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Reducing temporal light modulation to protect health and well-being: More than just visibility

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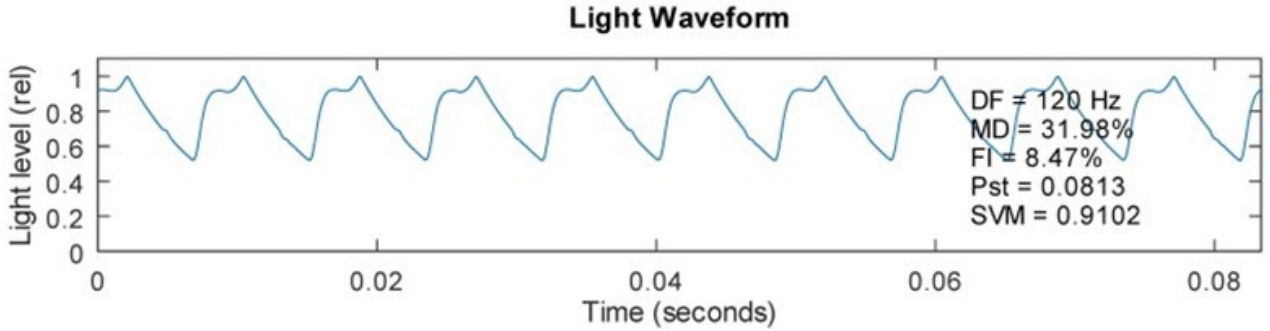
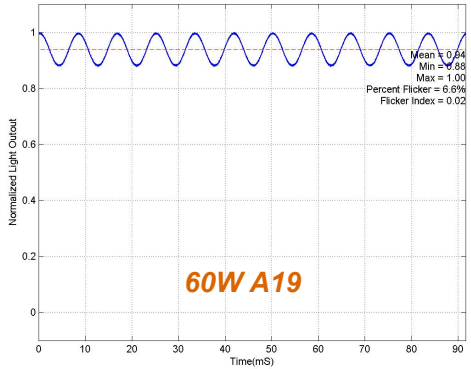
Definition: It's the stimulus!

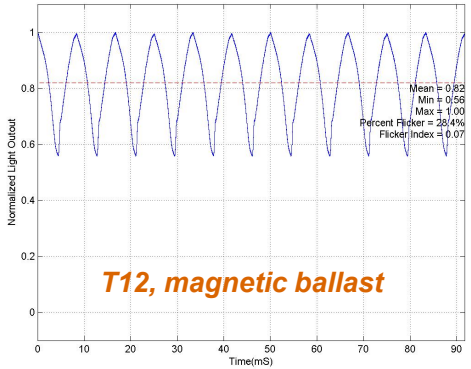
Temporal light modulation (TLM):– Fluctuation in luminous quantity or spectral distribution of light with respect to time [CIE TN 012:2021].

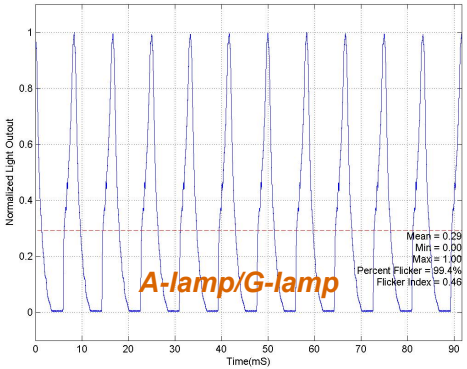
Description: A light stimulus with a waveform that exhibits time-based modulation, characterized with parameters including the frequency, modulation depth, waveform shape, and (for rectangular waves) duty cycle.

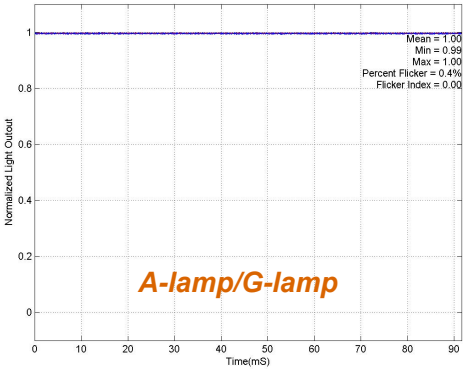


Temporal Light Modulation (TLM)



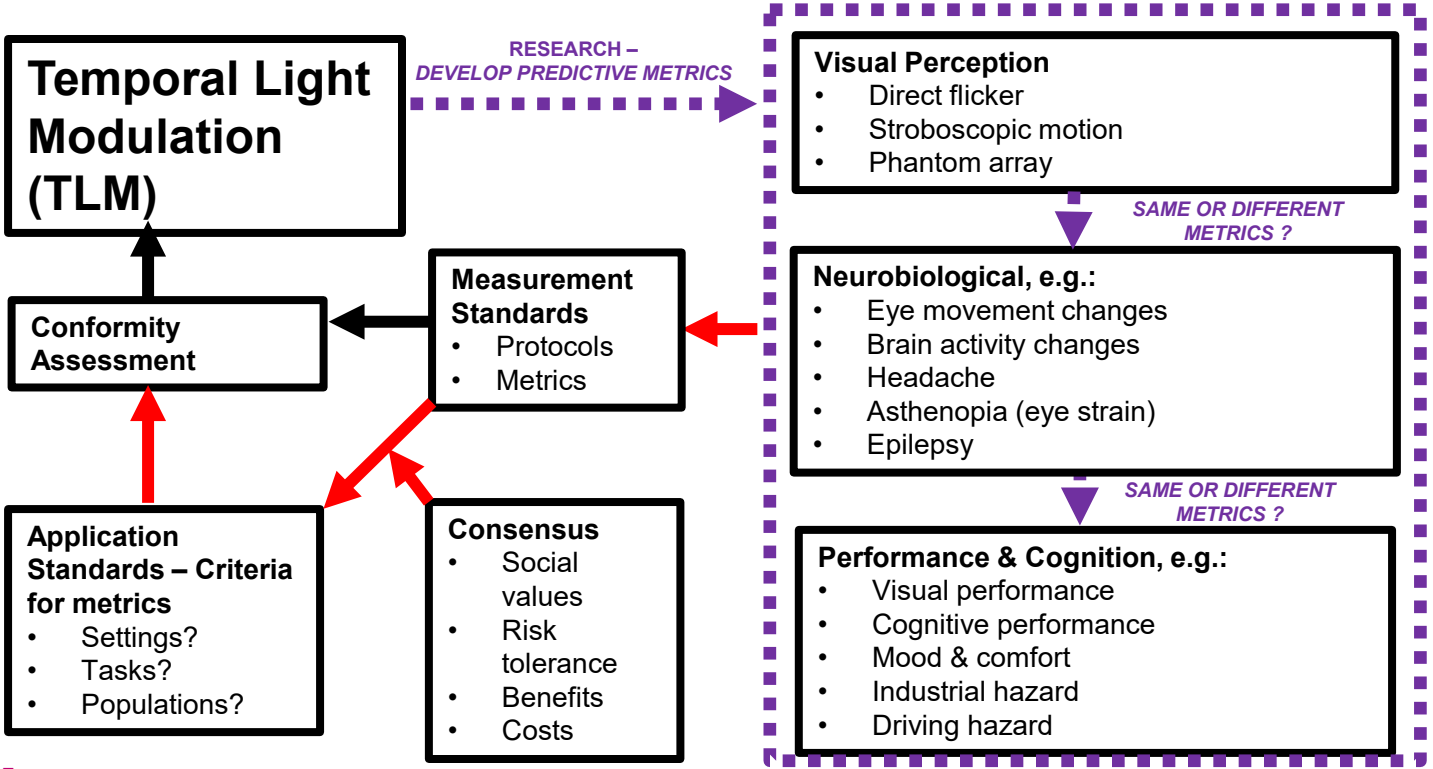






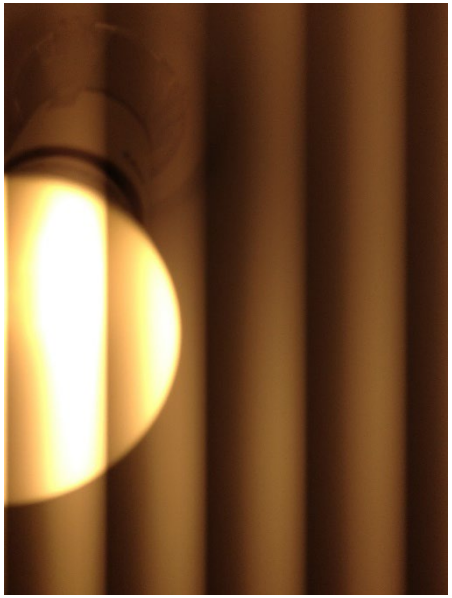
Source: M. Poplawski, PNNL

Standardization framework



See CIE TN 008:2017

Visual perception effects: Flicker



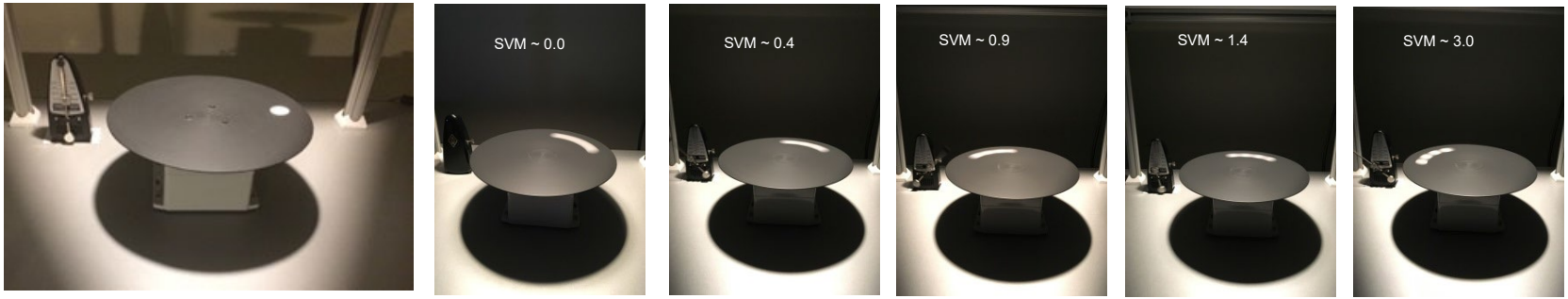
perception of visual unsteadiness induced by a light stimulus the luminance or spectral distribution of which fluctuates with time, for a static observer in a static environment
[ILV 17-22-092]

Generally, occurs for dominant frequencies between 3-90 Hz

Visual perception: Stroboscopic [motion] effect

Change in motion perception induced by a light stimulus the luminance or spectral distribution of which fluctuates with time, for a static observer viewing a moving object [CIE TN 006:2016]

Generally thought to be visible for dominant frequencies below 2000 Hz.



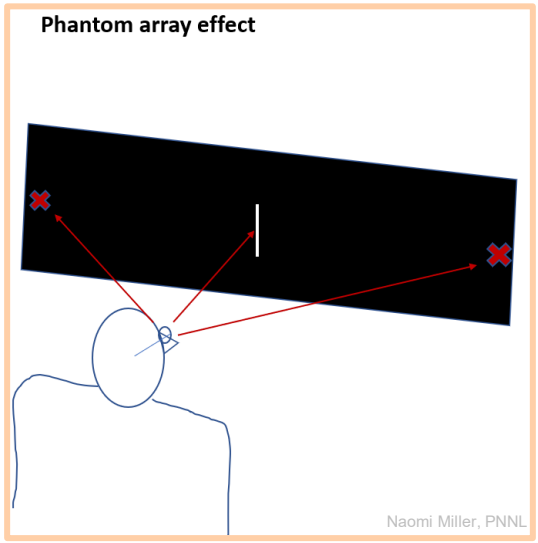
Veitch & Martinsons, 2020.
https://journals.sagepub.com/doi/abs/10.1177/1477153519898718

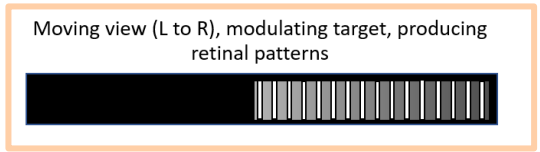
ecodesign regulations now

Flicker for LED and OLED MLS	P_{st} LM ≤ 1,0 at full-load
Stroboscopic effect for LED and OLED MLS	SVM ≤ 0,9 at full-load (except for light sources intended for use in outdoor applications, industrial applications or other applications where lighting standards allow a CRI < 80) From 1 September 2024: SVM ≤ 0,4 at full-load (except for light sources intended for use in outdoor applications, industrial applications or other applications where lighting standards allow a CRI < 80)

https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02019R2020-20210901

Visual perception: Phantom array



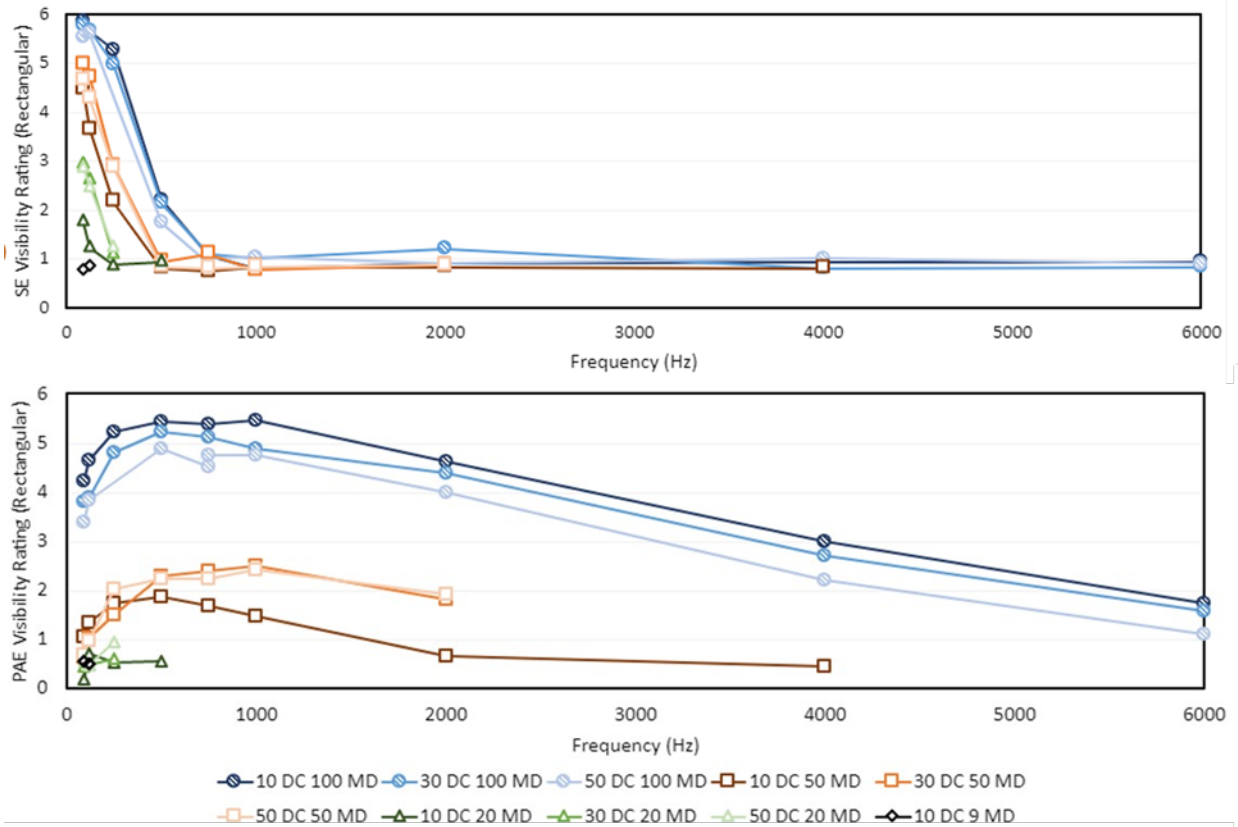


Change in perceived shape or spatial positions of objects, induced by a light stimulus the luminance or spectral distribution of which fluctuates with time, for a non-static observer in a static environment [CIE TN 006:2016]

Evidence shows it can occur across a frequency range from 80 to 11,000 Hz.

The effect occurs when the eye is making large saccades, because of spatially separated retinal images.

Phantom array & stroboscopic motion: PNNL



Average scores, N=36. Participants saw each of 74 waveforms once, in random order, PA first, then SE.

Figures courtesy Naomi Miller, used with permission.

Data from:
Miller, N. J., Rodriguez-Feo Bermudez, E. Irvin, L., & Tan, J. (accepted manuscript). Phantom array and stroboscopic effect visibility under combinations of TLM parameters. *Lighting Research & Technology*, in press.

Perception and consciousness

"If people can't see the flicker, does TLM even matter?"

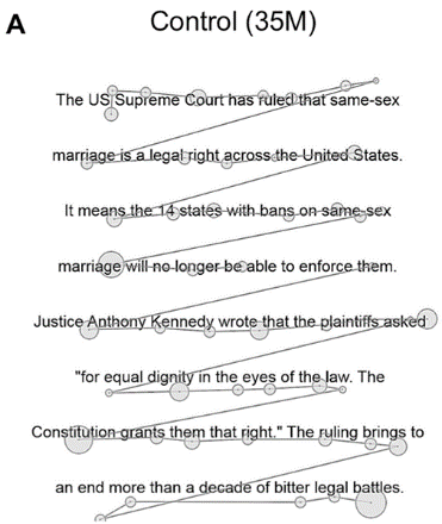
→ YES! (and I'll show evidence of responses that demonstrate this)

Do we demand that conscious reports are needed to confirm perception?

Are the effects of TLM exclusively those mediated through the visual cortex?

The phenomenon of blindsight is an example of the dissociation between perception and consciousness, in which people with damage to certain parts of the visual cortex can discriminate behaviourally between visual stimuli (e.g., flicker detection) despite not being able to verbally report seeing the stimuli.

TLM and eye movements



Chen Oh et al. (2018), fig. 7.
https://doi.org/10.1371/journal.pone.0203924.

Eye movements are controlled in part by visual information obtained during each saccade. Anything that disrupts eye movements makes neural computation more difficult.

Wilkins showed in 1986 that TLM from VDTs (50 Hz vs 100 Hz) and fluorescent room lighting (100 Hz vs 20 kHz) disrupted eye movements.

In each case, the lower frequency caused larger saccades.

In reading, longer saccades might mean that more corrective saccades are required, increasing fatigue and slowing performance.

TLM and brain activity

Electroretinogram studies showed phase-locked responses up to ~200 Hz

100 Hz magnetic and ~40 kHz electronic ballasts; Küller & Laike (1998) measured EEG responses, performance, and mood

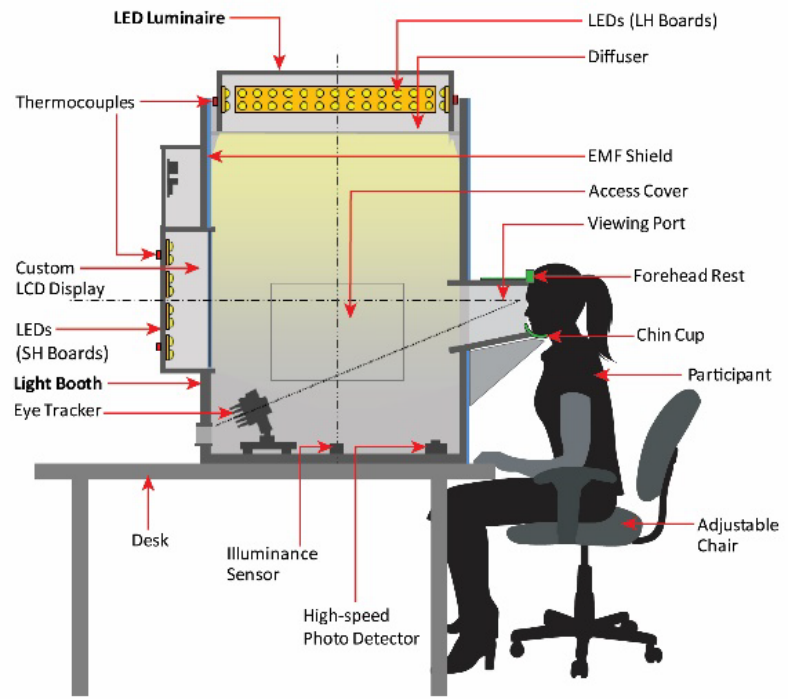
No overall EEG differences – but a subset of people with a higher CFF showed alpha wave suppression under the magnetic ballasts

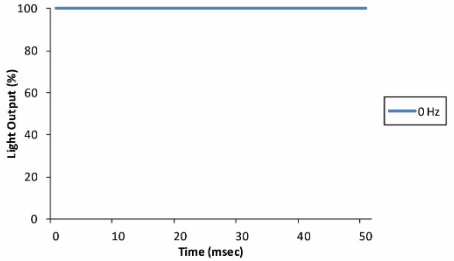
Zhou et al. (2020) tested 9 variations of TLM frequency (100, 400, 1500 Hz) and modulation depth (10%, 30% 70%)

Alpha suppression for 100 Hz compared to 1500 Hz (10% MD)

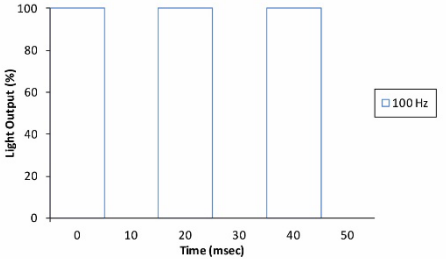
→ both suggest increased arousal at the lower frequency

Eye movement & brain activity & performance

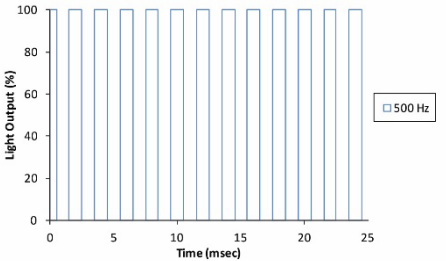




No TLM
FI = 0.0
P_{st}^{LM} = 0.00
SVM = 0.00



100 Hz,
100 % mod depth,
50% duty cycle
FI = 0.50
P_{st}^{LM} = 0.10
SVM = 4.89



500 Hz,
100 % mod depth,
50% duty cycle
FI = 0.50
P_{st}^{LM} = 0.00
SVM = 1.73

Veitch, J. A., Van Roon, P., D'Angiulli, A., Wilkins, A., Lehman, B., Burns, G. J., Dikel, E. E. (in press). Effects of temporal light modulation on cognitive performance, eye movements, and brain function. *LEUKOS*, in press. https://doi.org/10.1080/15502724.2023.2170883.

Dependent measures

Stroop cognitive interference task

Reading task

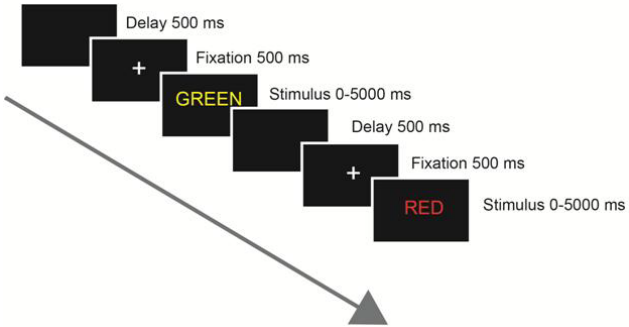
Eye movements

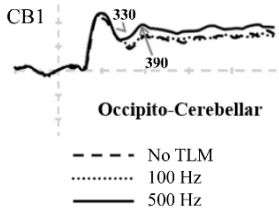
Pupil size, blinks, saccades, fixations

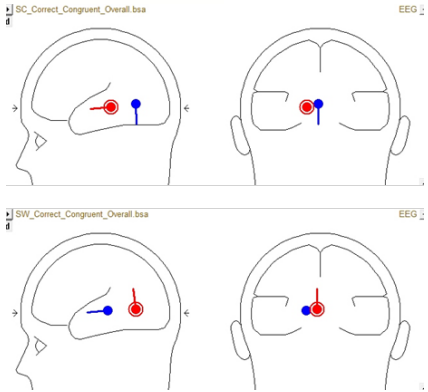
EEG recordings

Peaks and amplitudes of evoked potentials

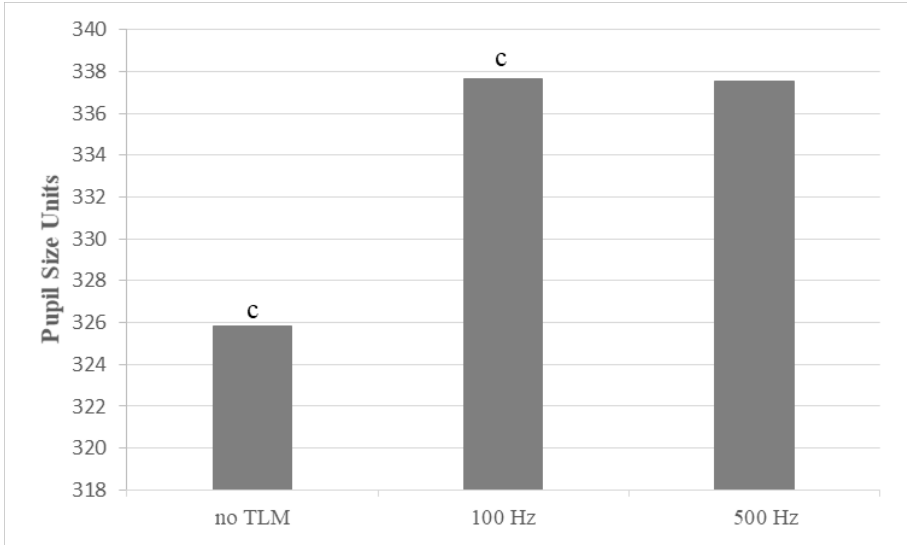
Source dipole analysis



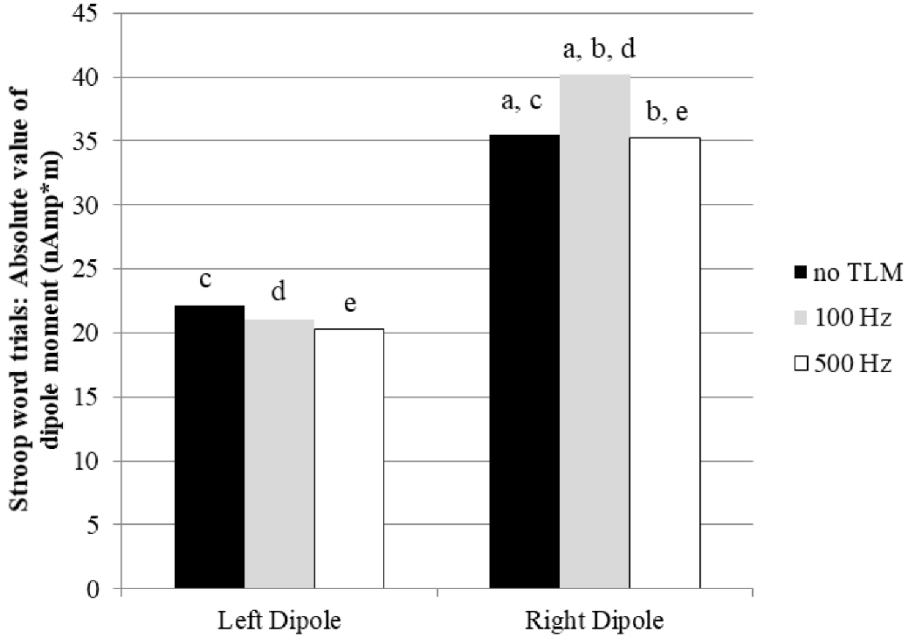




TLM affects arousal



Pupil size

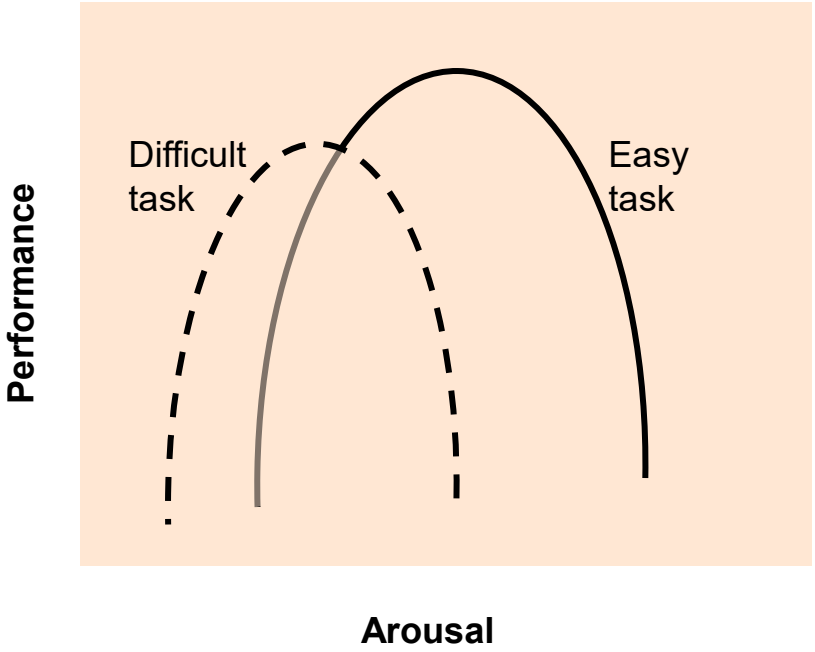


EEG-based source dipole strength

Aside: Performance and arousal

The 1908 (not a typo) Yerkes-Dodson law says that increasing arousal can increase task performance until there's too much arousal, but optimal arousal differs for different tasks.

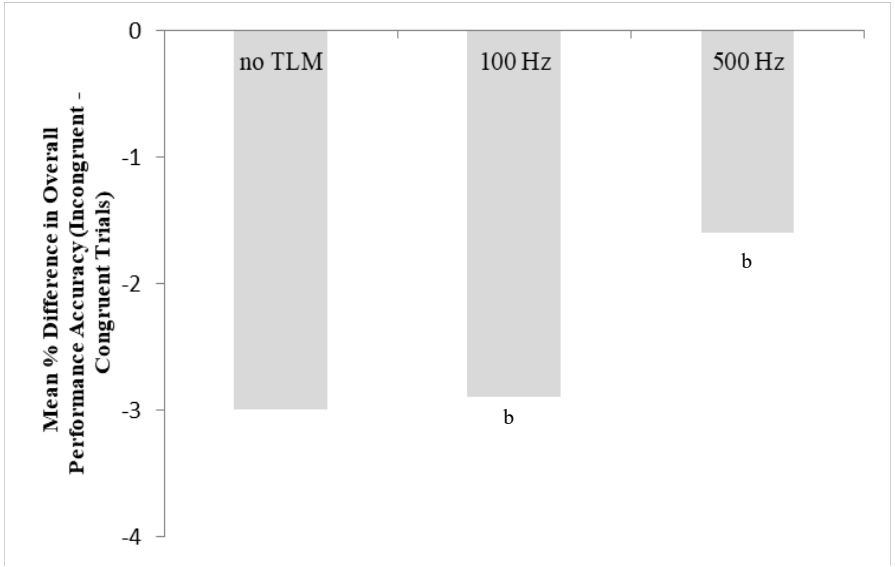
…however, there's no absolute measure of arousal and no guidance on what's the right level for any task



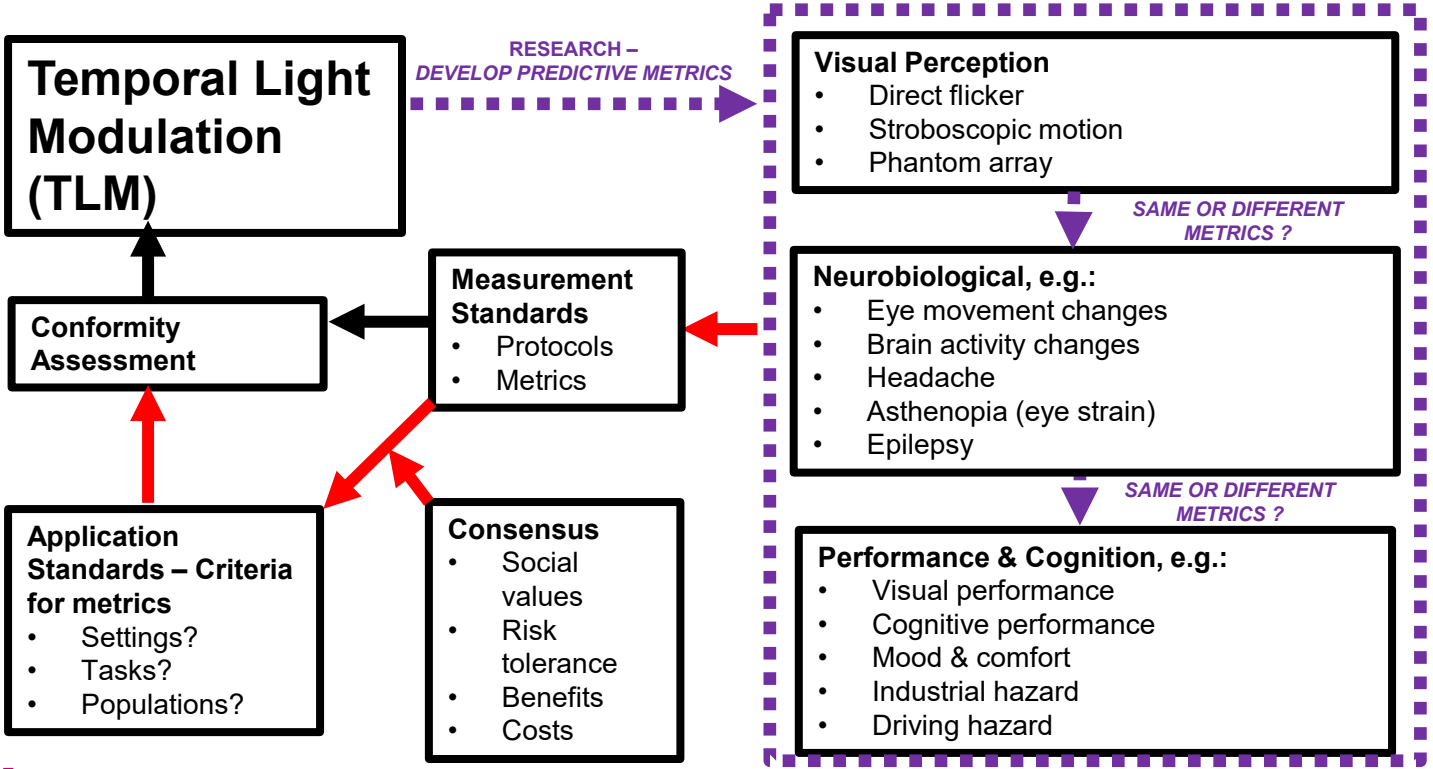
TLM affected performance

Overall and for the Stroop colour trials (which are more difficult than word trials) there was more cognitive interference for the no TLM and 100 Hz TLM conditions than for 500 TLM.

Arousal and stochastic facilitation theories provide possible explanations.



Standardization framework



See CIE TN 008:2017

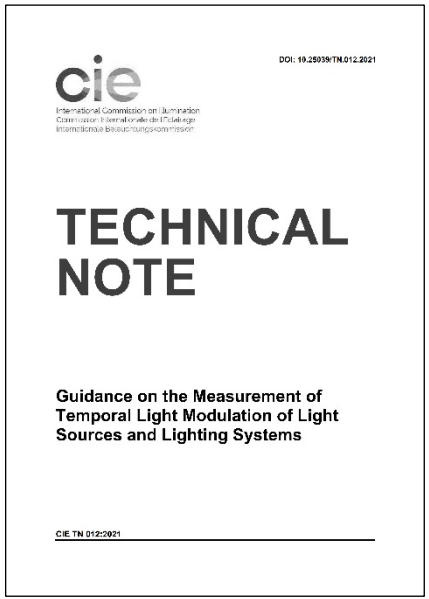
Measurement, conformity, uncertainty

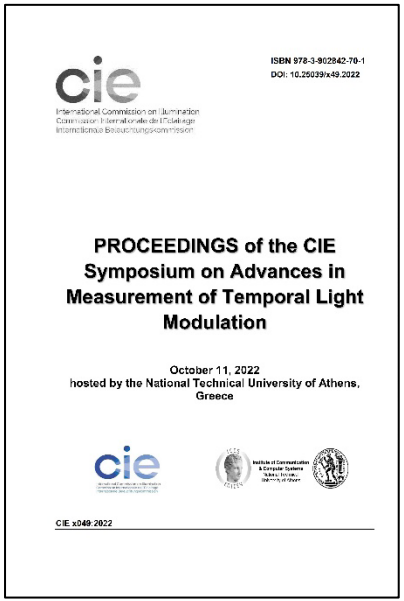
Measurement standards!

None of the guidance documents is (yet) sufficiently specific to inform non-expert labs about what to do.

MetTLM is an example of the research we need here

The IEA 4E Annex intercomparison (IC 2022) will help to build confidence among labs and in test results





Summary

The current *ecodesign* regulations are conservative in terms of preventing problems with flicker or the stroboscopic effect

...but these quantities don't predict the other visual perception (phantom array), and possibly don't predict other important behavioural and physiological outcomes

We might need new quantities to achieve the goal of protecting all of us

...Stay tuned for future research results!

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THANK YOU

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