

Temporal light modulation effects on visual perception, cognition, and comfort - Research in Canada and France

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Temporal light modulation (TLM)

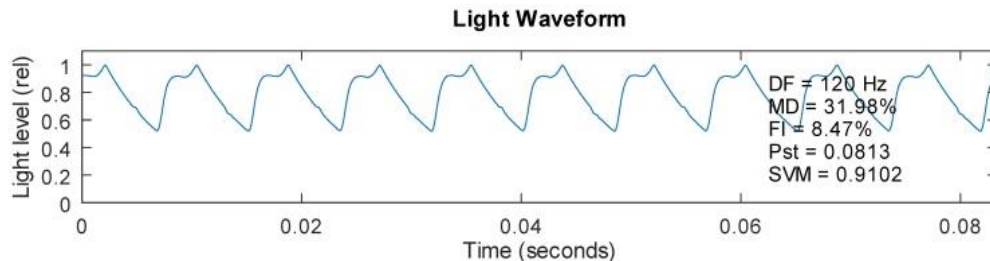
Cyclic variation in light output from a light source or lighting system

Known effects:

Visual perception: temporal light artefacts (TLM, stroboscopic effect, phantom array)

Task performance: reading, typing, eye movements

Neurobiological effects: headache, eyestrain, migraine, epilepsy, etc.

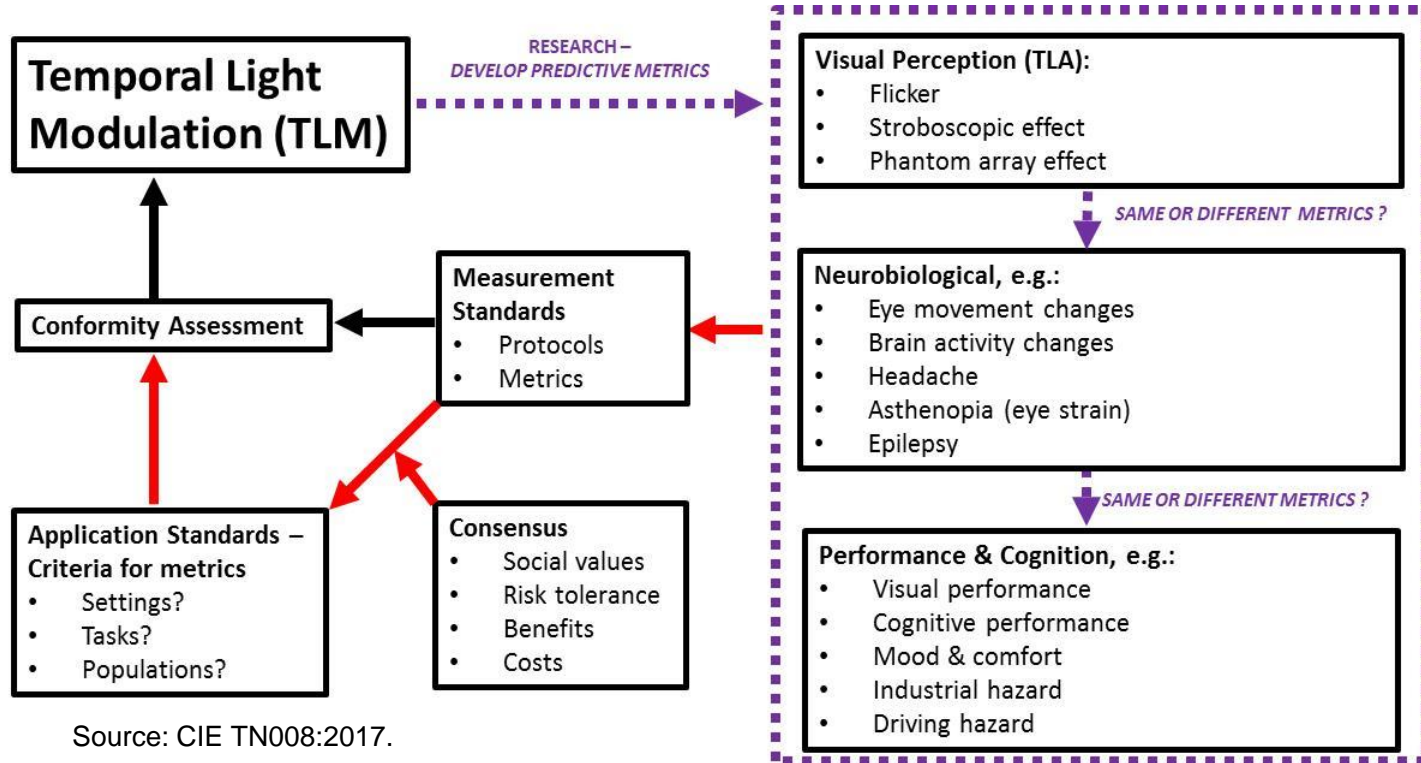


IEEE S1789-2015 Hazard analysis

		PROBABILITY				
		Very Low	Low	Medium	High	Very High
SEVERITY	Mild			Performance & Asthenopic Effects/Eye Strain		
	Harmful				Aggravation of Autistic Behaviors	
	Severe		Stroboscopic Effect			Migraine
	Catastrophic					Photosensitive Seizure

Source: IEEE S1789-2015.

CIE Stakeholder workshop on TLM standards



Source: CIE TN008:2017.



Outline

Visual perception experiment : Stroboscopic effect detection (Canada-France)

Veitch & Martinsons / Funding: SSL 4E Annex, CSTB, NRC, Independent Electricity System Operator Conservation Fund (Province of Ontario)

Cognitive performance, eye movement & brain activity experiment (TLM ex 1)

Veitch, Van Roon, D'Angiulli, Wilkins, Lehman, Burns, & Dikel / Funding: McClung Foundation, Natural Resources Canada, OSRAM SYLVANIA, NRC

Cognitive performance, eye movement & phantom array experiment (TLM ex 2)

Veitch, Kruihof, Mancini, & Zhang / Funding: McClung Foundation, Independent Electricity System Operator Conservation Fund (Province of Ontario), NRC

Conclusions & next directions

Canada-France experiment

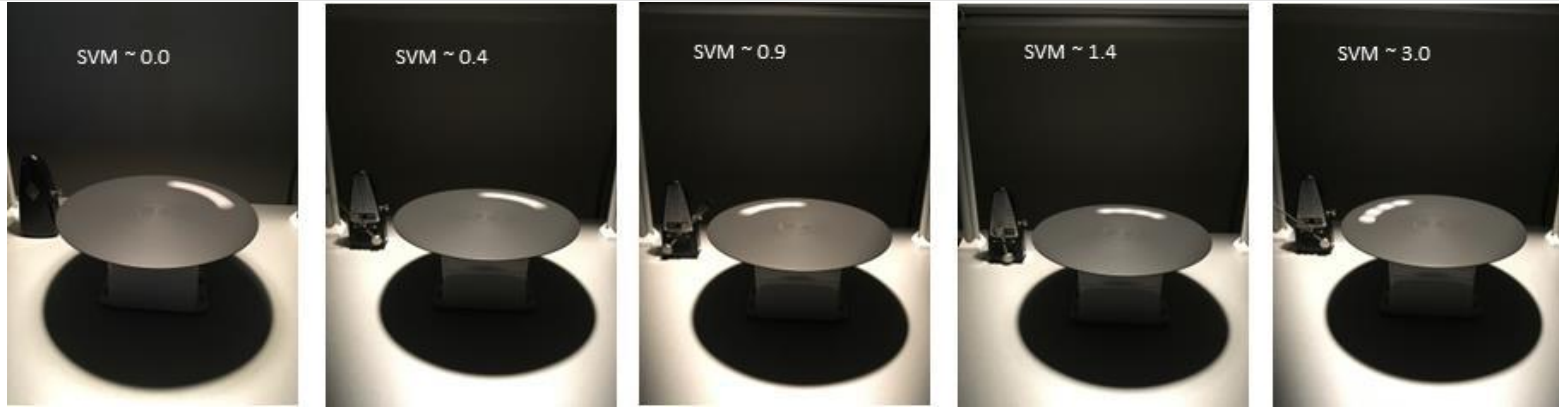
Same protocol in Canada and in France

5 commercially-available LED replacement lamps, chosen to meet SVM criteria

3 tasks: horizontal stroboscopic detection (rotating disc); vertical stroboscopic detection (metronome); acceptability & annoyingness ratings



Canada-France experiment - Hypotheses



H1: Participants will detect the stroboscopic effect on 50% of trials for SVM=1.

H2: Participants will detect the stroboscopic effect on an increasing percentage of trials with increasing SVM.

H3: Comfort and pleasantness drop with increasing SVM, and annoyingness increases with increasing SVM.

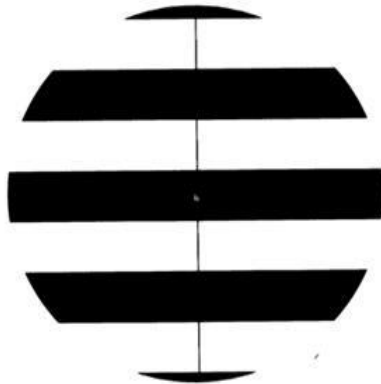
Canada-France experiment – Lamps

Condition	Dominant Frequency [Hz]	Modulation [%]	Flicker Index [%]	P_{st}^{LM}	SVM
NRC-1	120	4.7	0.43	0.05	0.04
NRC-2	120	14.0	3.79	0.07	0.42
NRC-3	120	32.0	8.47	0.08	0.91
NRC-4	120	55.6	13.25	0.06	1.38
NRC-5	120	91.5	29.99	0.33	2.80
CSTB-1	100	2.1	0.6	0.39	0.00
CSTB-2	100	11.8	3.7	0.05	0.43
CSTB-3	100	27.8	7.9	0.08	0.96
CSTB-4	100	40.2	12.3	0.26	1.47
CSTB-5	100	79.4	26.9	0.38	3.09

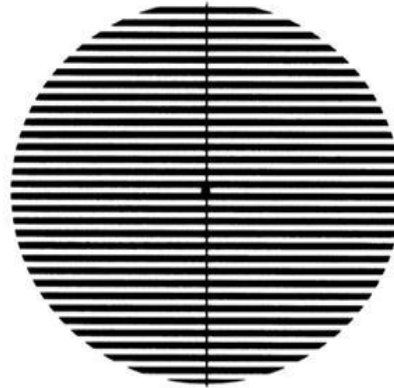
Canada – France experiment - Sensitivity

Wilkins & Evans (2012) Pattern Glare Sensitivity test

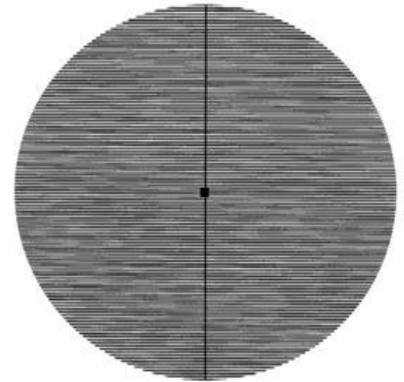
Predicts visual stress – headaches, discomfort from visual stimuli



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Canada – France experiment: Results

Preliminary results were presented at CIE 2019 – paper available in the online proceedings: <https://doi.org/10.25039/x46.2019.PP04>

Updated results shown on next slides are confidential (slides will be removed from shared file) – currently under peer review by a scientific journal

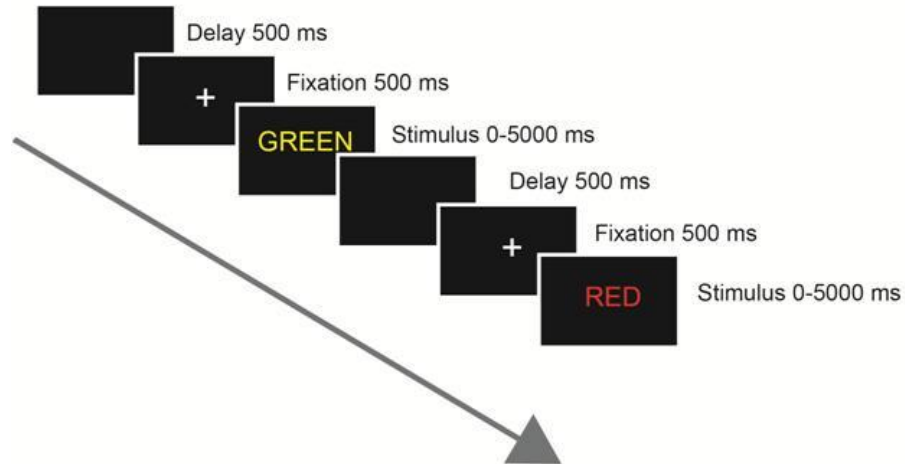
Cognitive performance, eye movement & brain activity experiment (TLM Ex 1)

Compared 0 Hz, 100 Hz, 500 Hz frequencies

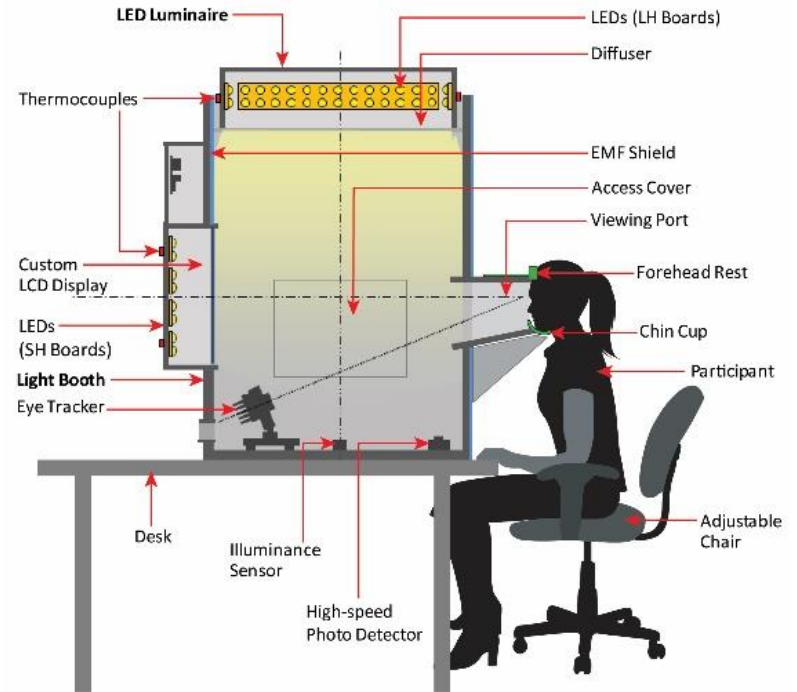
- square-wave, 50% duty cycle, 100% modulation depth

Measured eye movements, brain activity, cognitive performance, reading, anxiety

N=30 university students



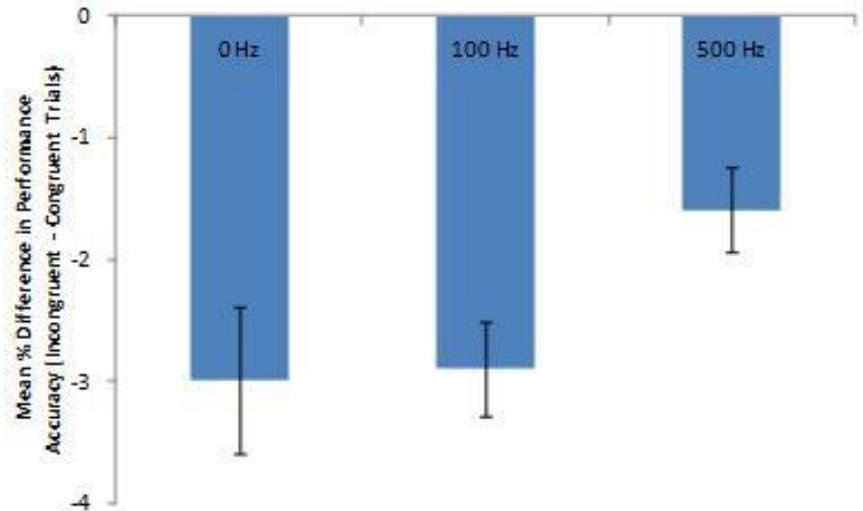
TLM apparatus



TLM Ex 1 results: Cognitive performance

Brain activity was affected by light source TLM, even at frequencies greater than the CFF. Statistically-significant, moderately large effects were observed for the following comparisons:

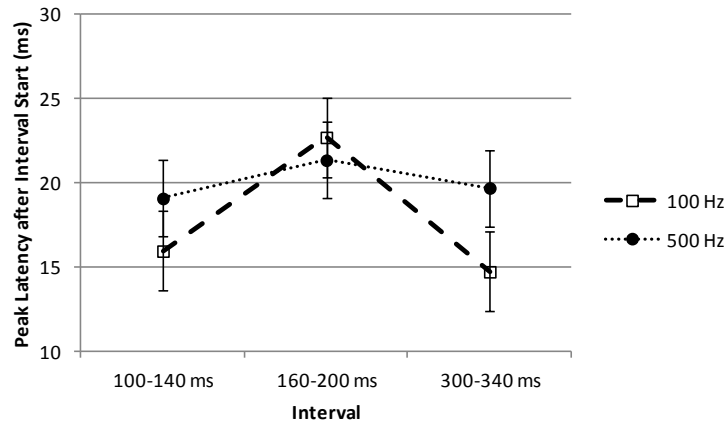
Cognitive effort (Stroop effect) was greater for 0 Hz and 100 Hz conditions than for 500 Hz, both overall and for the colour-identification trials specifically.



TLM Ex 1 results: Evoked potentials

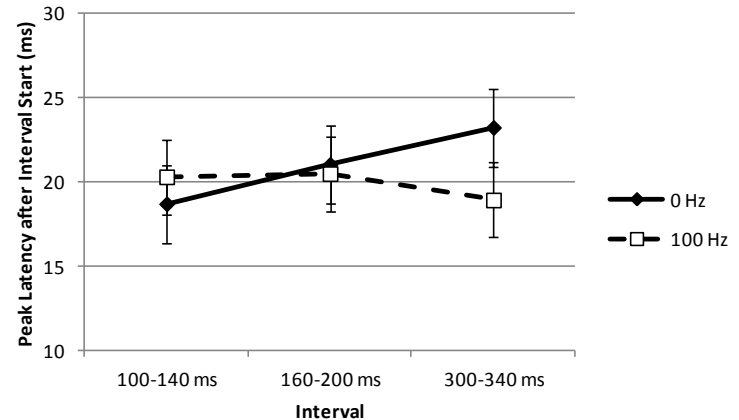
There were no effects of TLM on peak amplitudes.

The timing of peaks (“peak latencies”) following the start of each Stroop trial varied as a function of TLM and trial type.



The peak latency in Stroop word trials showed different quadratic trends for 100 Hz and 500 Hz TLM.

Chart shows means with standard errors.



The peak latency in Stroop colour trials increased linearly (i.e., peaks occurred later within successive intervals) for 0 Hz, but stayed constant for 100 Hz.

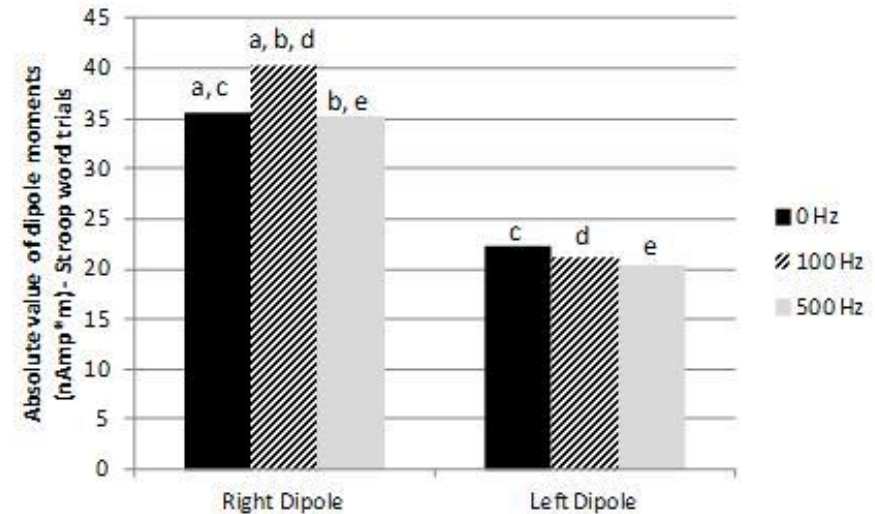
Chart shows means with standard errors.

NRC TLM ex 1 results - Dipole source analysis

The magnitude of brain activity (measured as source dipole strength) was greater in the right hemisphere than the left during both Stroop colour and word trials,

This difference was larger for 100 Hz in comparison to 0 Hz.

There was a smaller inter-hemisphere difference between 100 and 500 Hz during Stroop word trials only.



Graphical representation of the estimated marginal means for the interactions of Dipole x TLM (planned comparisons) on source dipole strength during Stroop word trials. Bars surmounted by the same letter have statistically significant post-hoc tests ($p < .05$).



NRC TLM ex 1 -- Implications

100% TLM at rates higher than the CFF caused changes in brain activity: stronger dipole moments during 100 Hz exposure than 0 Hz, and differences in the timing of peaks in activation across TLM rates.

The changed brain activity under 100 Hz was not accompanied by a difference in task performance as compared to 0 Hz;

but exposure to a higher TLM rate (500 Hz) apparently reduced cognitive interference, both for the Stroop task overall and for the Stroop colour trials in particular.

Arousal, as indexed by pupil size, was greater in the presence of any TLM than under 0 Hz operation.

The increased arousal might be beneficial in the short term for these relatively easy tasks (stochastic facilitation)

Cognitive performance, eye movement & phantom array experiment (TLM ex 2)

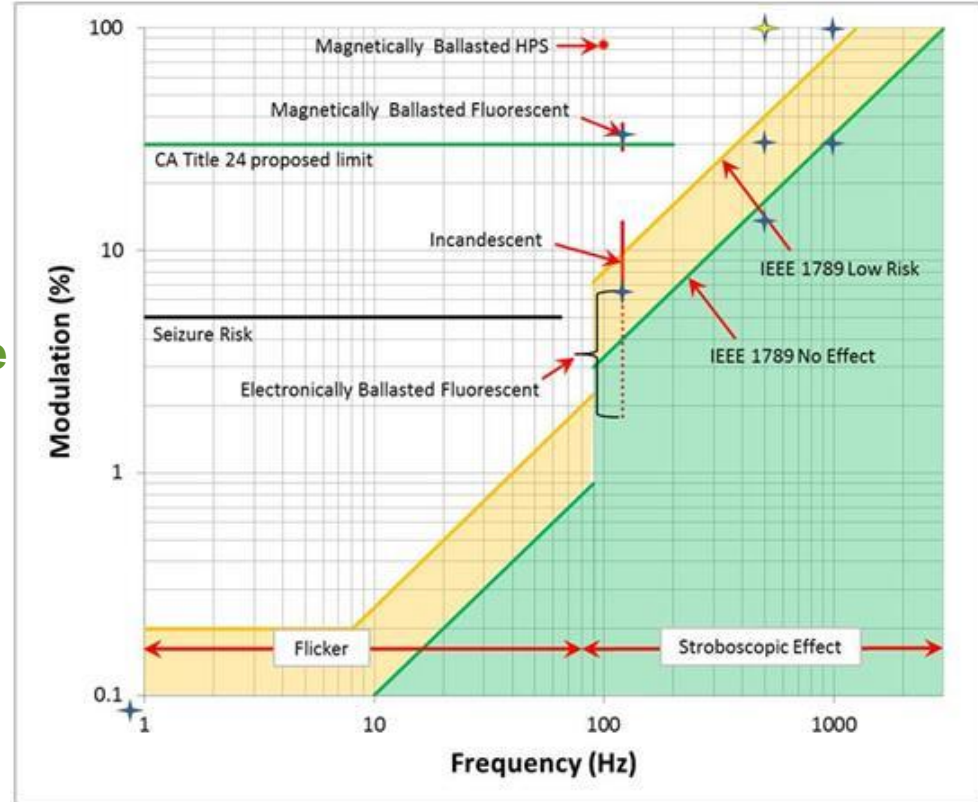
Compared 9 conditions defined as no, low, or high-risk according to IEEE 1789-2015

DVs: eye movements; pupil size; reading performance; Stroop cognitive interference; phantom array detection

Individual differences:
Pattern Glare Sensitivity

N=25 men, 25 women, 18-65 years

~15-20 min per exposure



TLM ex 2: Experimental conditions

Label	Hz	Mod %	Duty cycle%	Shape	Calc. FI	Meas. FI	Meas. P_{st}^{LM}	Meas. SVM
TLM1	0	0		flat	0	0,01	0,10	0,11
TLM2	120	6,6		sine	0,02	0,03	0,09	0,31
TLM3	120	28,4		sine-ish	0,07	0,07	0,10	0,77
TLM4	500	100	50	square	0,5	0,48	0,91	1,79
TLM5	500	30	50	square	0,15	0,13	0,19	0,49
TLM6	500	100	30	square	0,7	0,64	1,27	2,32
TLM7	500	15	50	square	0,08	0,05	0,08	0,20
TLM8	1000	100	50	square	0,5	0,45	0,96	1,34
TLM9	1000	30	50	square	0,15	0,09	0,21	0,28

<https://doi.org/10.25039/x46.2019.OP04>

TLM ex 2: Hypotheses

Test Label	Condition 1	Condition 2	Expected Outcome
LS1	DC	60 W incandescent	Probably no effect
LS2	DC	T12 magnetic ballast	Diminished performance and disrupted eye movements under 120Hz_T12 mag
MD1	500 Hz, 100 % MD, 50% Duty	500 Hz, 30 %MD, 50% Duty	Poorer performance under 100% modulation depth than 30%
MD2	500 Hz, 30% MD, 50% Duty	500 Hz, 15% MD, 50% Duty	30% vs 15% modulation depth, probably no effect.
MD3	1000 Hz, 100 % MD, 50% Duty	1000 Hz, 30 %MD, 50% Duty	100% modulation depth should give poorer performance than 30%.
DUTY	500 Hz, 100 % MD, 50% Duty	500 Hz 100 % MD, 30% Duty	30% duty cycle (v3) should give poorer performance than 50%.
FR	T12 magnetic ballast	1000 Hz, 30 %MD, 50% Duty	At 30% modulation depth, the simulated T12 magnetic ballast (120 Hz) should show worse performance than the 1000 Hz square wave.
REP	DC	500 Hz, 100 % MD, 50% Duty	Replicating prior work, predicted better performance under 500 Hz, 50% modulation depth, 50% duty cycle

TLM ex 2: Dependent measures & controls

Wilkins Rate of Reading test

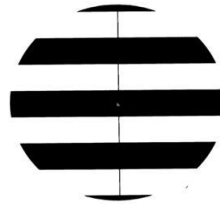
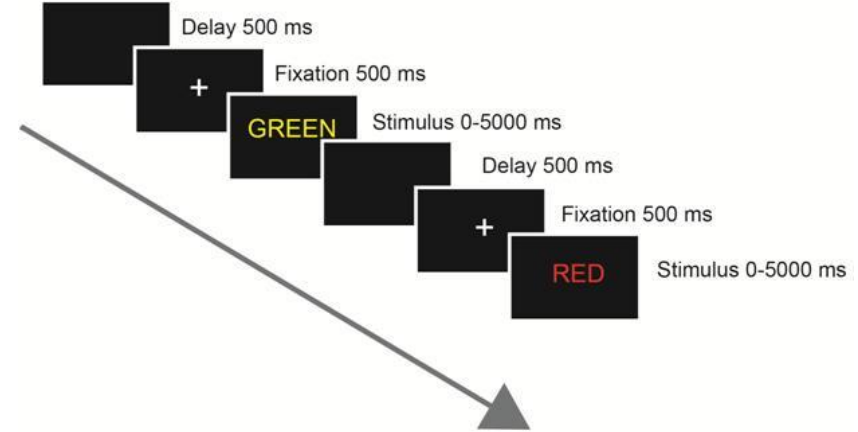
Stroop cognitive interference task

Phantom array detection

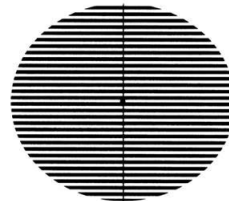
Eye movements

Visual discomfort

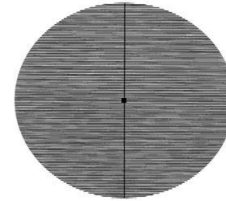
Individual difference:
Pattern Glare Sensitivity



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TLM ex 2: Results – Modulation depth

Small effects, not on all outcome measures

Phantom array eye movements:

At 500 Hz, smaller pupil size for 30% modulation compared to 100%

Reading:

At 1000 Hz, fewer reading errors at 30% modulation than 100%:

TLM8 (1000 Hz, 100% mod depth) $M = 2,58$ (SD = 2,19)

TLM9 (1000 Hz, 30% mod depth) $M = 2,15$ (SD = 1,73)

Visual discomfort:

At 500 Hz, unexpectedly lower discomfort for 100% modulation than for 30%
...but both were very low (0,47 and 0,56 on a scale from 0 [low] to 4 [high])

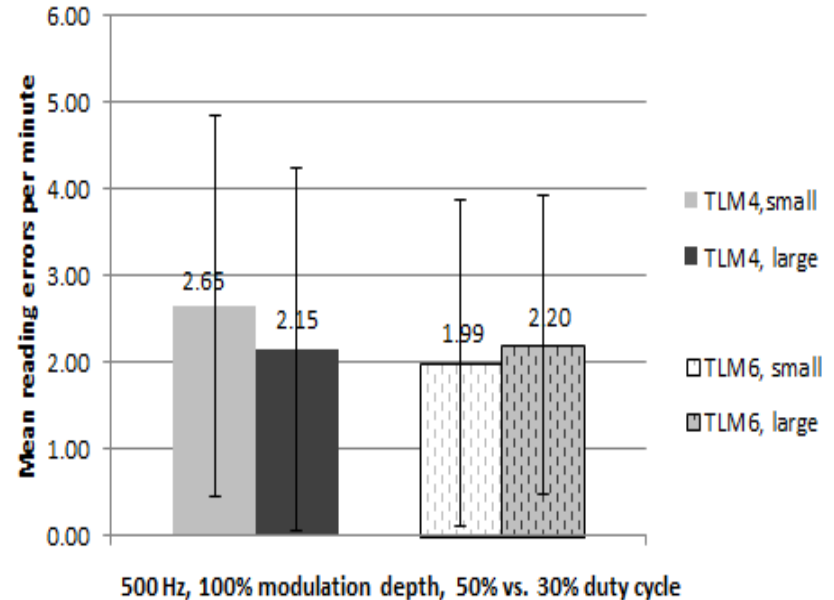
TLM ex 2: Results – Duty cycle

Interaction of duty cycle and print size for reading error rate – all small effects

For 50% duty cycle, print size mattered; errors were higher for small print

For 30% duty cycle, errors were the same for both print sizes

Overall, errors were higher for 50% duty cycle than 30%



TLM ex 2: Conclusions

Small effects with these short exposures – typical of TLM literature

Few studies have examined effects of duty cycle – more data needed!

This is critical because of the widespread use of PWM dimming

Didn't replicate Stroop effect, but did see fewer reading errors at 500 Hz 30% duty cycle than 500 Hz 50% duty cycle (interaction with task difficulty)

Possible link to literature on stochastic facilitation

Phantom array was detected in these photopic conditions – also worthy of further study, with less restrictive viewing

Deeper analyses of data from sensitive individuals still to come

Conclusions and next steps

Verbal reports of visual detection are not required for behavioural and brain activity effects to occur

Visual perception effects happen fast; other effects require a longer time course

Visual perception effects might or might not predict other behavioural or health effects

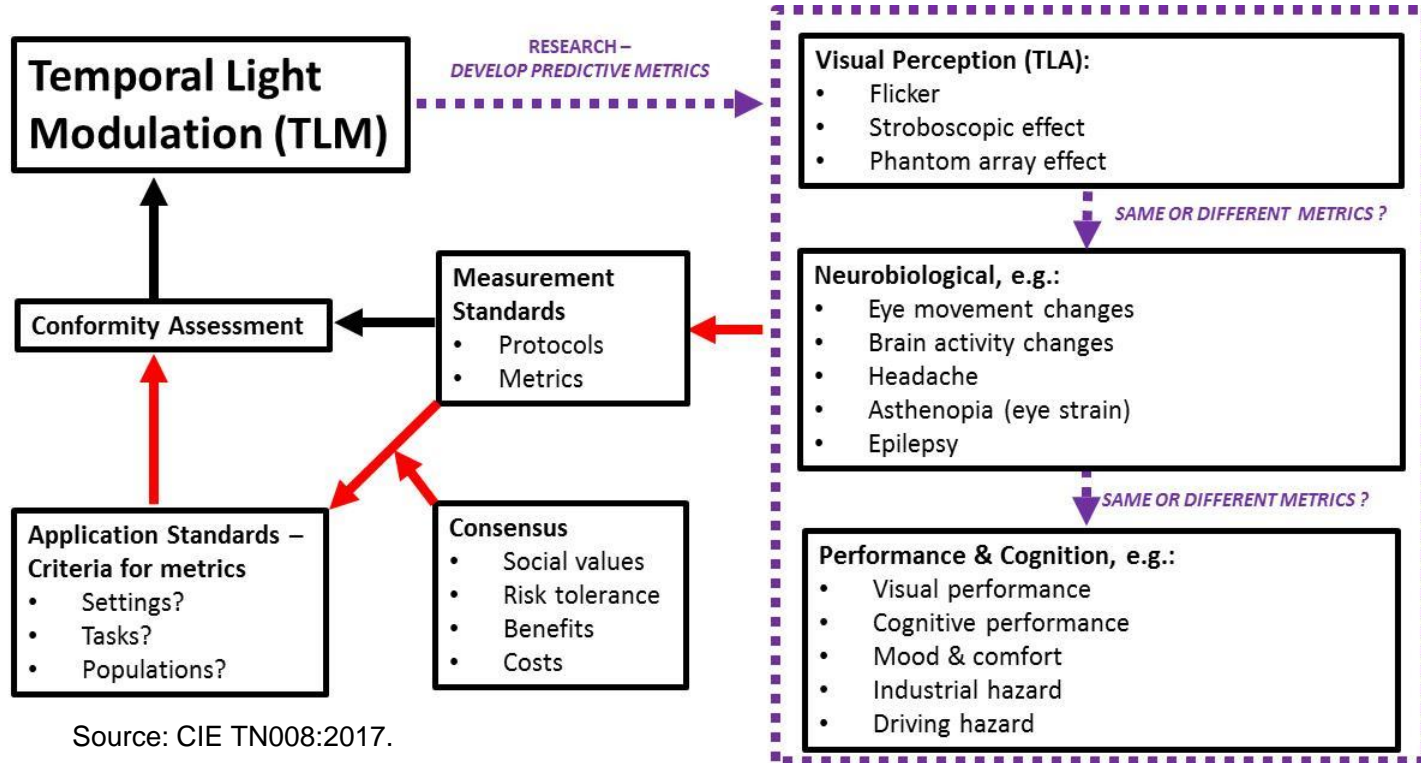
Some people seem to be more sensitive to such effects

How might we identify these individuals? What are the effects on these people, how severe are they, and when do they arise?

Metrology: measurement in a lab is comparatively easy (CIE TC 2-89)

Field measurement is a harder challenge – instruments are inconsistent & multiple luminaires in the space add complexity

CIE Stakeholder workshop on TLM standards



Source: CIE TN008:2017.



THANK YOU

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