Lighting up our eyes
(at the right times)

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2020 DoE SSL R&D Workshop

Optimizing Lighting for Circadian and Non-visual Effects

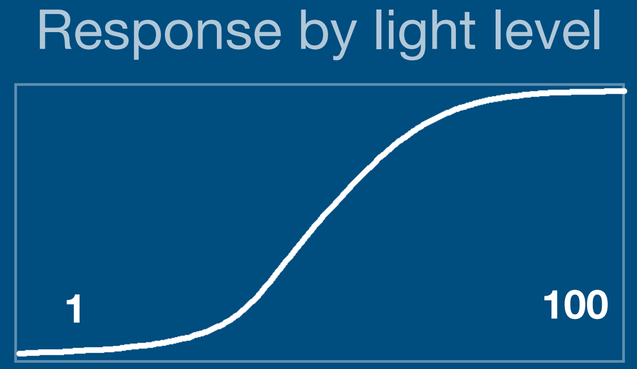
Circadian Contrast

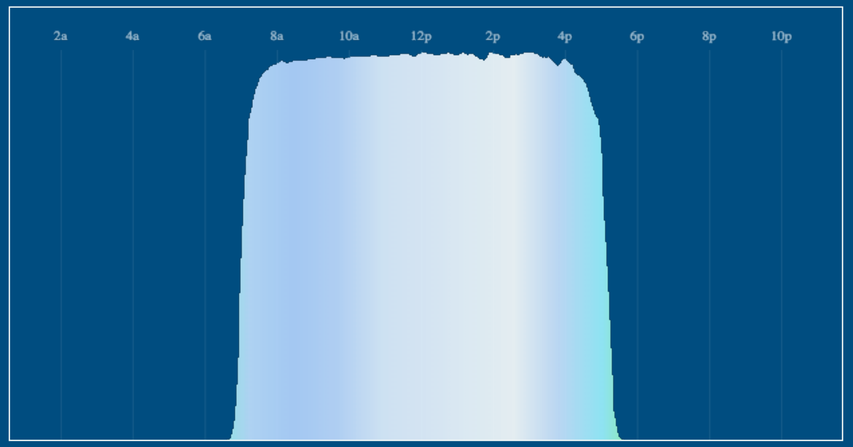
- Outdoors, daytime is a million times brighter than nighttime

- We need 100:1 to tell the body it's day vs. night

- **Circadian Lighting 1.0**:
  - Change something, apply science gently
  - Don't mess up the solar signal too much

- **Circadian Lighting 2.0**, some goals:
  - Lights must run on a daily schedule
  - Measurable contrast from day to night
  - Levels informed by research
  - Flexible timing (shiftwork, chronotype)





“More light during the day and less at night”

Does this mean…
“More **energy** during the day and less at night?”

(a lot more on average?)

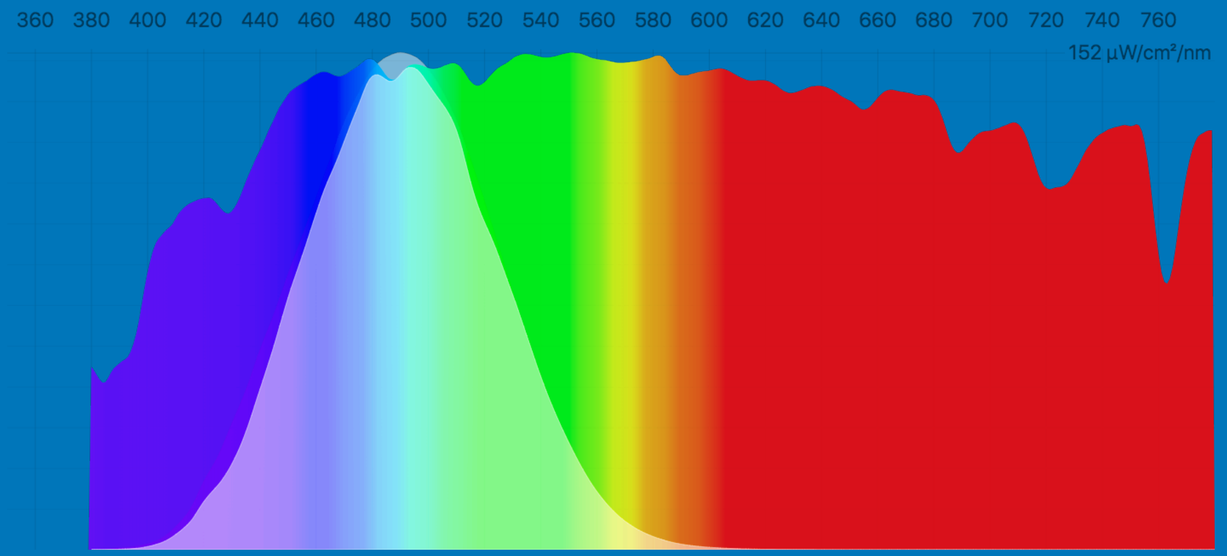
Ways to make “more” light (compared to overhead lighting)

Change	Circadian Potential (log_{10})—goal is >2	Energy cost (linear)	Problems
Dynamic spectrum	+/- 0.2	~1x	Acceptability
Levels (30%-300%)	+/- 0.5	>2x average	Glare
Bright Task + Screen	up to +1	1-2x	Glare, Duration
Distribution and Surfaces	up to +1	1-2x (surfaces free)	Building cost
Timing (+pulses)	up to +1	1-2x	Acceptability
Daylighting	>>1	…	Availability, Cooling

*Circadian contrast overall should be **>2 log units from day to night.***

Spectrum

Melanopic Radiometric Efficiency
Comparing “melanopic watts” per “visible watts”

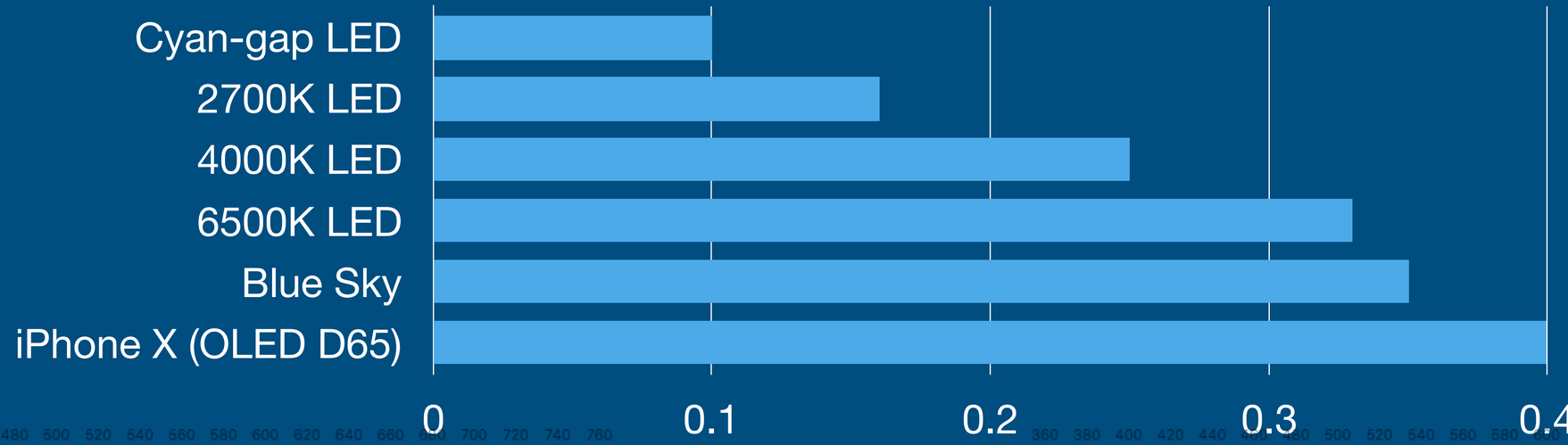


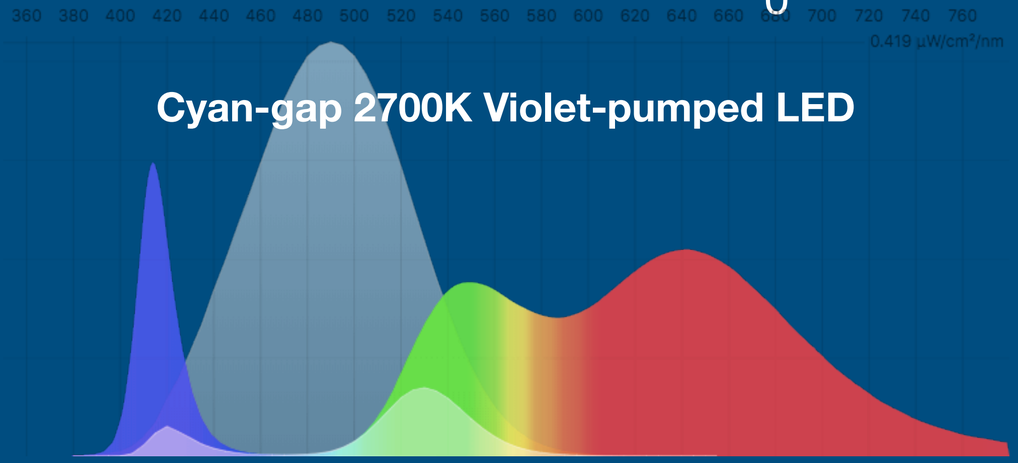
Here, melanopsin absorbs about 24% of the total energy in D65. Lots of NIR.

Spectral tuning alone

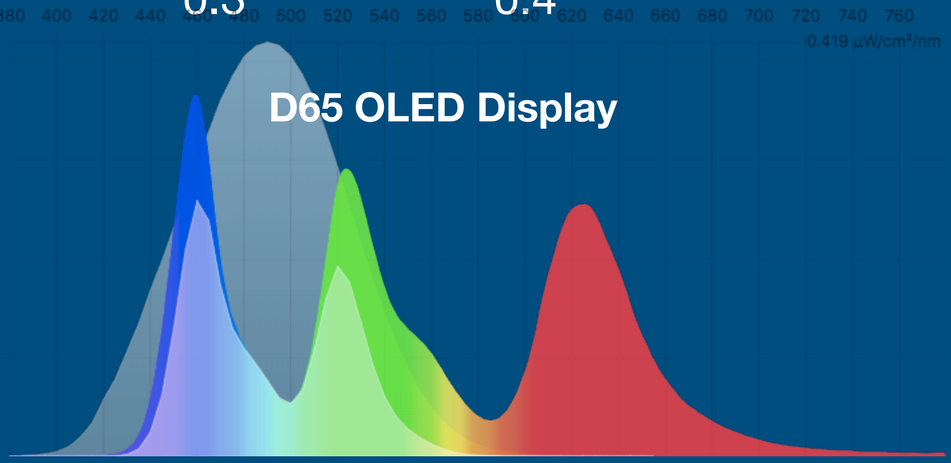
(Some opportunities here, but not as many as people think)

Melanopic Efficacy per Watt (380-780nm)





Cyan-gap 2700K Violet-pumped LED



D65 OLED Display

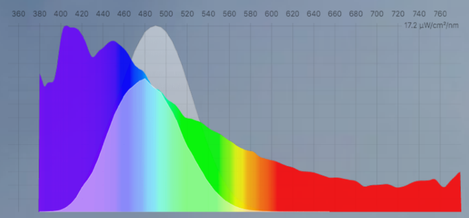
People say: 5000K is “too blue”

What if? Low glare with a bright, blue 20,000K source?

Outdoors, Rayleigh scattering splits daylight
to give us warm direct + cool indirect.

Changes direction and intensity over time.
Direct sunlight is 5000K, but *looks warm.*

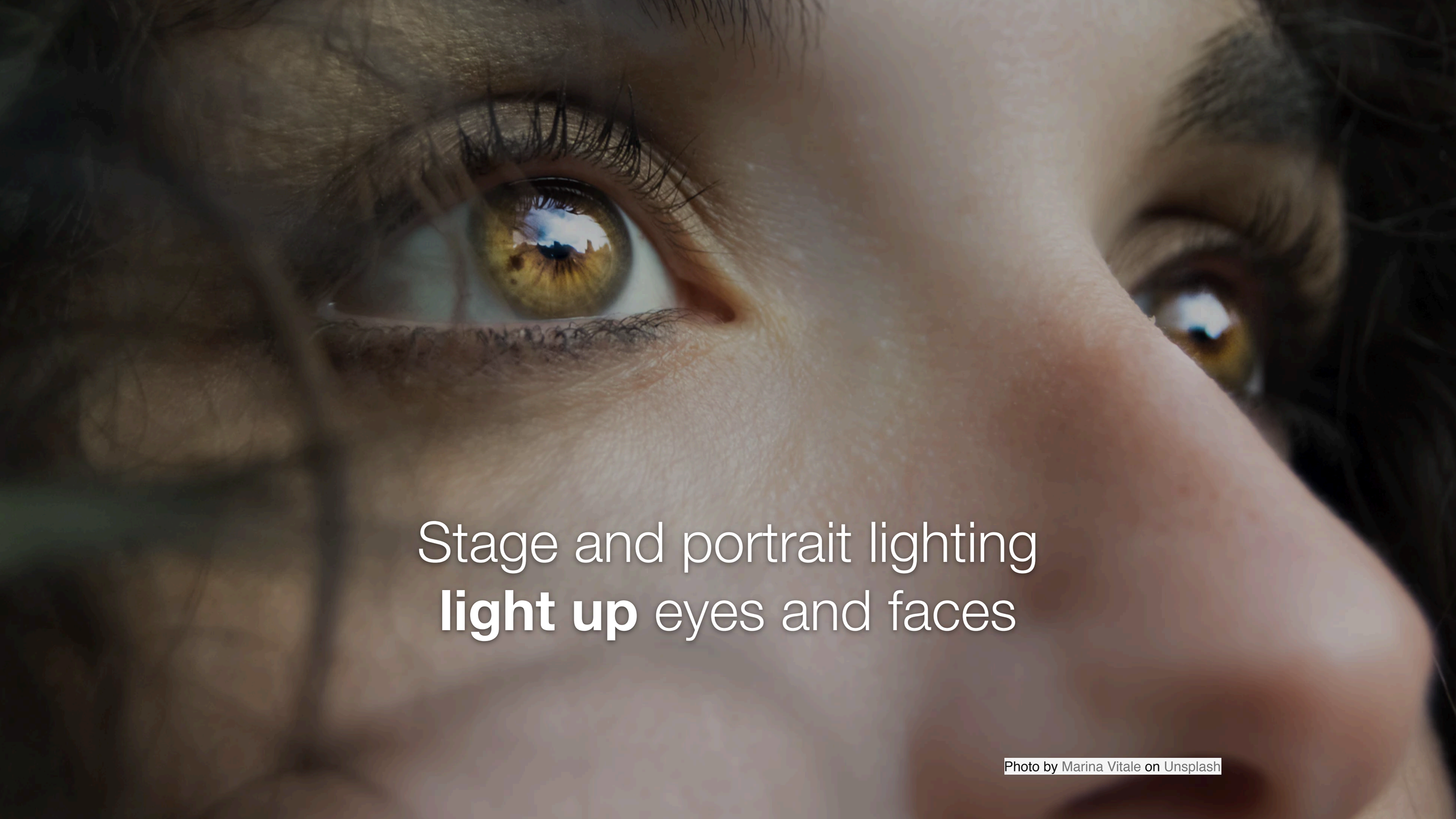
1600 cd/m² and 10,000 lux



Position, Distribution, and Intensity

More Intensity, low glare

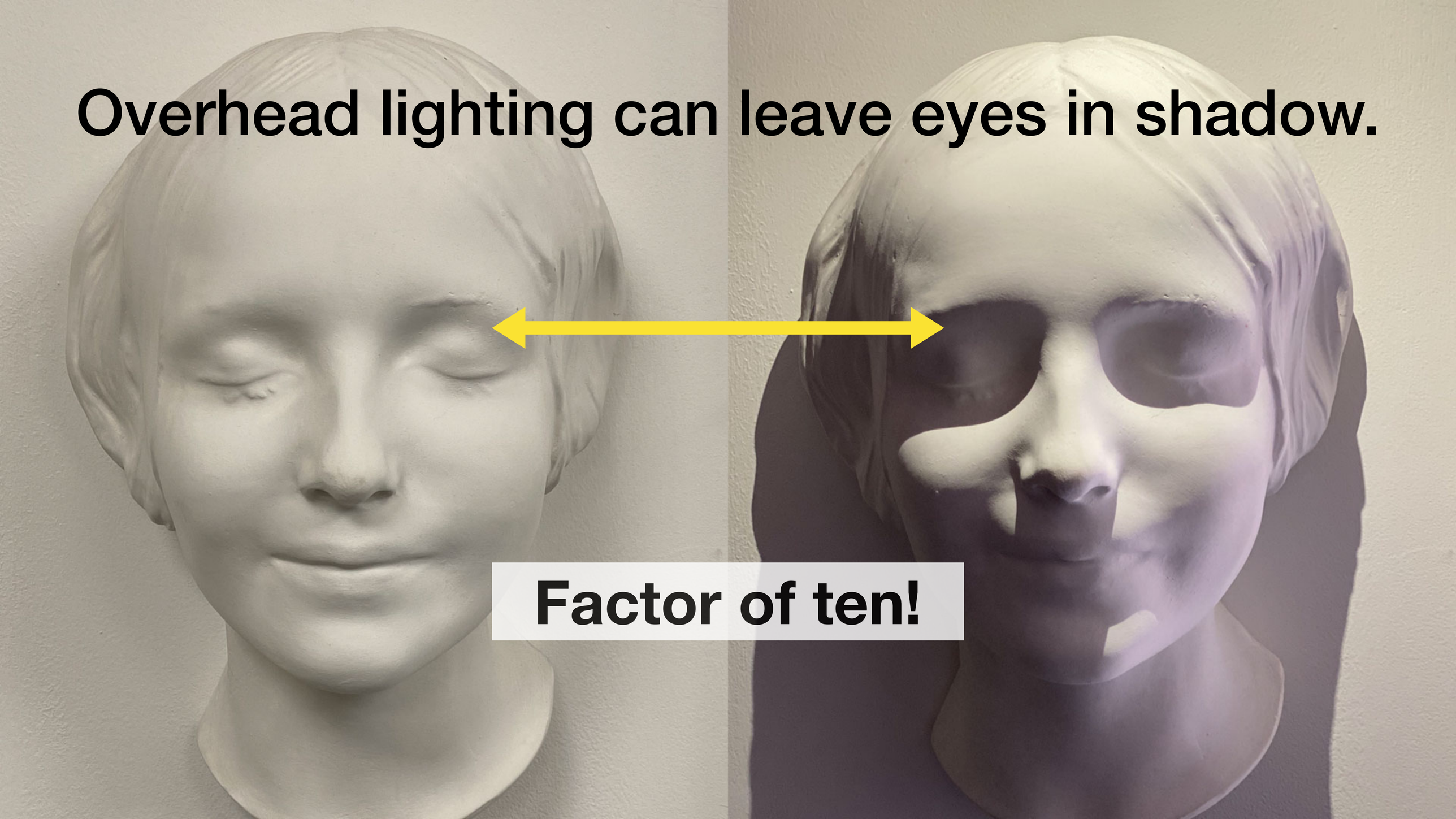
- How to get enough light indoors to convince people it’s daytime?
  - With more lumens in ceiling troffers, glare goes up
  - Need more reflective walls and indirect sources
- **What can we learn from a sunny day (and glare models)?**
  - To raise illuminance, you need to increase your background luminance. Also, light comes from every direction.
  - Color contrast works—it can make 5000K seem warm.



Stage and portrait lighting
light up eyes and faces

Photo by Marina Vitale on Unsplash

Overhead lighting can leave eyes in shadow.



Factor of ten!

Intensity and Position

Position: task lamps and screens are much more efficient at delivering bright light to the eyes than general lighting.

DisplayHDR 1400 displays are shipping…

(People don’t spend all their time with screens, however.)

Still need bias lighting to make these luminances acceptable

Timing

Night and Day, not just one

- Most people are either working on delivering “more light” or “less light”
- **…but not both at once**
- **If you build really effective daytime lighting, people will use it all night, even if you tell them not to.**
- Lighting at night matters too, and we can get a lot dimmer.
- We’re more sensitive than we thought to light at night.
  Phillips 2019 says the *midpoint* of the response is <25 lux

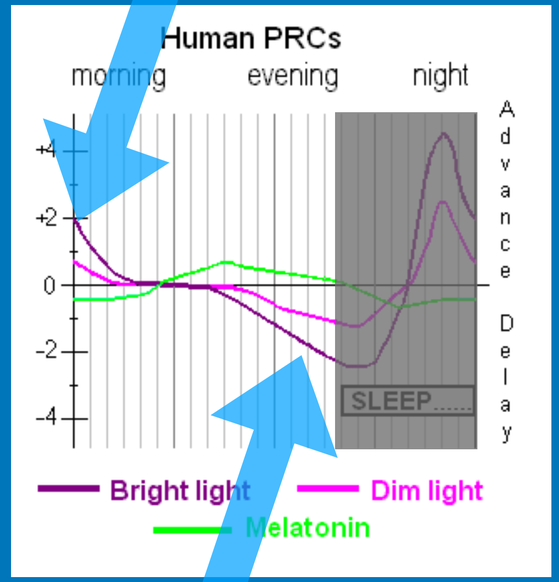
Timing and Sensing

- **Circadian lighting means you need a clock.**
- We should turn down the lights *without asking* at night
  - Clocks in our brains and in our eyes don’t work well with constant light
  - Better to turn down public lighting after a set time—niches for wildlife
- **Sensing**
  - Measure to understand dose received in parts of a space
  - Adapt in realtime based on **who is there,** not just occupancy

Optimizing Timing, More

- Circadian responses are maximized at two times: the morning and evening
- Entrainment is not stable under a single bright light pulse (so we use many hours of bright light)
- A **two-pulse** “skeleton photoperiod” (a pulse of light in the morning and a second in the evening) is the shortest duration of light known to stably entrain animal models. (It’s also been used in Antarctica on humans.)

Light in the morning advances the clock



Light at night delays the clock

Shorter Durations? Recent work

- Rahman 2018 shows: **after a 12-minute pulse of very bright light, the SCN is “blind” to further light for nearly two hours.**
    - Walking to a meeting outdoors could be more effective than constant indoor light. (No sunglasses allowed.)
- Extremely short-duration repeated flashes during sleep can shift the circadian system (Zeitzer 2014)
- Bright light earlier in the evening can reduce sensitivity to light before bed (Kulve 2019)

Combining it all

- Raising background levels so we can have more light in our spaces
- Light up the eyes, but without glare
- Adjusting spectrum by application, and using color contrast to our advantage
- Using task lighting and screens well
- Showing extra light at the most effective times
- **Day and night**, not just one or the other

Thank you

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fluxometer.com

(spectrum visualizations)