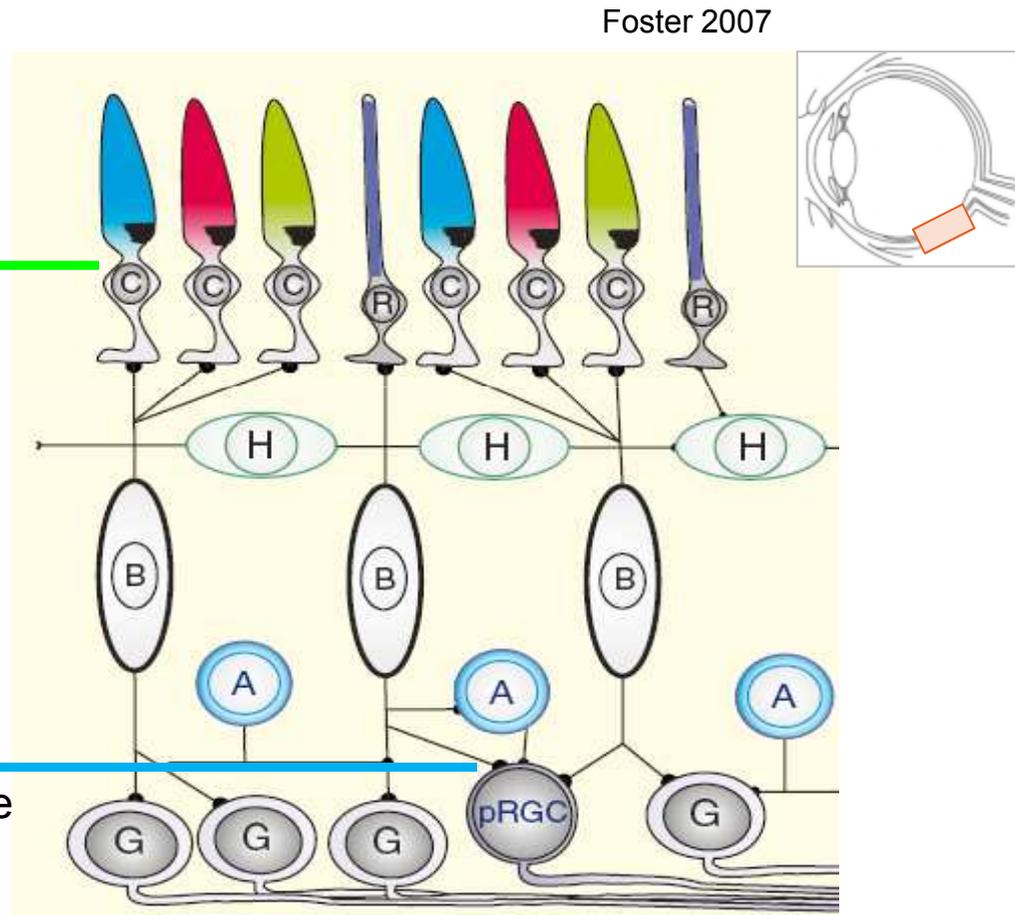
visual

rods and cones

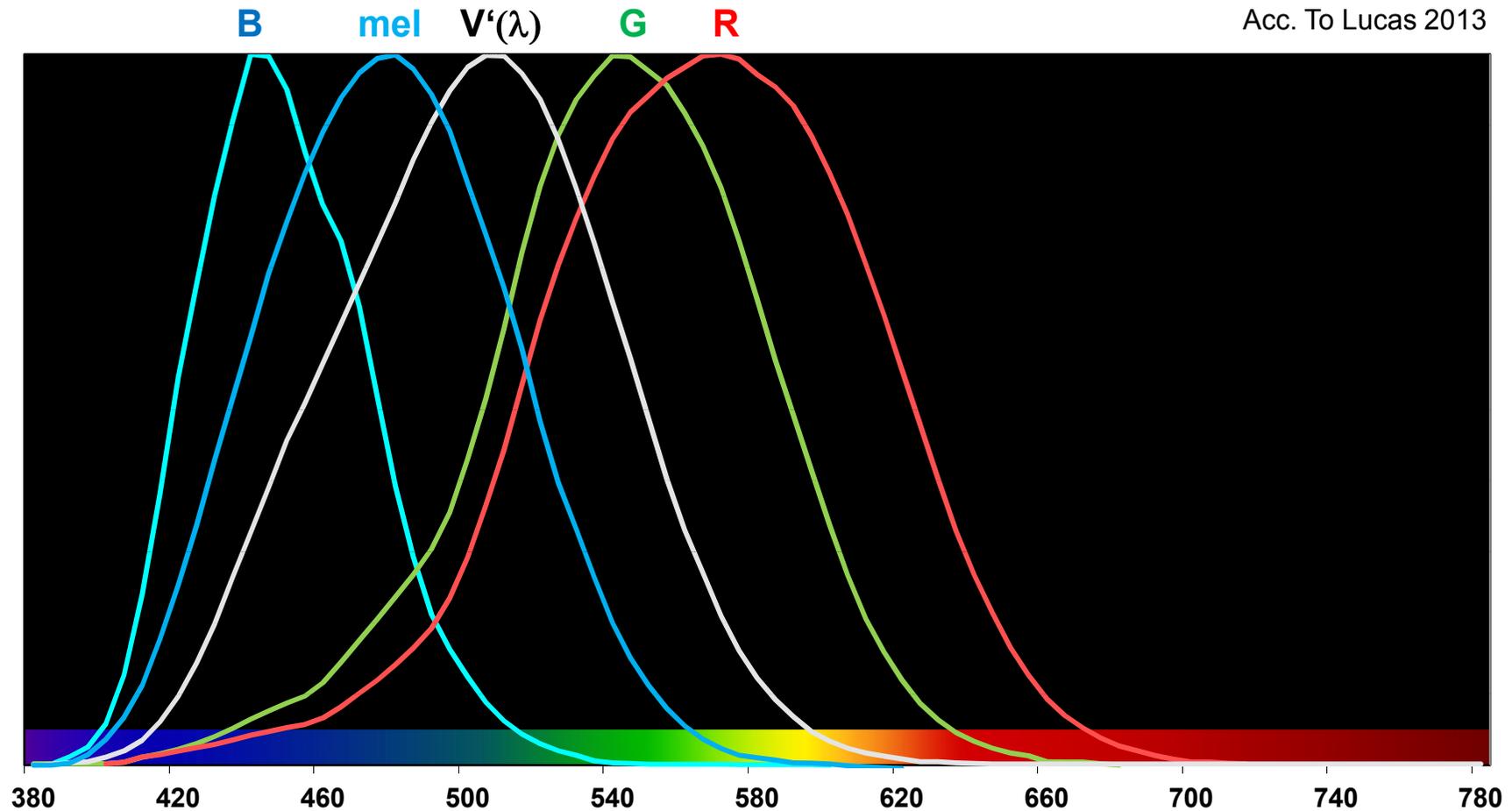


biological

ipRGC (intrinsic photo-sensitive retinal ganglion cells)



Action Spectra of Retinal Photoreceptors



Photoreceptor Cells in the Retina



visual

Cones are concentrated in the fovea

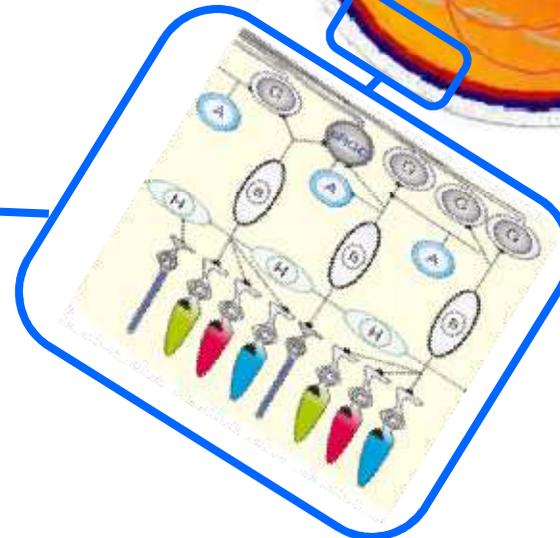
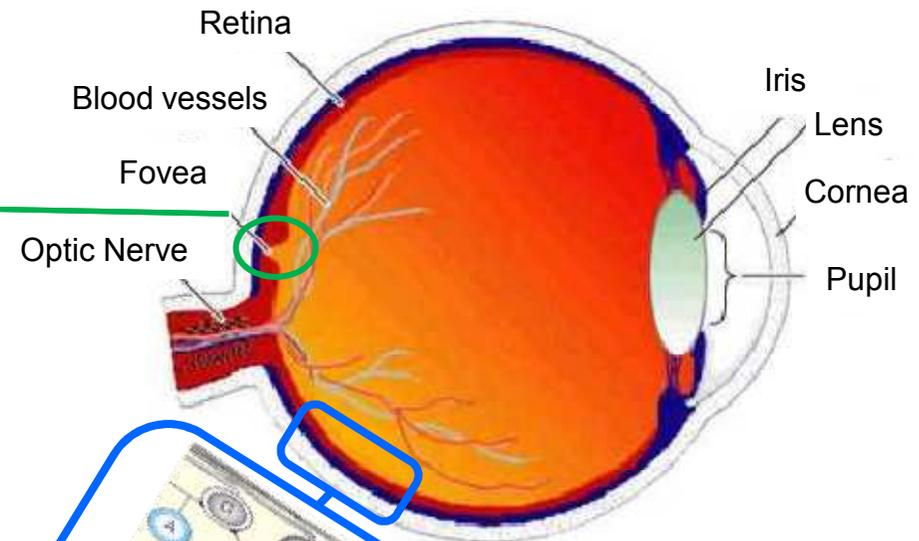
- Image forming
- High resolution



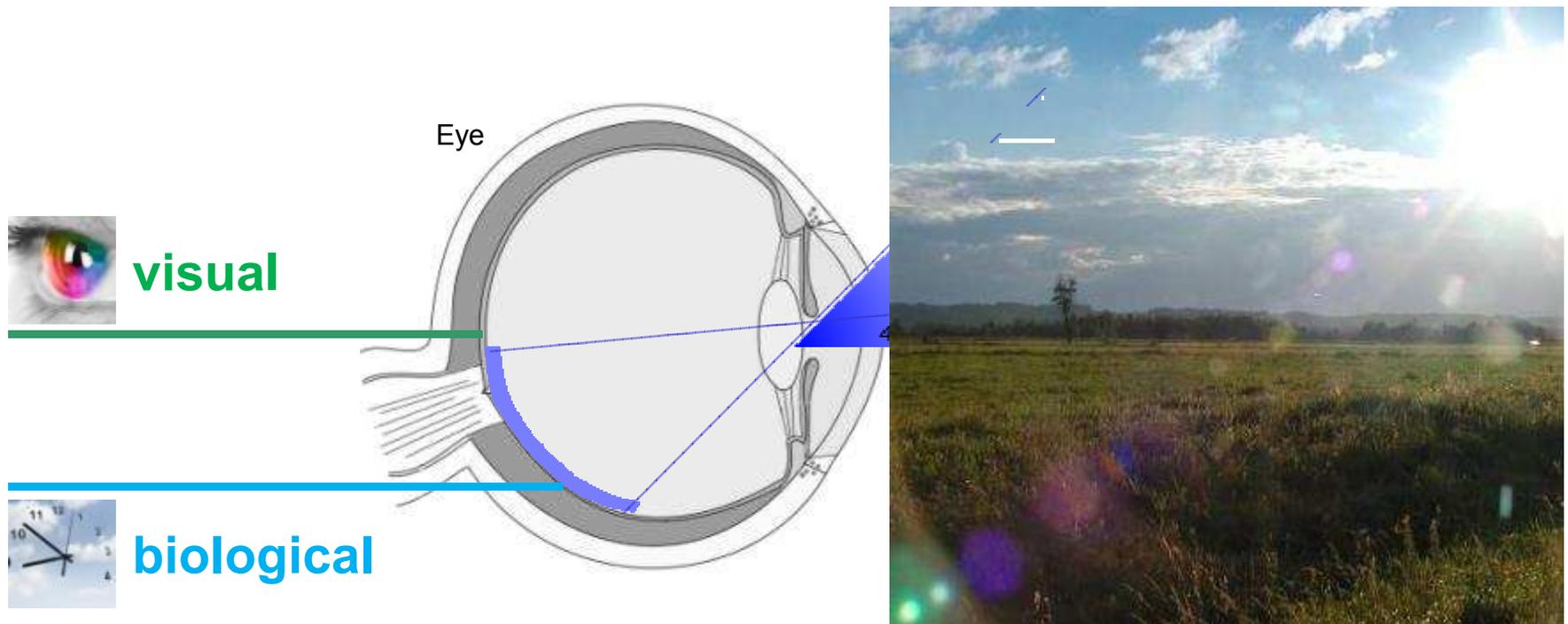
biological

ipRGCs are widely distributed

- Higher sensitivity in lower retina
- Large receptive fields



Area Light from Above is More Effective → Luminaires



Right Light @ the Right Time @ the Right Place

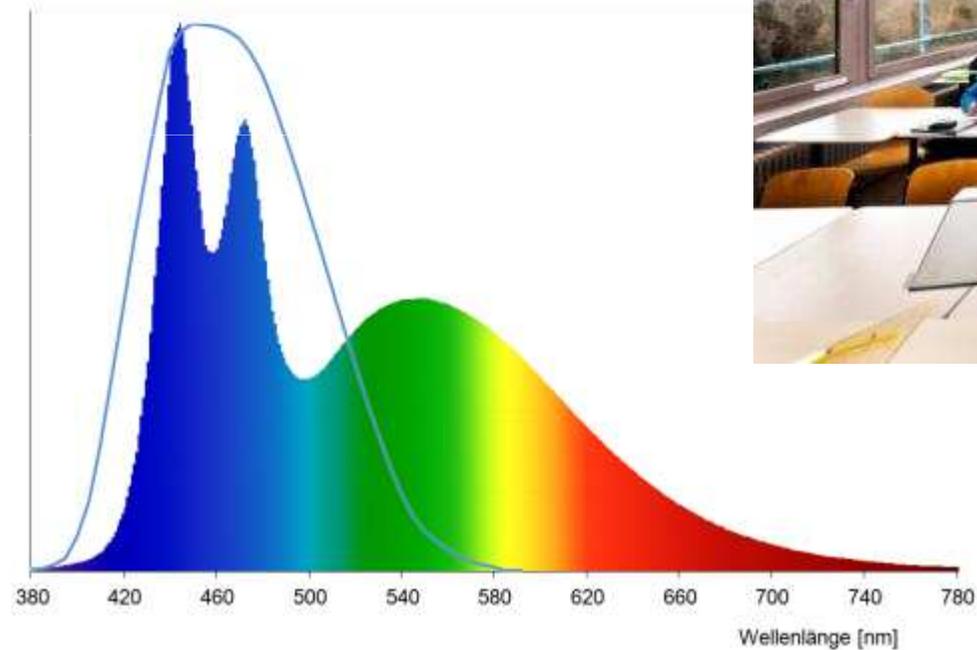


- Distribute light across large area to mirror distribution of retinal receptor
- visible illuminances at ceiling and upper part of walls to reflect sensitivity distribution of receptors

-
Best Option !

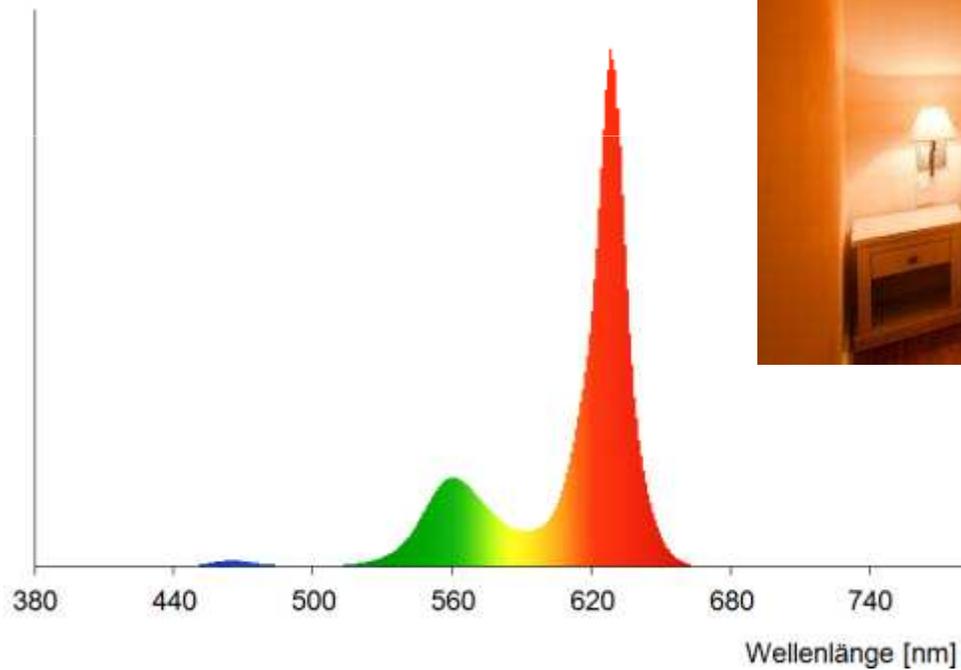
LED Combinations - Arranged to Exert High Melanopic Stimulation

- LED Spectrum with coolwhite and blue
- 12000 K with Ra=80



LED Combinations - Arranged to Exert Low Melanopic Stimulation

- LED Spectrum with amber, green, blue
- 1500 K with Ra=90
- $a_{mel, v} = 0,05$



Success in Many Studies Shows the Way

Light therapy

Nursing homes

Office

School

aircraft

Wellness hotel

Pain therapy

Faster recovery

Active day smooth night

Stronger synchronization

Improved learning

More comfort and relaxation

Sleep and recovery improved

Study ongoing high acceptance



FL Project Example: Psychiatric Clinics (Vivantes, Berlin)



Objectives:

- Support of therapy against depression
- Stabilizing of biological rhythms
- Generate nice ambience in clinics

Results:

- Reduction in therapy duration against unipolar depression
25.9 d -> 22.0 d (Staedt 2009)

FL Project Example: Nursing Home Studies



Objectives:

- Prove benefits of biologically effective light on health and well being of elderly
- Gain experience and references in nursing homes

Results:

- Significant improvement in daytime activity and alertness
- Better sleep at night
- Excellent acceptance and feedback by nursing staff

Improving learning by better classroom lighting

Field study in Ulm (Ger) to test non-visual lighting effects in older pupils

Objectives

Hypotheses:

- Chronobiologically improved classroom lighting improves scholar performance of older school pupils.
- The improved lighting concept counteracts social jetlag and makes them awake and activated earlier in the morning.

Concept



Reference =
Standard lighting

Partner



Interference =
Chronobiologically
improved

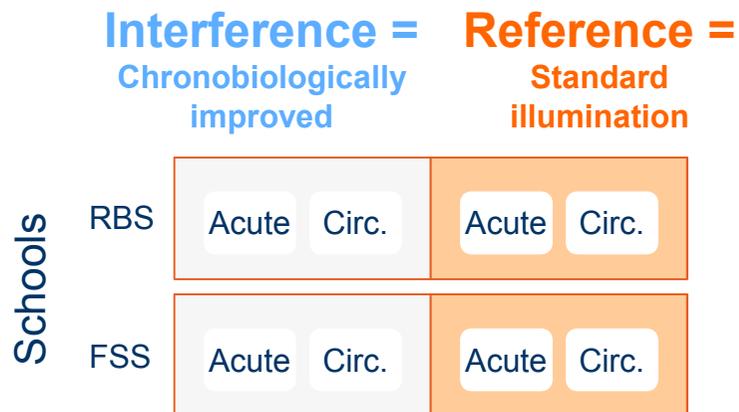


School Study Ulm: Set-up

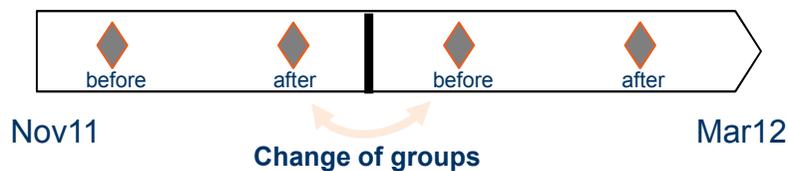
Intraindividual comparing before/after on acute and delayed (circ.) effects

Study design

- Groups:



- Cross-over



Instruments

- Attention (d2)
- Cognitive task speed (ZVT, number tracking)
- Memorization (VVM, verbal and visual)
- Mood (POMS)
- Auditive Vigilance, visual vigilance (2-back)
- Sleep log
- Chronotyping (MCTQ)
- Control measurements (vision etc.)



School Study Ulm: Light Intervention

Adjustments in spectrum and light distribution, but not in illuminance

Reference

- Fluorescent neutral white light (4000 K)
- Standard luminaires (pendant or recessed)
- 700 lx horizontal, 300 lx vertical



Intervention

- Full LED solution, 4000 K direct; indirect UW and blue
- Standard luminaires “upgraded” with LED modules
- 700 lx horizontal, 300 lx vertical



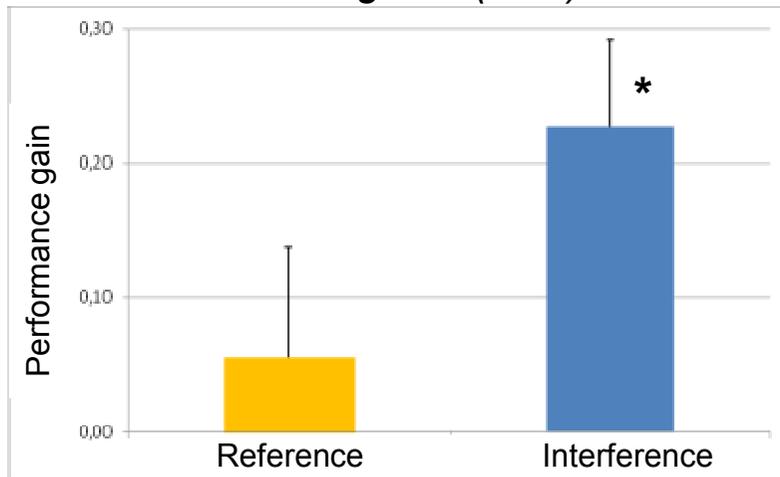
School Study Ulm: Main Results

Attention and performance increased after short or mid term exposure in chronobiologically improved lighting

Visuo-motor performance

- * Increased speed in task accomplishment compared to reference

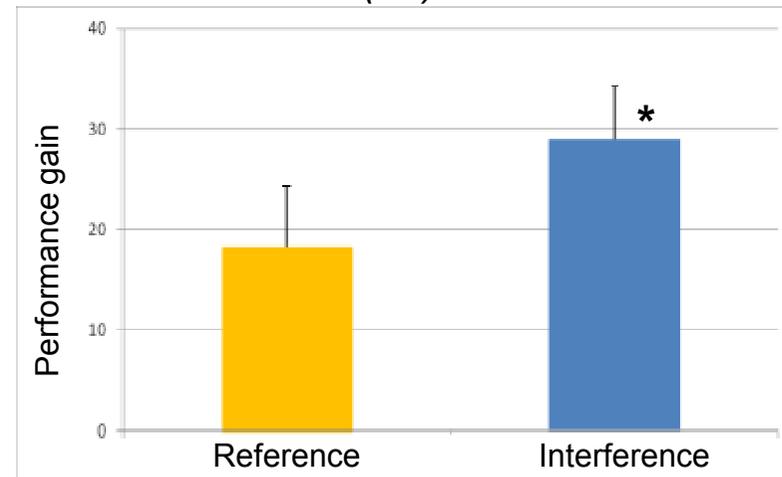
Gain in speed of handling number tracking test (ZVT)



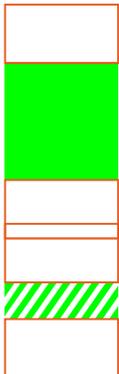
Attention

- * Improvements in overall ability to perform task (Concentration performance)
- * Lower error rate

Gain in concentration performance (d2)

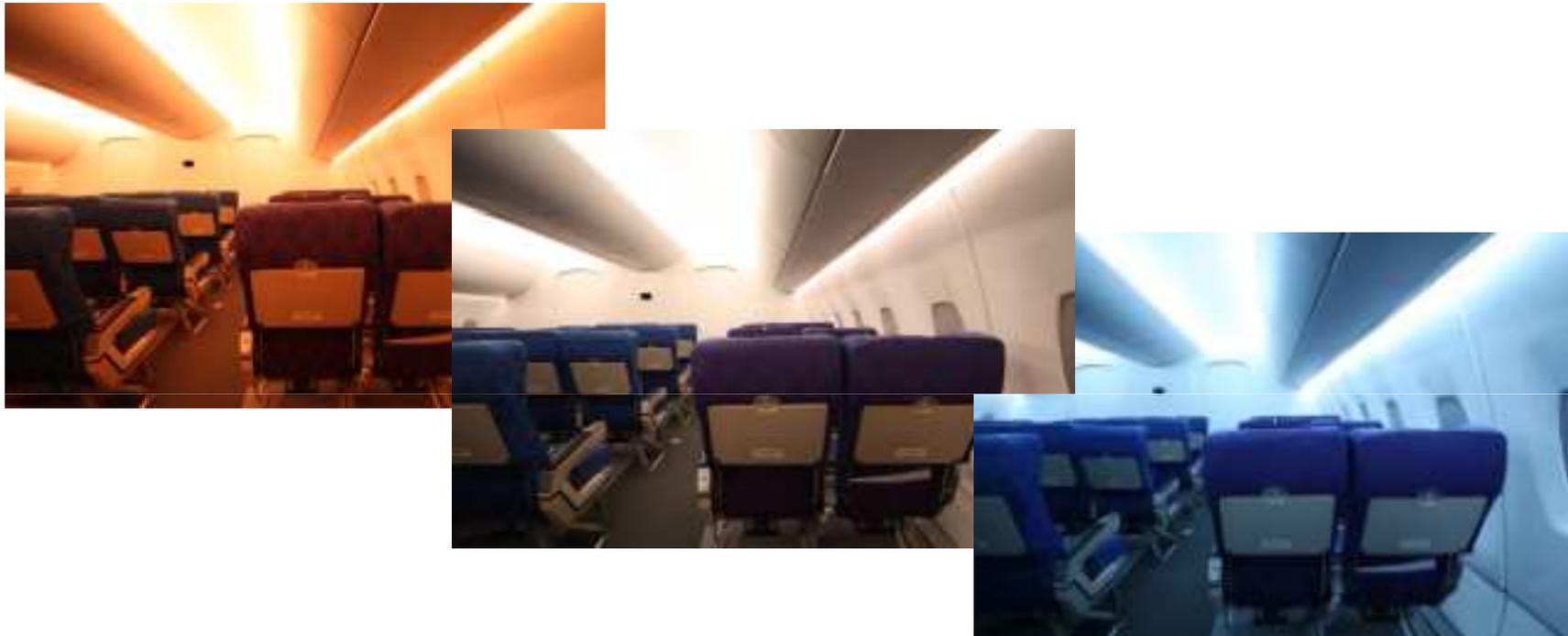


School-Study Ulm: Results Overview

	Phase 1	Phase 2
Performance <ul style="list-style-type: none"> d2 speed d2 error rate D2 concentration performance ZVT (trail making) VVM_route_visual VVM_construction_verbal Computer aud. correct Computer vis. correct 		
Mood <ul style="list-style-type: none"> Neg. feeling Pos. feeling Interest Excitation/agitation Alertness 		
Circadian Rhythm <ul style="list-style-type: none"> Chrono questionnaire Sleep log 		
Acceptance <ul style="list-style-type: none"> Lighting questionnaire 		

 significant
 n.s.
 significant against aim

L&Q Project Example: Aircraft Cabin Study



Objectives:

- Show better evening and nocturnal relaxation and morning activation by improved lighting dynamics
- Use new full LED cabin lighting luminaires and tune spectrum and timing during flight

Results:

- Improved physiological parameters of passengers
- Better hormone release in evening
- Improved relaxation in the evening and night
- Self-reports of volunteers show consistently higher comfort

Improve Comfort in a Wellness-Hotel

Fieldstudy on non-visual effects of light in hospitality application

Objectives

Hypothesis:

Chronobiologically adapted illumination in a hotel improves the recovery by

- less circadian light effects in the evening and night by light with low melanopic stimulation as well as
- stronger daytime activation by light with high melanopic stimulation

Concept



reference =
“standard”-
lighting

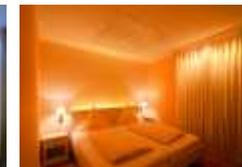
Partner



BERGISCHE
UNIVERSITÄT
WUPPERTAL



intervention =
chronobiologically
optimized



Hotelstudy: Methods

Study design

- 84 volunteers in 2 groups / Ø 42,1 Ys / average chronotype / single-blind
- regular hotel guests, randomized groups
- simulated „weekend-stay“
- standard lighting vs. modifications in illuminance levels, light spectrum and time course

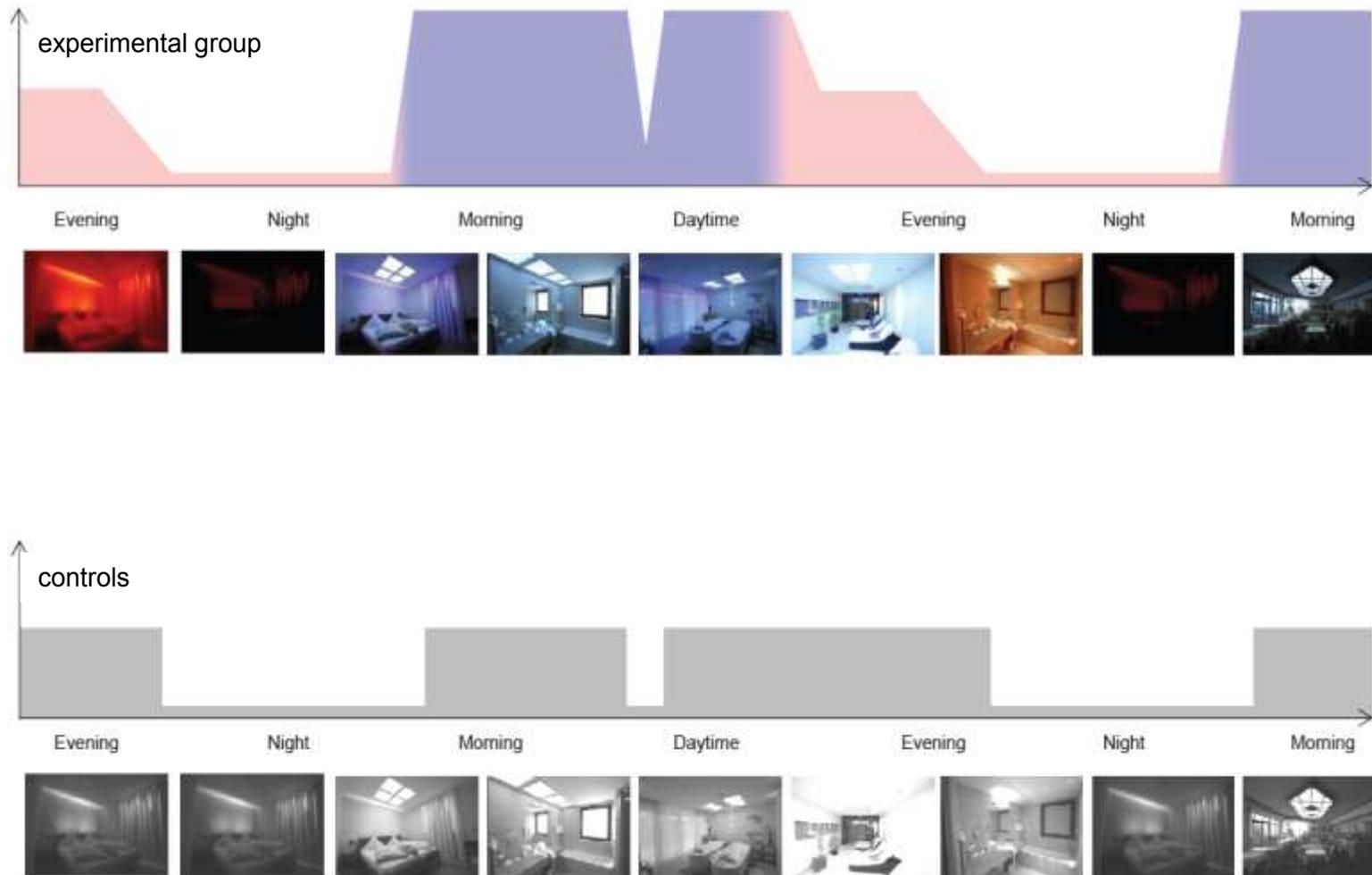


Instruments

- hormones: Melatonin /Cortisol
- cardiovascular: heart rate and heart rate variability (HRV, LF/HF)
- electrodermal activity (SCR ampl., SCR count)
- movement sensors, step count
- questionnaires: sleep (PSQI, sleep logs), sleepiness (KSS), wellbeing (VAS), light acceptance, mood / stress
- Lightwatcher-measurements (part of the groups)



Daylight Simulation

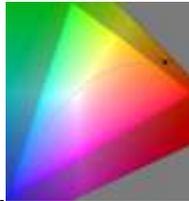


Lighting in Spa Areas - Whirlpools

The whirlpool bath is used during the morning hours

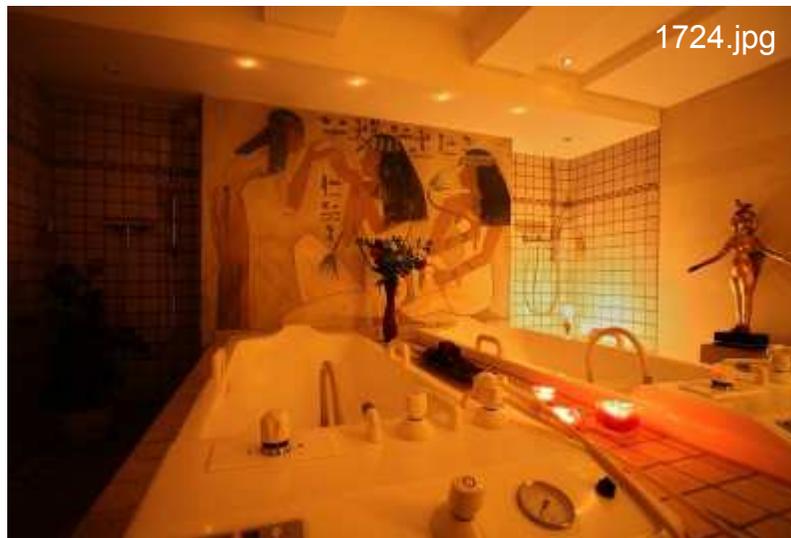
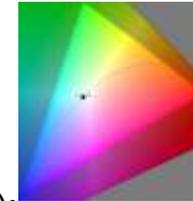
Reference

- No daylight
- Halogen Spots and Candles
- Light at eye level (av. both sides):
 - 1 lx @ 1770 K
 - 0,3 cd/m²



Intervention

- Daylight
- Light Ceilings 8000 K FL
- LED Wallwasher at curtains
- Light at eye level (av. both sides):
 - 1560 lx @ 6000 K
 - 512 cd/m²

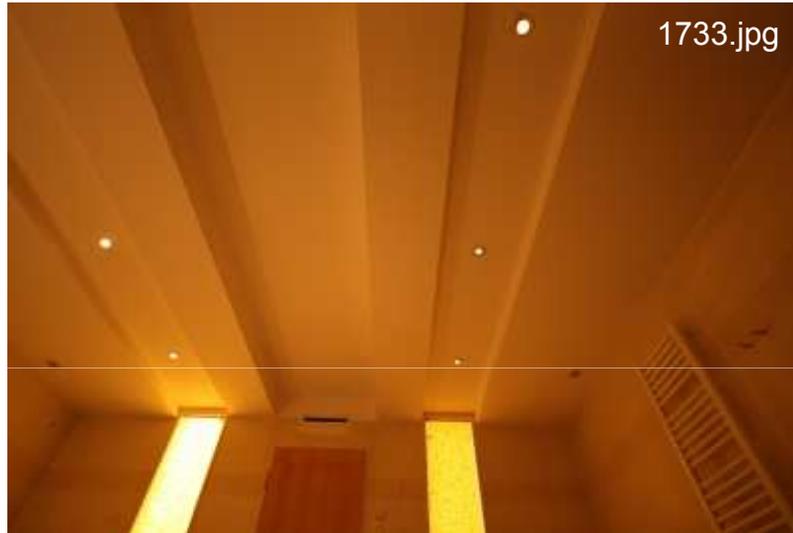


Whirlpools - Luminance in direction of view

Reference

Intervention

Photo



Luminance (log.)

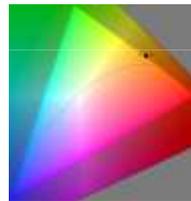


Lighting in Salt Water Spa

This area is used during the morning hours (in this study)

Reference

- Daylight only at outer door & skylight
- Halogen Spots and 3000 K FL
- LED ceiling washer orange (red, green)
- Light at eye level on lounger (av.):
 - 35 lx @2400 K
 - Av. 12,1 cd/m²



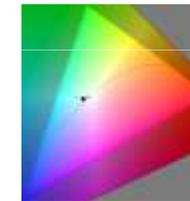
1681.jpg



1691.jpg

Intervention

- Daylight close to door and skylight
- Artificial sky lights and voute 8000 K FL
- LED ceiling washer blue/green
- Light at eye level on lounger (av.):
 - 800 lx @ 6500 K
 - Av. 199 cd/m²



1958.jpg



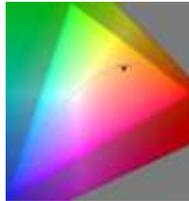
1693.jpg

Lighting in the Restaurant

Breakfast, lunch and dinner situations for the intervention group

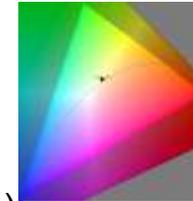
Reference

- low daylight
- Halogen Spots and Candles
- Light at eye level (av. all places):
 - 34 lx @ 2720 K
 - 6,5 cd/m²



Intervention

- Daylight
- Light Ceilings 8000 K FL
- Halogen and LED Spots
- Light at eye level (av. day places):
 - 700 lx @ 4380 K
 - 125 cd/m²

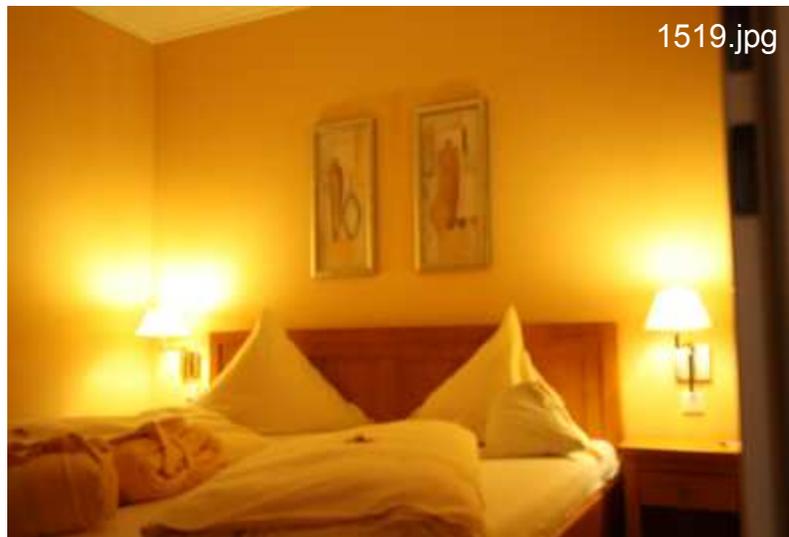
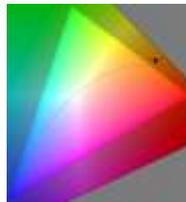


Lighting in Guest Suites – Bedrooms

Scenarios for day and evening plus wake-up light

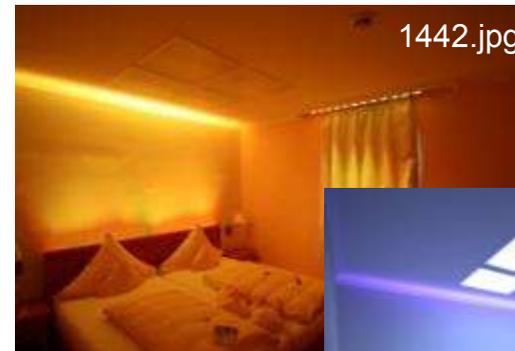
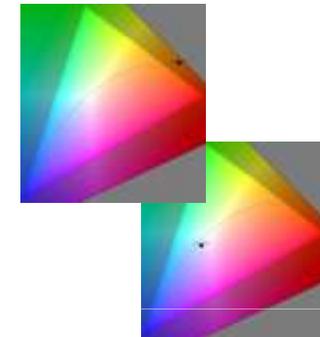
Reference

- No daylight (in this study)
- Compact fluorescent lamps
- Light at eye level (hor. on bed):
 - 26,8lx @ 1990 K
 - 4,8 cd/m²



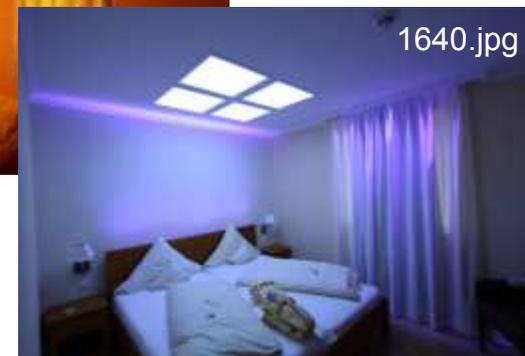
Intervention

- No daylight (in this study)
- Light Ceilings 8000 K FL
- LED fixtures (wallwashers) RGB towards curtain and wall
- Light at eye level (hor. on bed):



1442.jpg – 73 lx @ 1840 K
– 28,4 cd/m²

– 1462 lx
@ 6810 K
– 468 cd/m²

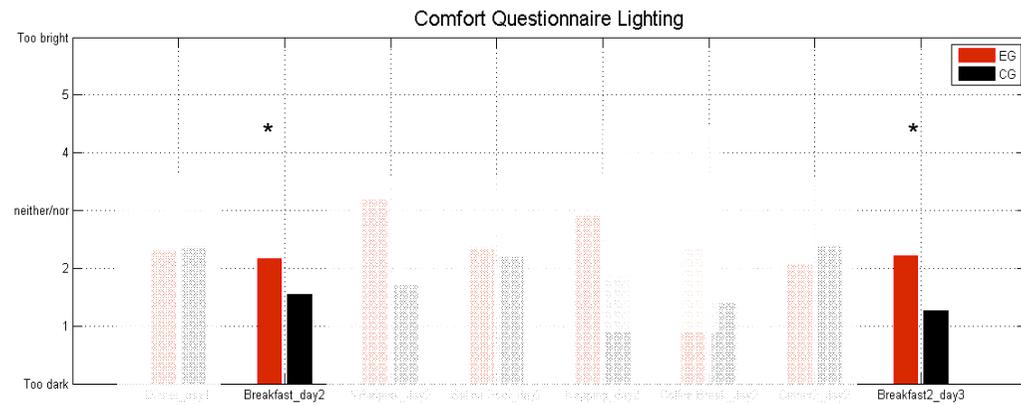
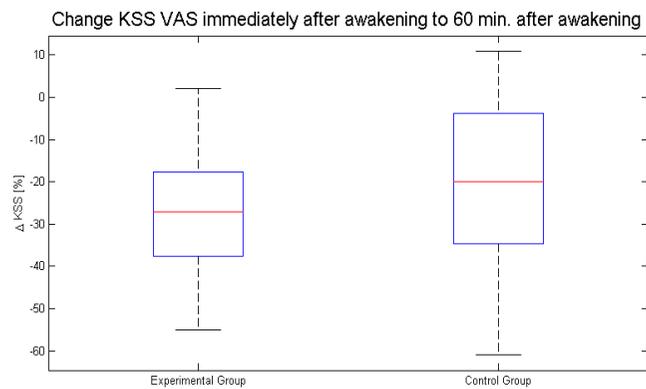
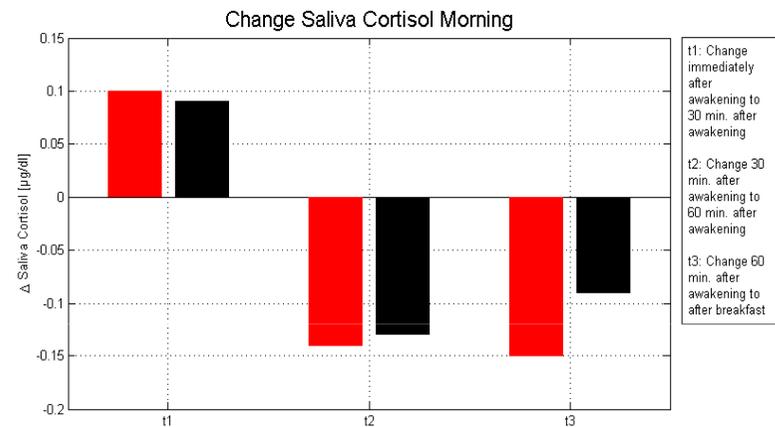
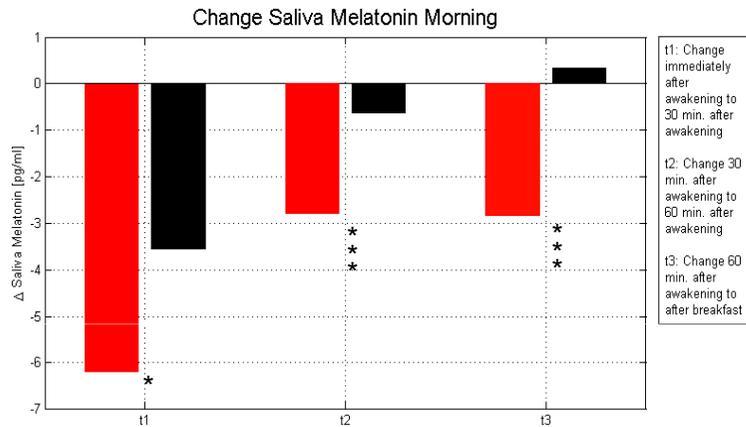


Results: Morning Data (Example)

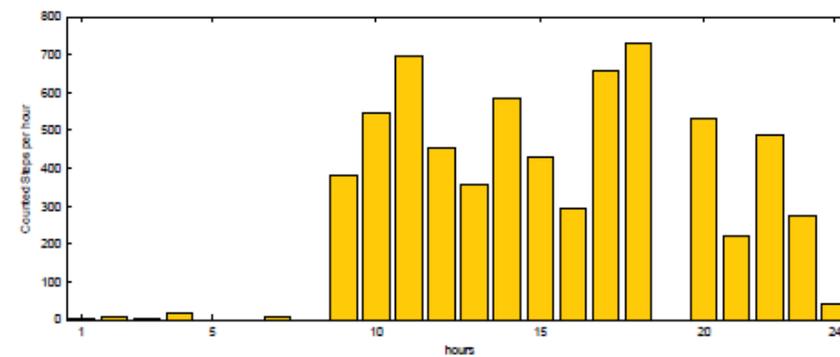
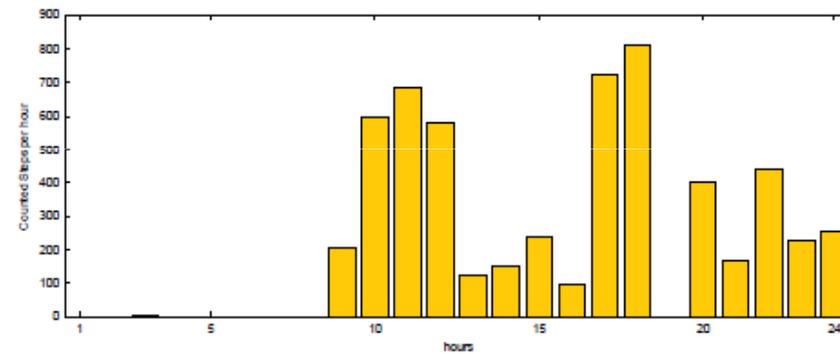
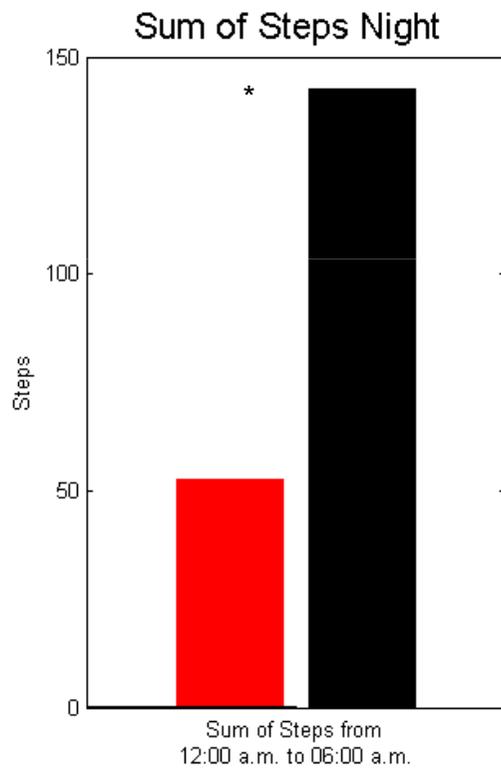
Melatonin ↓
Cortisol ↑
Sleepiness ↓
Light Accept. ↑

↑

morning



Nocturnal Activity



Results Overview Hotel-Study

	Melatonin	Cortisol	HR LF/HF	EDA	Movement	Self Reports		
						Sleepiness	Sleep	Acceptance
Awakening	■	□						
Morning	■	□				■		■
Day	■	□				□		■
Evening	□	□				□		■
Night			□	□	■		■	

 significant
 trend, n.s.
 significant against objectives

L&Q Project Example: Center for Chronic Pain Therapy



Objectives:

- Part of multimodal therapy against chronic pain
- Structuring the day and stabilizing sleep/wake cycle
- Anti-depressive illuminance levels
- Use of standard products from existing portfolio

Expected Results:

- Study started, gain in therapy effectiveness of >10% expected
- Media and public interest very high
- High attention in chronic pain societies

Summary: Triple Win

Lighting quality that matters – performance, health and wellbeing

User

- health, well-being, activity, performance, stabilized biological rhythm, sleep quality, ...

Environment

- balance of energy efficiency and human needs, sustainable products, ...

Industry

- innovation, peace of conscience, new business, high value products, ...



The best transfer of positive health effects of daylight to artificial lighting indoors

www.osram.de

Many Thanks.

