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Opportunities and Challenges to Understanding Temporal Light Modulation Effects on People

Jennifer A. Veitch, Ph.D., FIES

CIE Australia Lighting Research Conference, 2022-02-07

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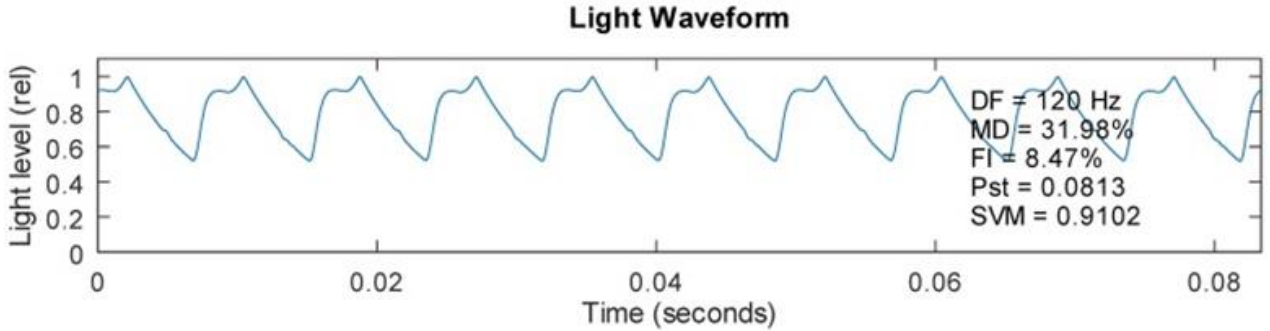
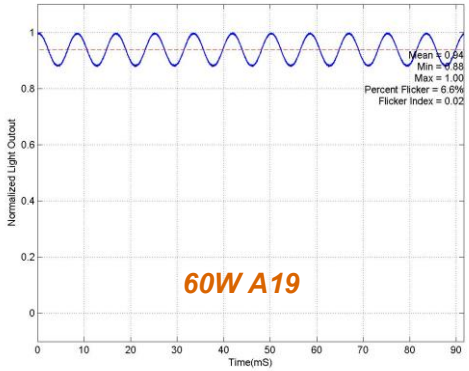
Definition: It's the stimulus!

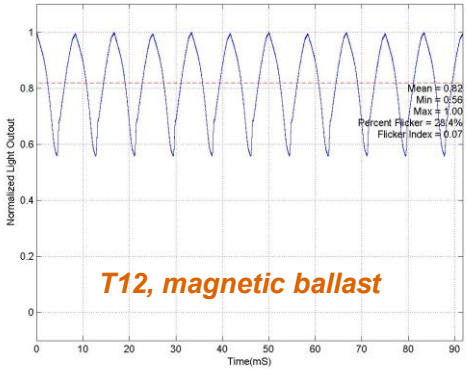
Temporal light modulation (TLM):– Fluctuation in luminous quantity or spectral distribution of light with respect to time [CIE TN 012:2021].

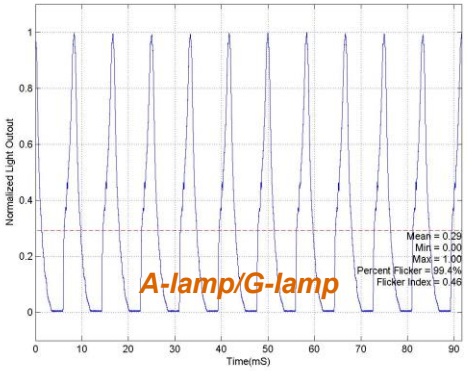
Description: A light stimulus with a waveform that exhibits time-based modulation, characterized with parameters including the frequency, modulation depth, waveform shape, and (for rectangular waves) duty cycle.

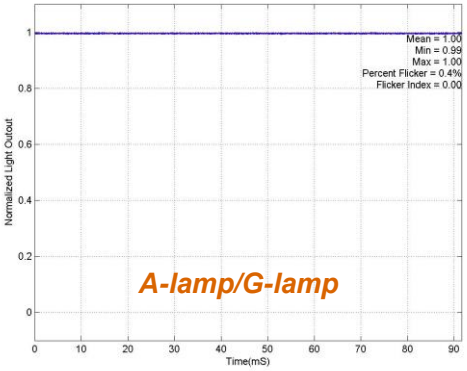


Temporal Light Modulation (TLM)



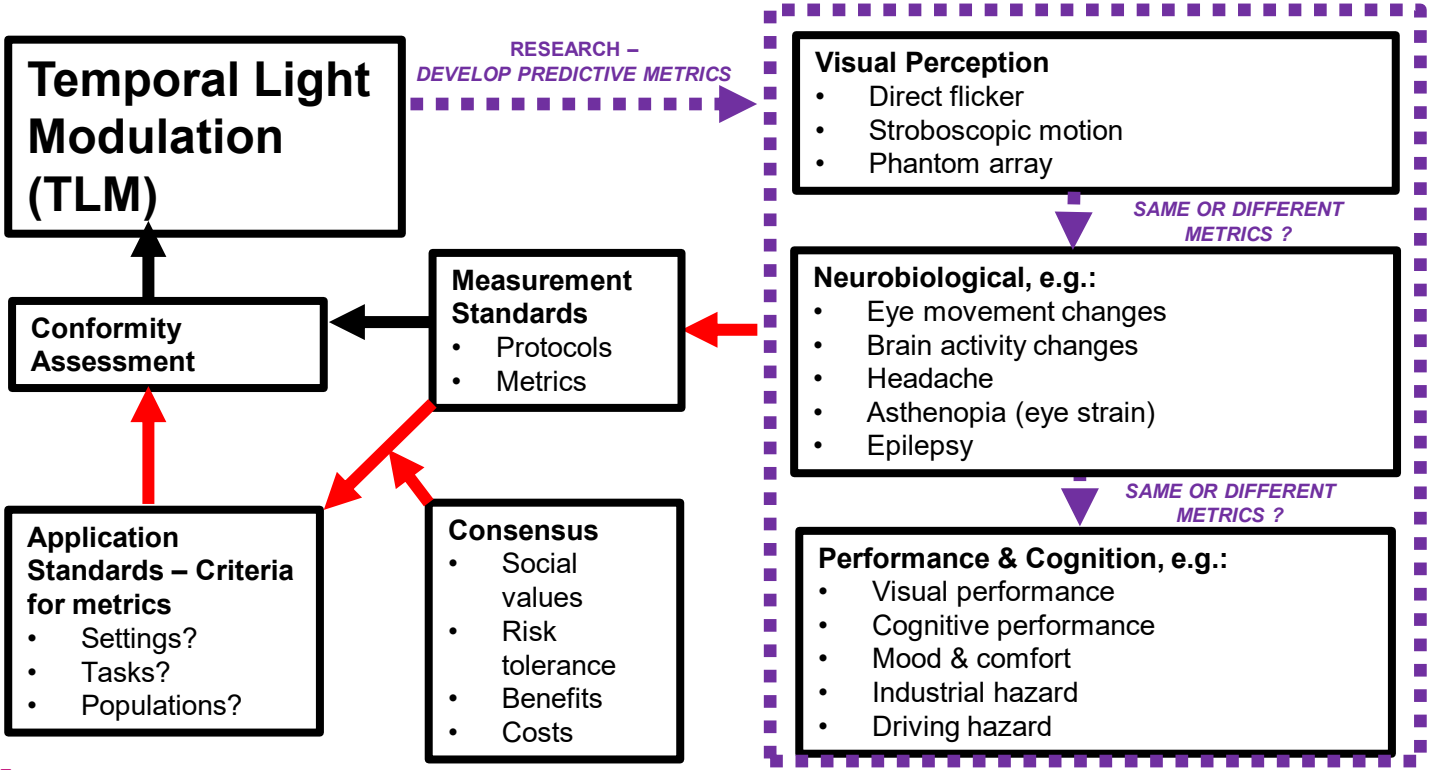






Source: M. Poplawski, PNNL

Opportunities and challenges



See CIE TN 008:2017

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?

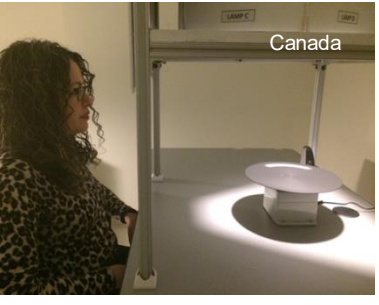
Are the effects of TLM exclusively those mediated through the visual cortex?

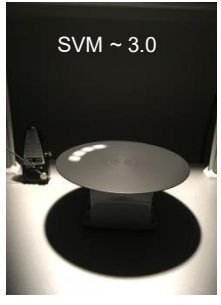
The phenomenon of blindsight is an example of the dissociation between perception and consciousness, in which people with damage to certain parts of the visual cortex can discriminate behaviourally between visual stimuli (e.g., flicker detection) despite not being able to verbally report seeing the stimuli.

Stroboscopic visibility

- Joint work with CSTB in France
- Sponsored by IEA 4E SSL Annex (including Canada, through NRCan-OEE)

- SVM is a threshold measure of the visibility of the stroboscopic effect suitable for office tasks
- Average person sees it 50% of the time for SVM=1
- What about sensitive people?





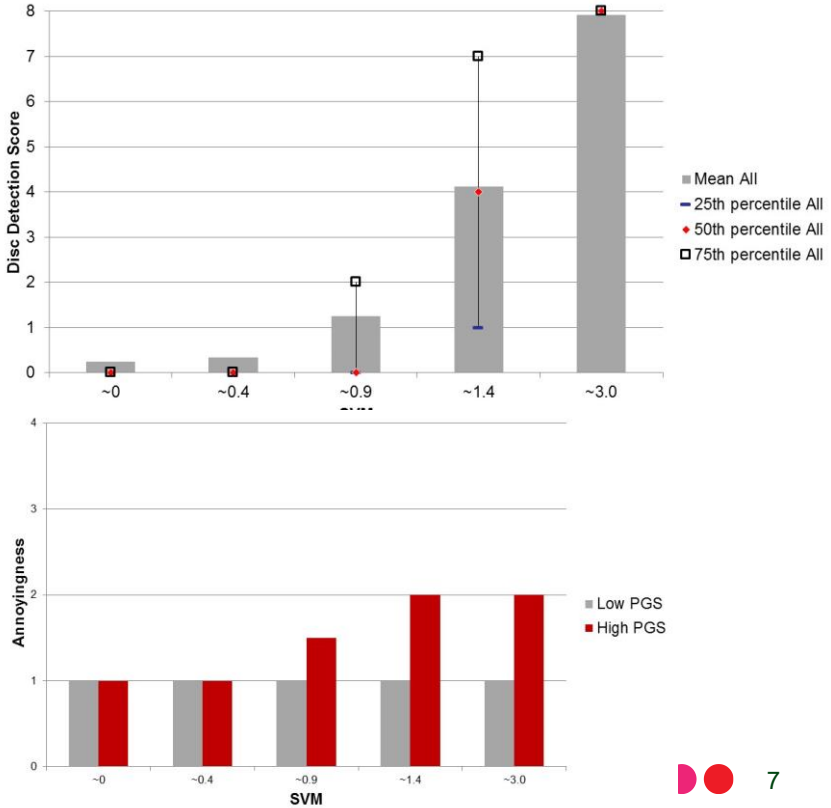
Stroboscopic visibility

N=85, 5 levels of SVM, replacement A lamps

Stroboscopic visibility same for groups regardless of sensitivity to visual stress

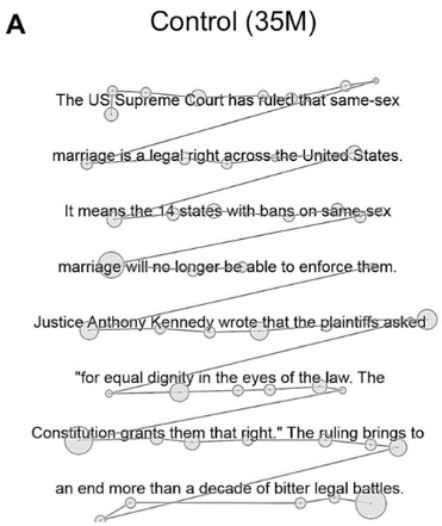
But!

High pattern glare sensitivity was associated with greater annoyingness for SVM= 1.4 and 3.0



Veitch, J. A., & Martinsons, C. (2020). Detection of the stroboscopic effect by young adults varying in sensitivity. *Lighting Research & Technology*, *52*(6), 790-810. https://doi.org/10.1177/1477153519898718

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; Kuller & Laike (1998) measured EEG responses, performance, and mood

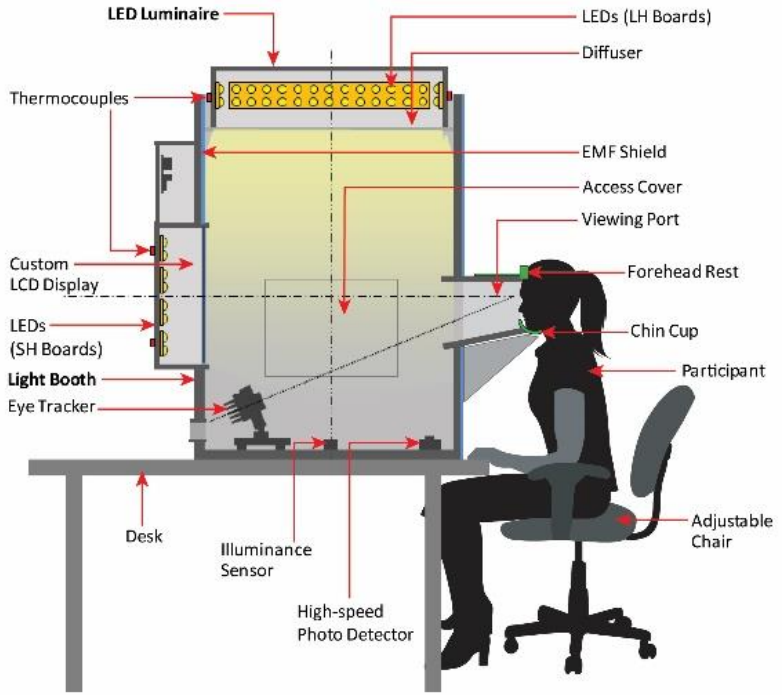
No overall EEG differences – but a subset of people with a higher CFF showed alpha wave suppression under the magnetic ballasts

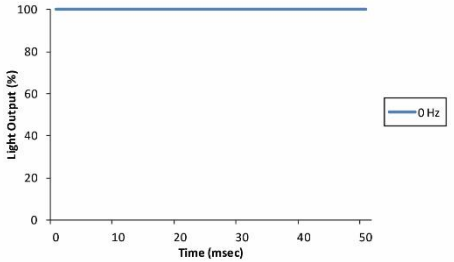
Zhou et al. (2020) tested 9 variations of TLM frequency (100, 400, 1500 Hz) and modulation depth (10%, 30% 70%)

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

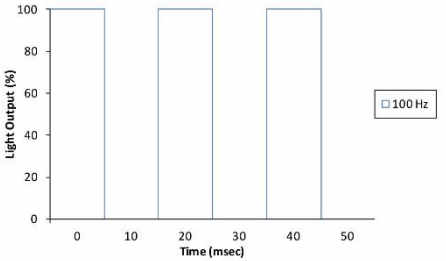
→ both suggest increased arousal at the lower frequency

Eye movement & brain activity & performance

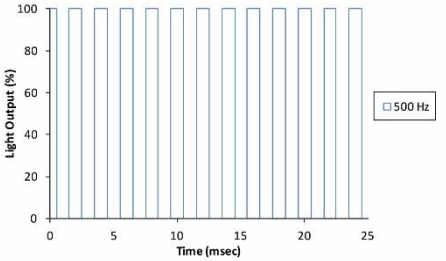




No TLM
FI = 0.0
P_{st}^{LM} = 0.00
SVM = 0.00



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

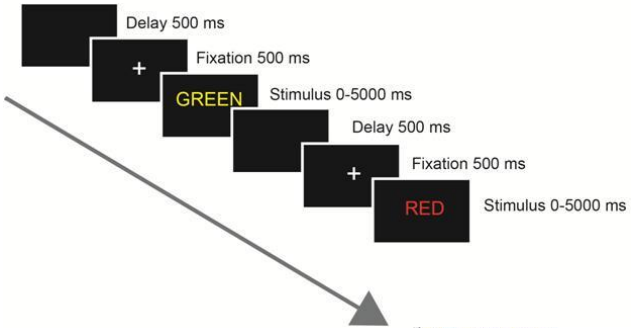
Eye movements

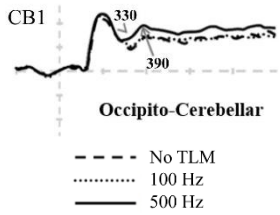
Pupil size, blinks, saccades, fixations

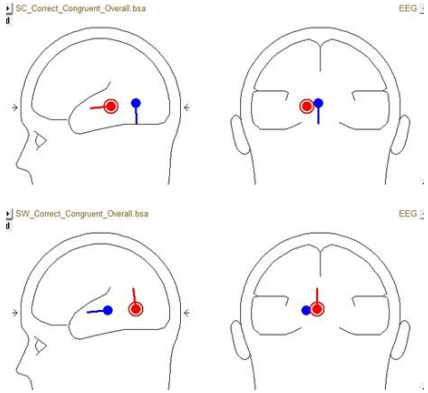
EEG recordings

Peaks and amplitudes of evoked potentials

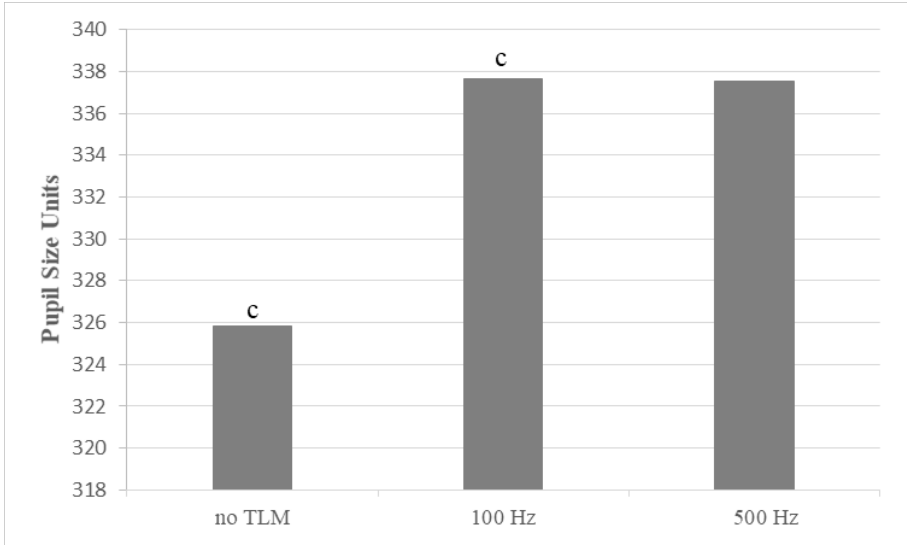
Source dipole analysis



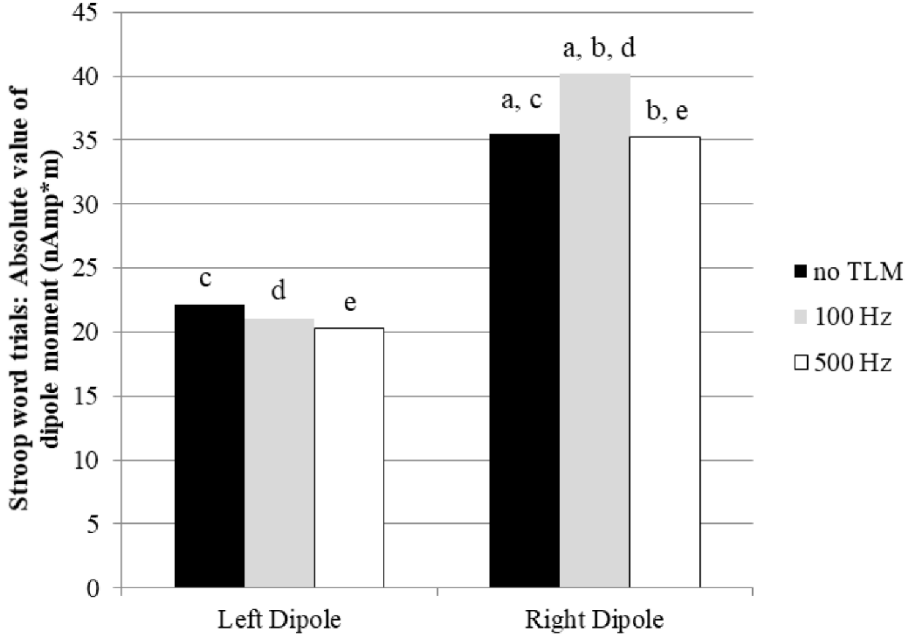




TLM affects arousal



Pupil size

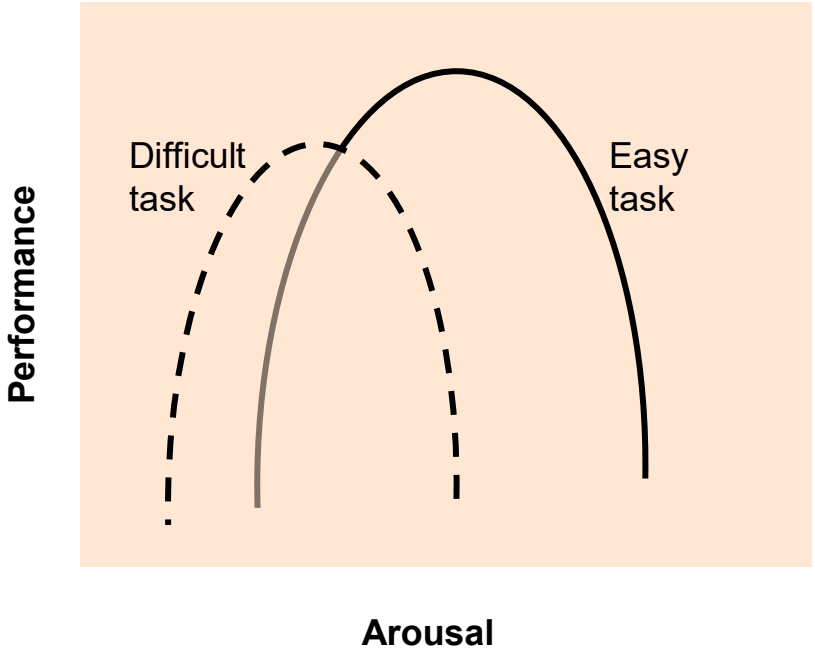


EEG-based source dipole strength

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.

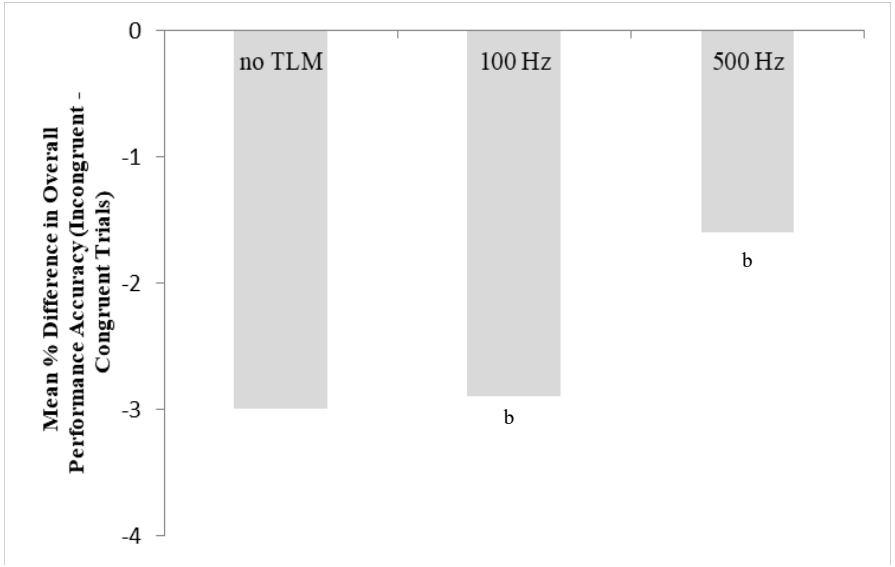
…however, there's no absolute measure of arousal and no guidance on what's the right level for any task



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.



Opportunities and challenges 1

Sophisticated research designs!

More diverse outcome measures (not just visual perception)

Technical difficulties in combining techniques (e.g., eye movements and EEG)

Truly interdisciplinary teams

Statistical power

Focus on sensitive individuals

Increase sample size

Longer & more realistic exposures

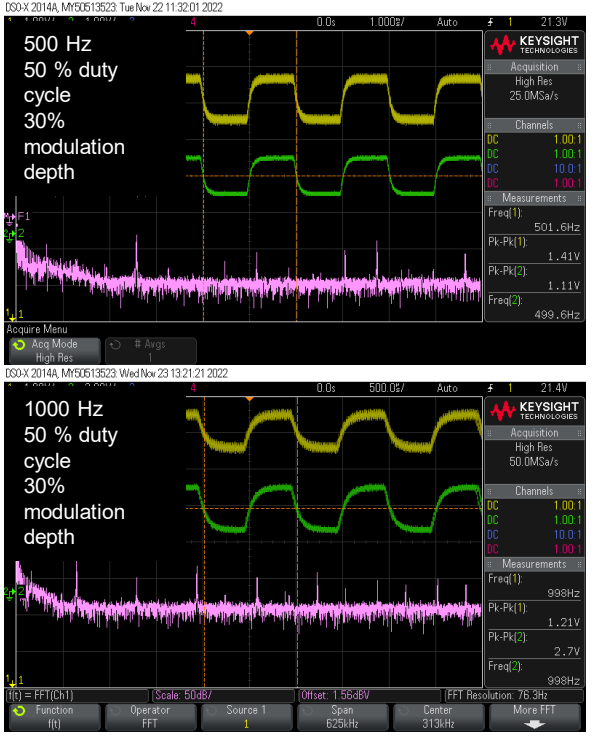
Opportunities and challenges 2

Delivering stimuli accurately and at scale

Experiments need to deliver a range of defined waveforms while holding other variables constant (e.g., vary frequency and duty cycle while maintaining a stable illuminance)

Commercial products that can do this with a whole luminaire (or synched luminaires in a room) are hard to find and expensive

The absence of them limits full-scale research



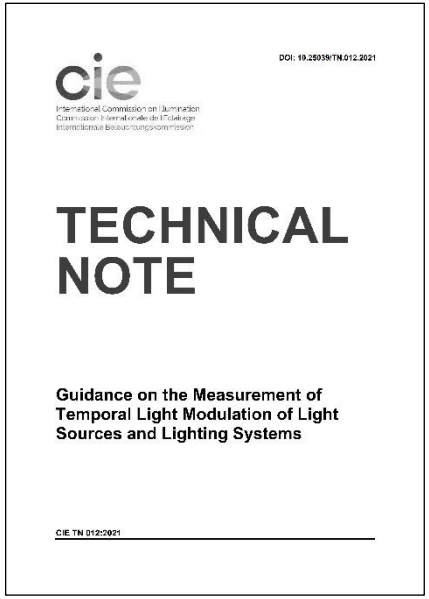
Yellow: power supply delivered
Green: illuminance detector observed

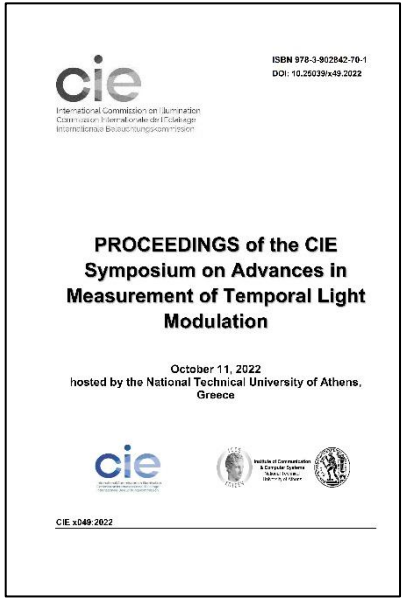
Opportunities and challenges 3

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

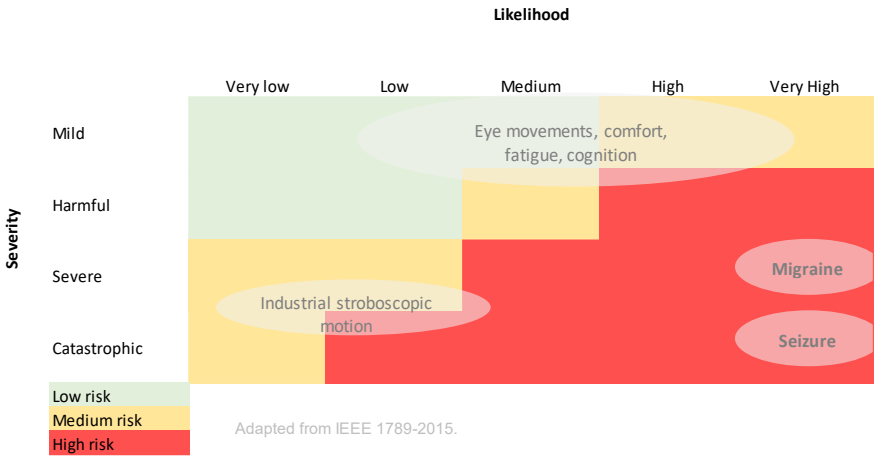




What's the payoff?

My personal 2022 update of the IEEE 1789-2015 hazard analysis suggests that although we know more now than in 2015, we don't see evidence that moves TLM into the upper left corner of this matrix.

Facing the challenges will give us the opportunity to remove risks for most of the population.



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THANK YOU

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