MetTLM WP3:

VISIBILITY OF THE PHANTOM ARRAY EFFECT

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Lighting Europe Webinar

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Research Institutes of Sweden

Outline

- Introduction to the phantom array effect
- Brief review of the work and goals in MetTLM (WP3)
- Some results from previous studies
- Examples from experiments carried out in MetTLM
- Summary

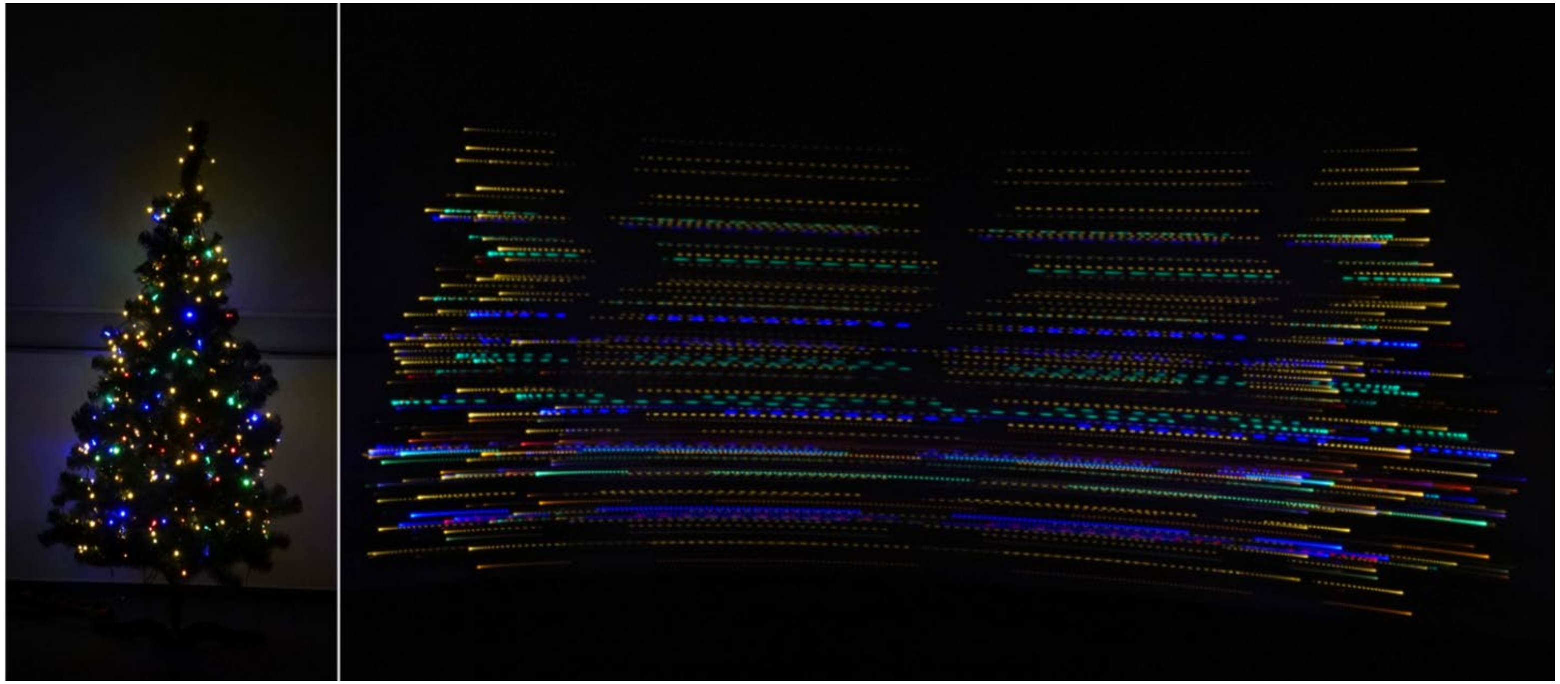


Figure. Decorative lighting on christmas tree, steady and moving camera (Johannes Ledig, PTB)

What is the phantom array effect?

Definition (CIE 249:2022)

phantom array effect / ghosting

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

Or more simply put:

Seeing repeated images of the light source when making a rapid eye movement (saccade) across a modulated source.

My colleague's car (Volvo V70)

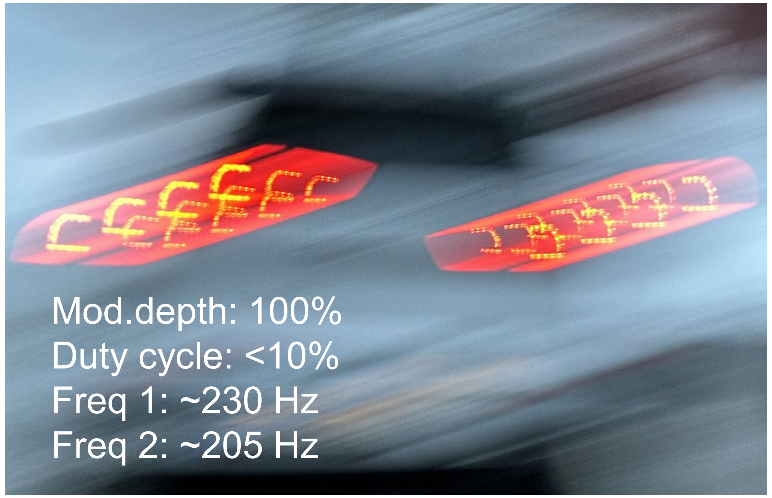
Figure. Illustration of the phantom array effect using a mobile camera, steady (top) and rapidly rotated (bottom).

Examples of common phantom array sources

- Car lamps – mainly tail lamps but also daytime running lights
- Interior lighting in cars
- Decorative lighting in general

My car - interior lighting

My car (Kia eNiro - rear lamps)



Some more examples

Unknown Volvo V70 on a country road

New Volvo EX30 on display at Landvetter Airport

The phantom array effect can be seen on both older and newer car models with LED lamps

Brief review of the work and goals in MetTLM (WP3)

- To develop a model that describes visual sensitivity to the phantom array effect based on subjective experiments that measure visibility for different light conditions.

- The visibility threshold should be measured for a large variety of light conditions (as a function of e.g., modulation frequency, waveform, duty cycle, modulation depth, size of the light source and light level).

- Based on these perception measurements, we aim to model the visual sensitivity to the phantom array effect.

- The work includes a literature review and several experiments:
    1. (TU/e): Effect of Frequency and Chromaticity (Naïve Observers)
    2. (TU/e): Effect of Frequency and Contrast (Naïve Observers)
    3. (CSTB): Effect of Frequency and Saccade Amplitude (Naïve Observers)
    4. (CSTB): Effect of Frequency and Adaptation Level (Expert Observers)
    5. (RISE): Phantom array effect in real-life applications

Brief summary of literature review

(from Kong et al. TOWARDS MODELLING THE VISIBILITY OF THE PHANTOM ARRAY EFFECT
CIE Expert Tutorial and Symposium on the Measurement of Temporal Light Modulation, Oct 10-11, 2022)

Summary of factors influencing the visibility of the phantom array effect

Characteristics of individuals	Characteristics of the viewing geometry	Characteristics of the light modulation
Age	Eye saccade amplitude (deg)	Modulation frequency / PWM frequency (Hz)
Gender	Contrast pattern / surround	Modulation Depth (%)
Saccade speed	Spatial distribution of the light source (luminance profile)	Waveform
	Observing condition (foveal / peripheral)	Duty cycle
	Beam size / Field-of-view (deg)	Color / Chromaticity
	The relative motion of the light source to the observer	Luminance (direct viewing) (cd/m^2)
		Illumination level (indirect viewing) (lx)

Summary of litterature review cont.

Independent variable	+ / - / ?
Temporal frequency	? ~ bandpass filter?
Target average luminance	+
Background luminance	-
Modulation depth	+
Shape of the waveform	*
Color (spectral power distribution)	*
Size of the target	-
Spatial frequencies	+
Age dependent	-

'-' means that the phantom array effect is less visible if the value increases

'+' means that the phantom array effect is more visible if the value increases

'?' means inconclusive or inconsistent results

'*' means more research / experimental data are needed

Example of factors influencing the visibility

Geometry (size)

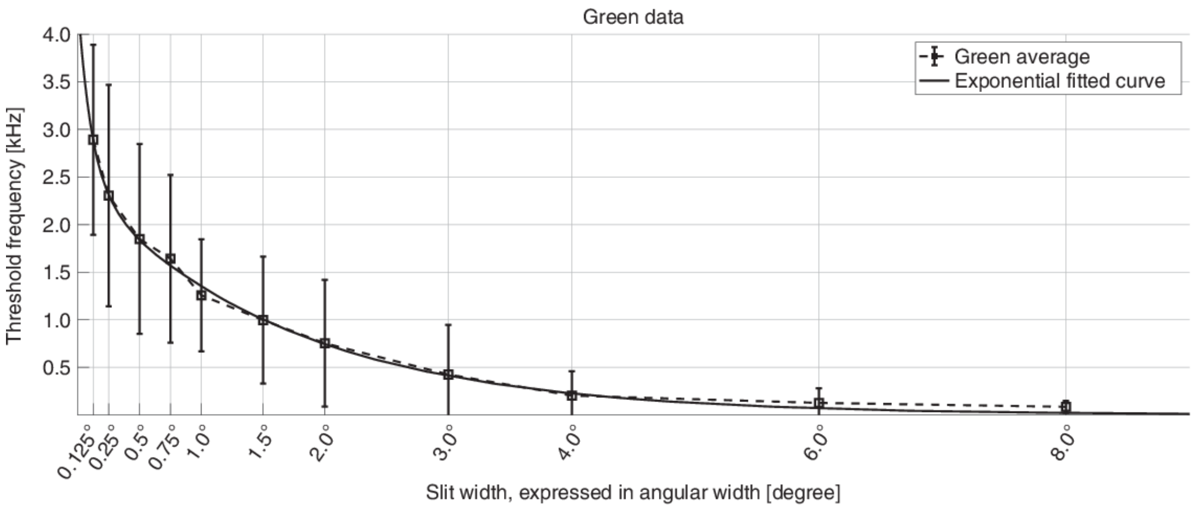
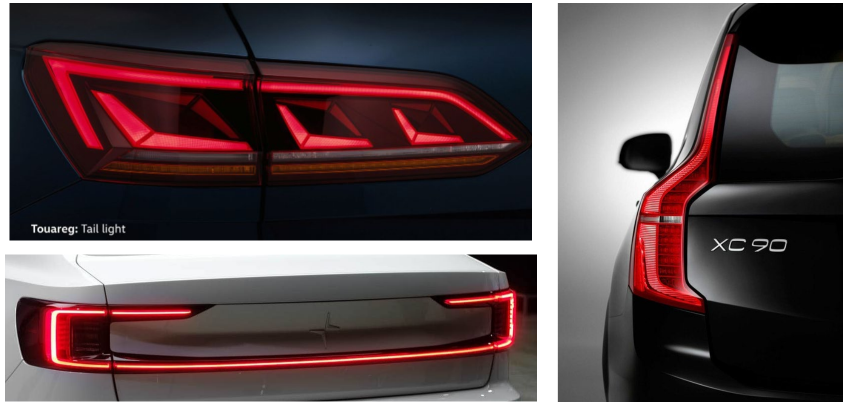


Figure 1. Relation between the angular width of the source and threshold frequency (*Visibility of the phantom array effect according to luminance, chromaticity and geometry*, Park et al 2020)

Geometry (shape)



Saccade speed

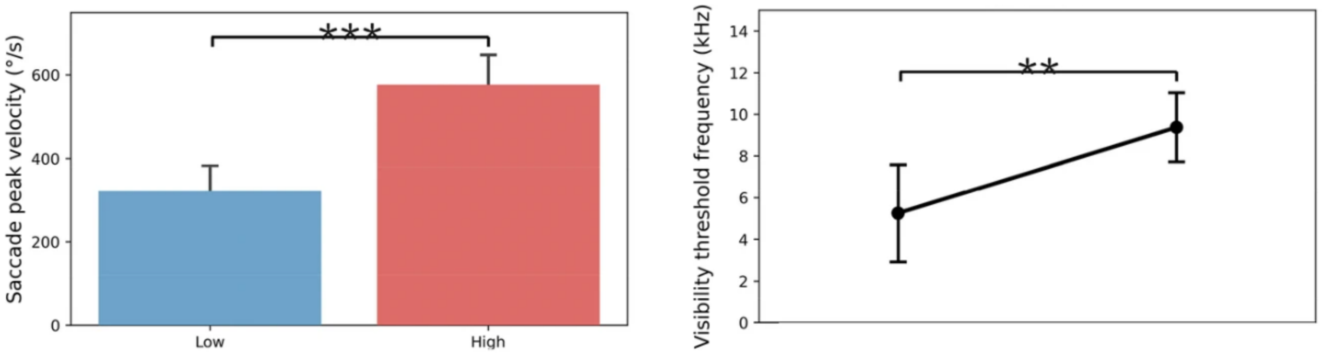


Figure 2. Relation between saccade speed and threshold frequency (*Saccadic eye movement speed is related to variations in phantom array effect visibility*, Kang et al 2023)

Luminance / chromaticity

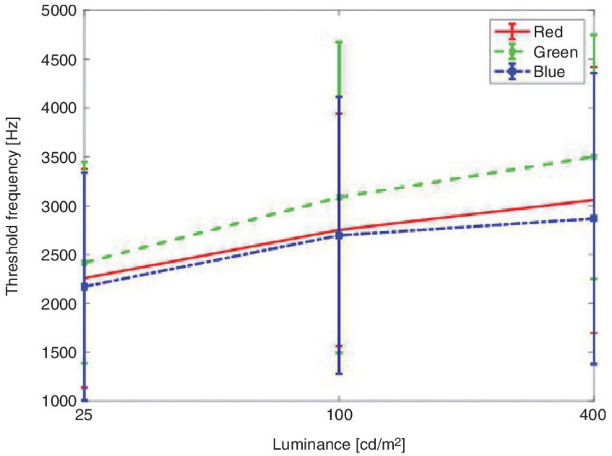


Figure 3. Relation between the threshold frequency and source luminance and color (Park et al 2020)

General experimental methods for TLM

- Quantitative experiments
  - – determination of threshold / sensitivity
  - – general adaptive psychophysical methods (staircase, Bayesian, ML)
  - – typicall requires many subjects and repetitions
- Qualitative experiments
  - – using some graded scale (e.g., 0–X)
  - – typically fewer repetitions

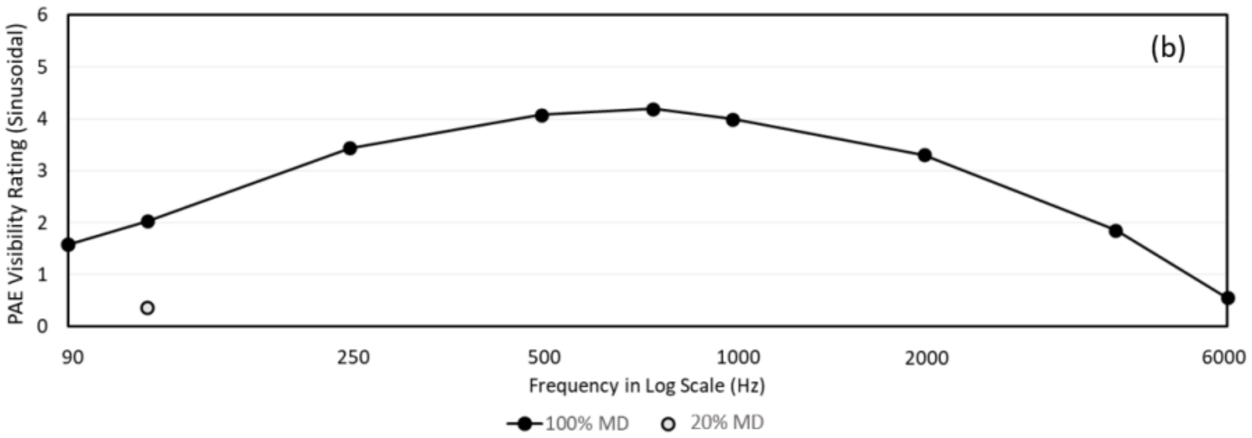


Figure 1. Example of average visibility rating for the phantom array effect (*Phantom Array and Stroboscopic Effect Visibility under Combinations of TLM Parameter*, Miller et al 2023)

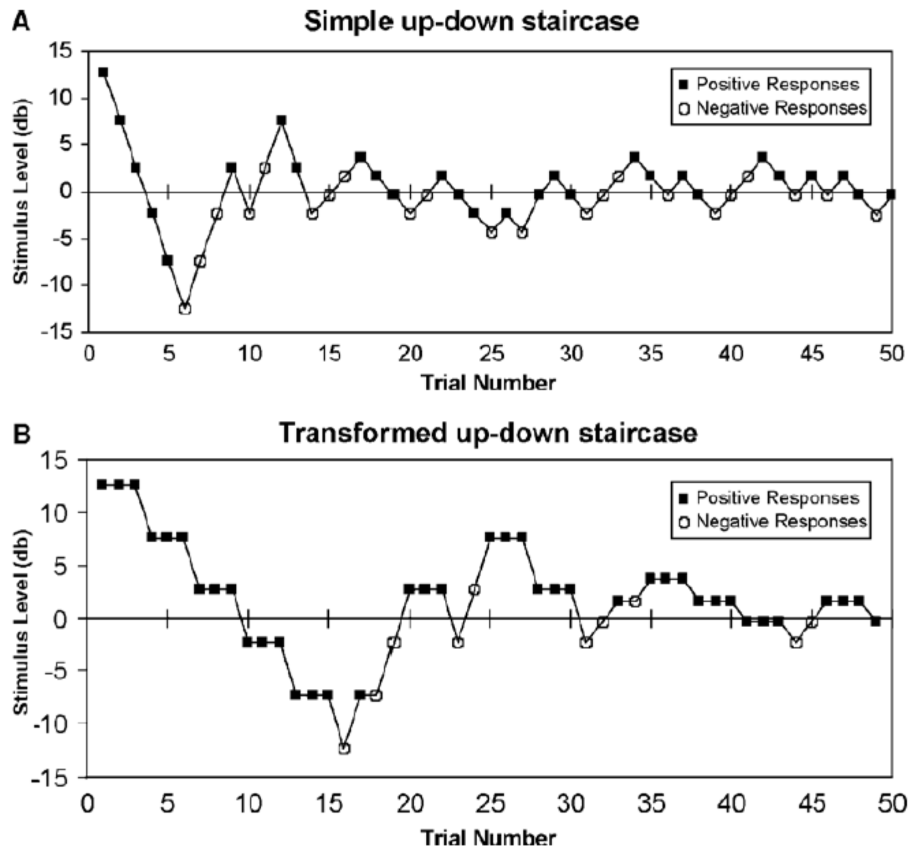


Figure 2. Example of two different staircase procedures (*Adaptive procedures in psychophysical research*, MARJORIE R. LEEK 2001)

Effect of Frequency and Chromaticity (TU/e)

(from Kong et al. DEPENDENCE OF TEMPORAL FREQUENCY AND CHROMATICITY ON THE VISIBILITY OF THE PHANTOM ARRAY EFFECT, CIE 2023 – 30th Quadrennial Session of the CIE, Sept 21-23, 2023)

Experimental design

Colors:	3 (Red, Green and Warm White)
Frequencies:	6 (80, 300, 600, 900, 1200, 1800 Hz)
Modulation:	Sinusoidal
Participants:	20 (11 male, 9 female, 19-23 years)

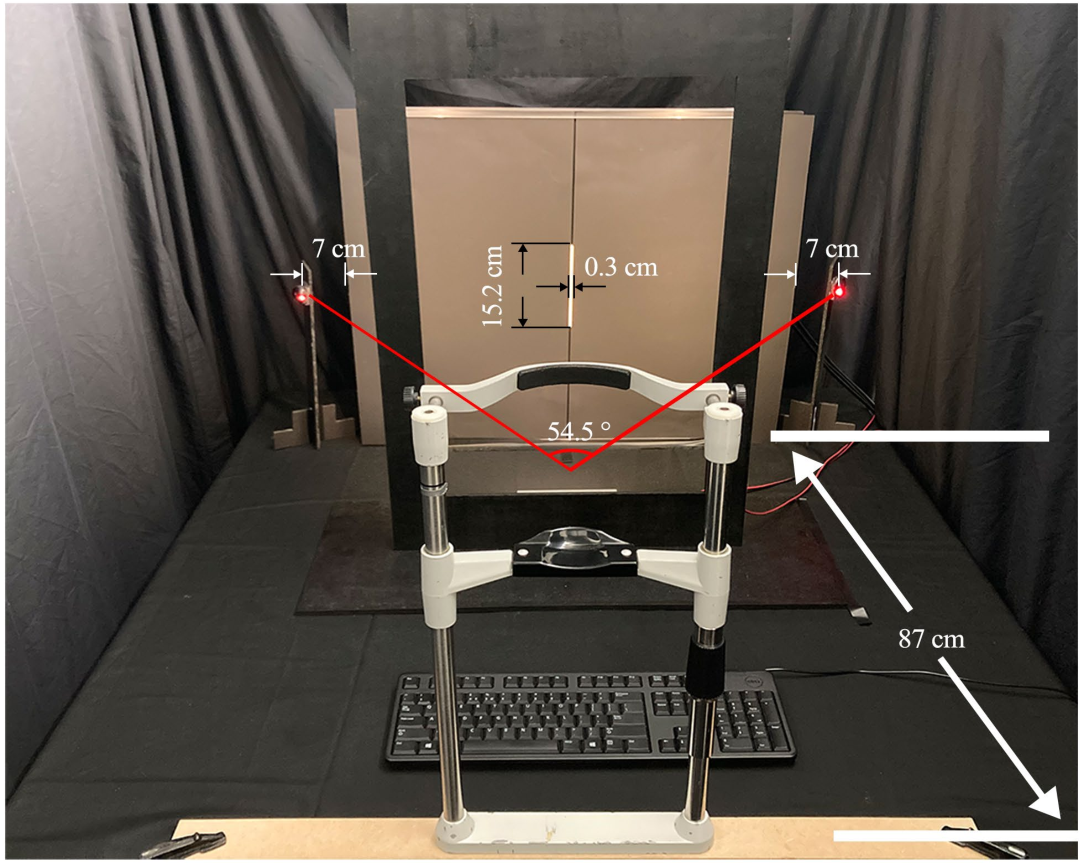
Fractional Factorial 3 (Color) x 6 (Frequency)
Mixed Design

General procedure

Two-interval forced choice (2IFC), always one direct current (DC)

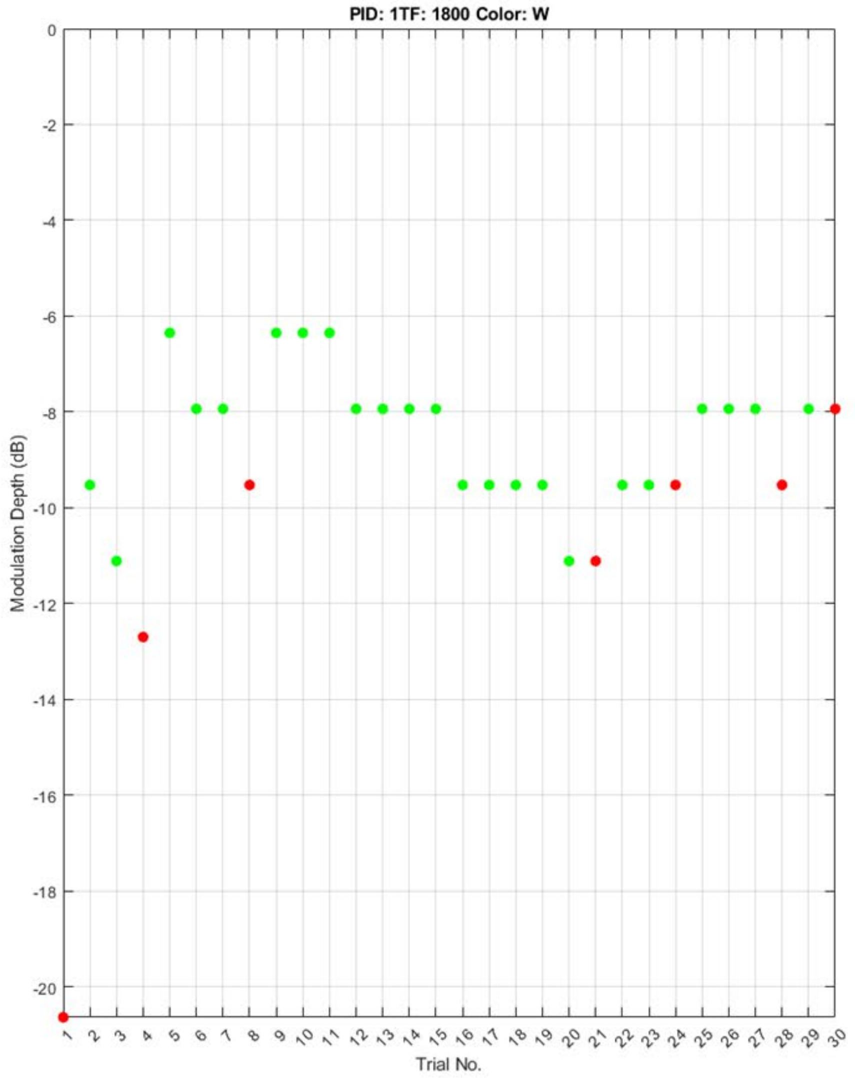
First stimulus (4 seconds)	Second stimulus (VAR seconds)
Either DC or Modulated	Either DC or Modulated

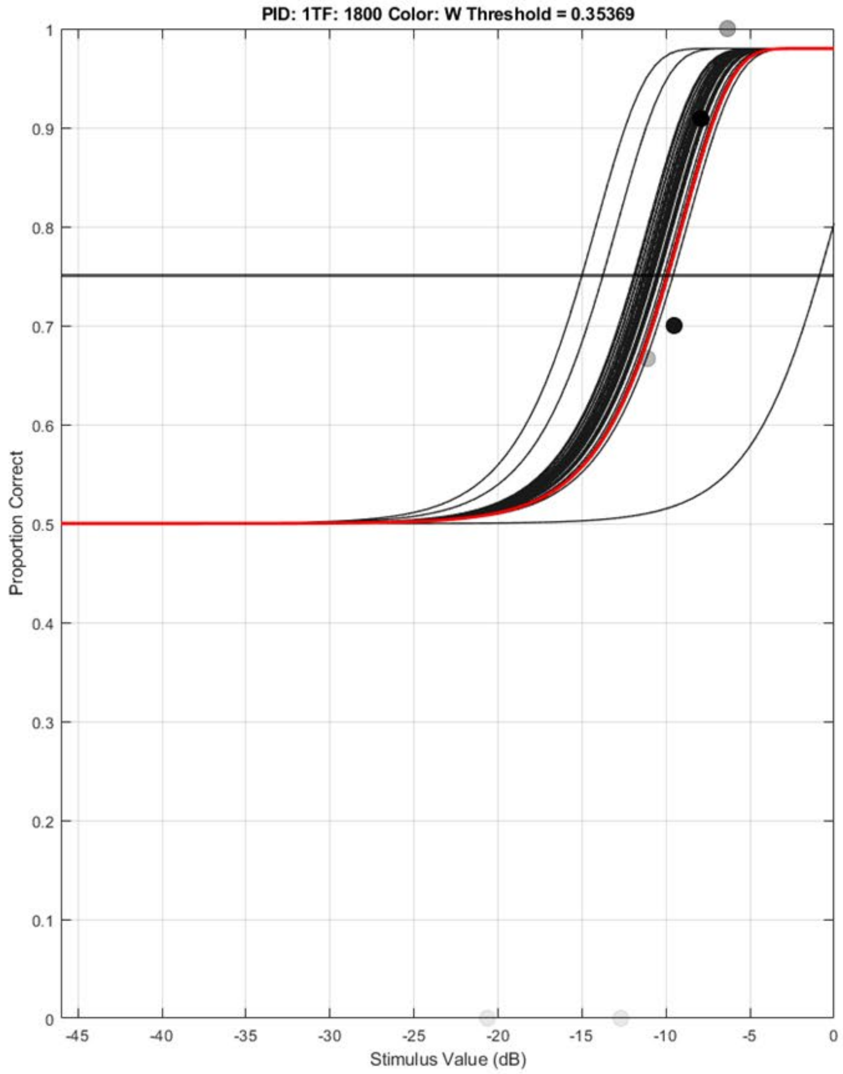
Experimental setup



Effect of Frequency and Chromaticity

Fitting a Psychometric Function with QUEST+ (An Adaptive Procedure)

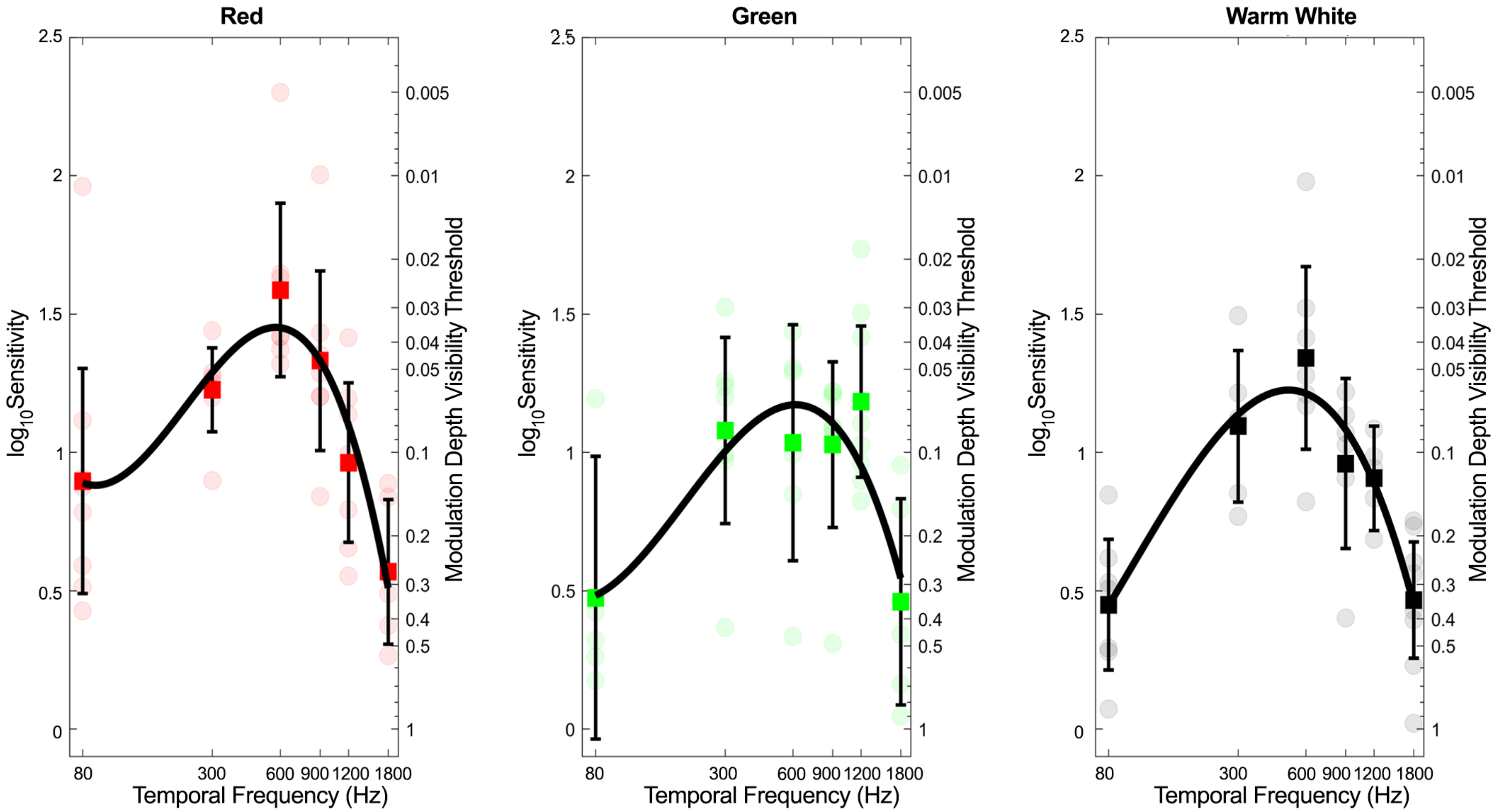




Correct response

Incorrect response

Effect of Frequency and Chromaticity - results

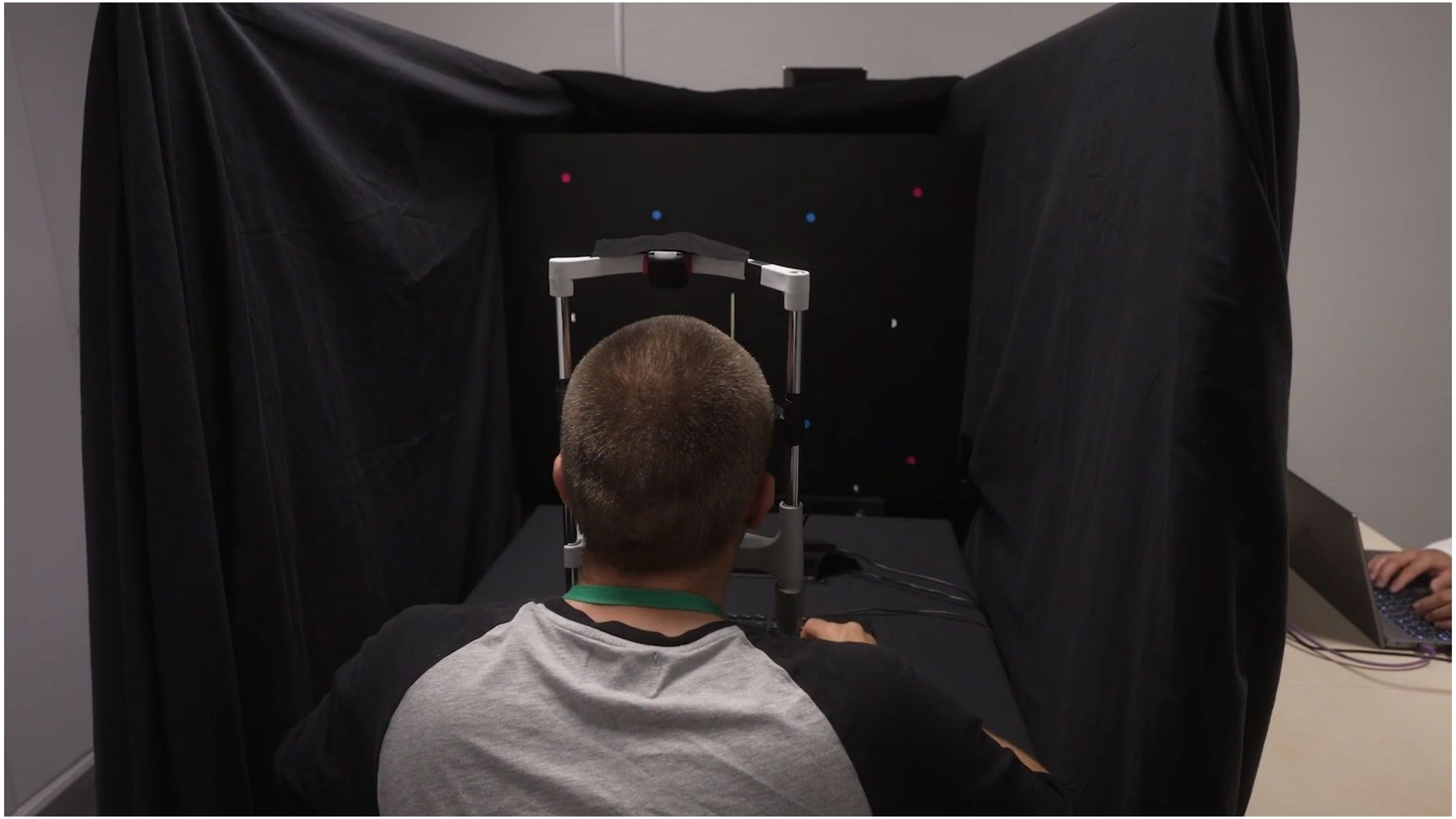


Effect of Frequency and Saccade Amplitude (CSTB)

- Similar setup, design and frequencies as TU/e
  - – 2IFC, QUEST+
- Two different saccade amplitudes (20° and 40°)
- Using and eye-tracker to analyse saccade speed and eye movement
- A publication is on the way

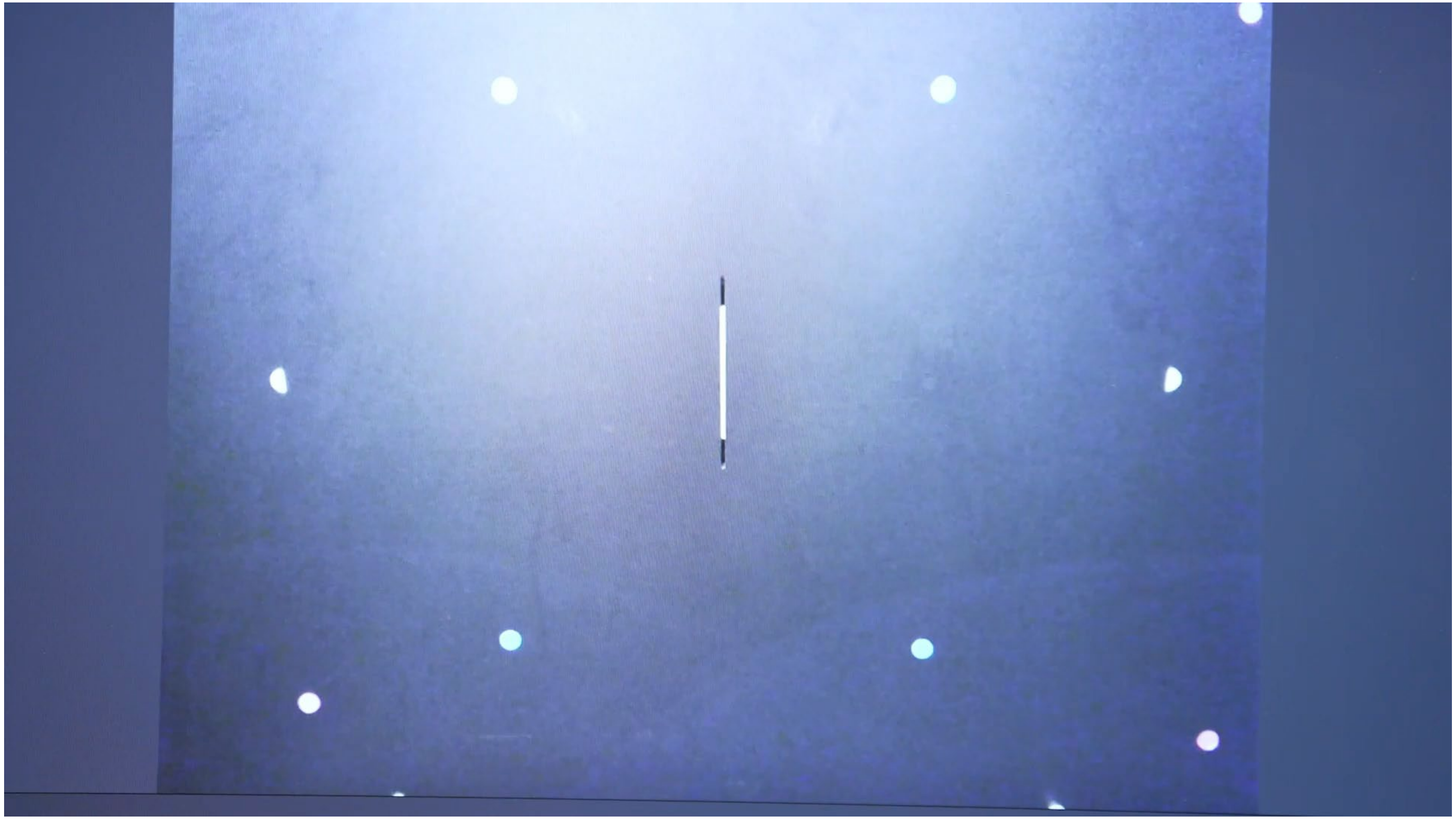
Effect of Frequency and Saccade Amplitude (CSTB)

Short movie from the experiment – test setup



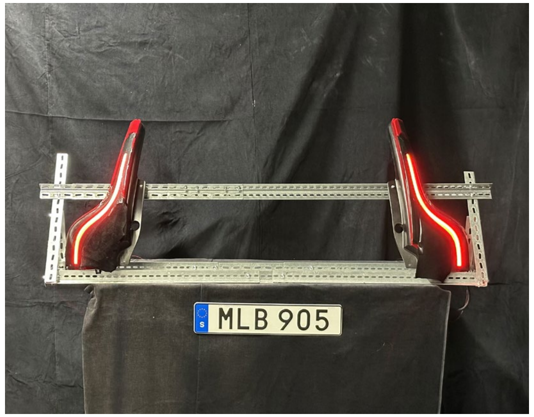
Effect of Frequency and Saccade Amplitude (CSTB)

Short movie from the experiment – eye-tracker data

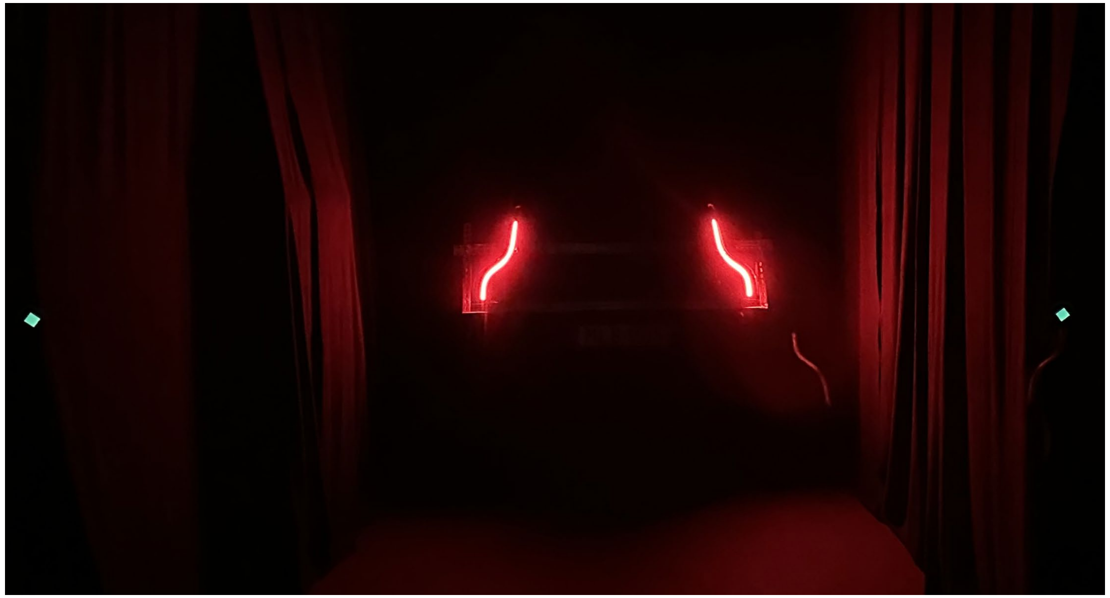


Phantom array effect in real-life applications (RISE)

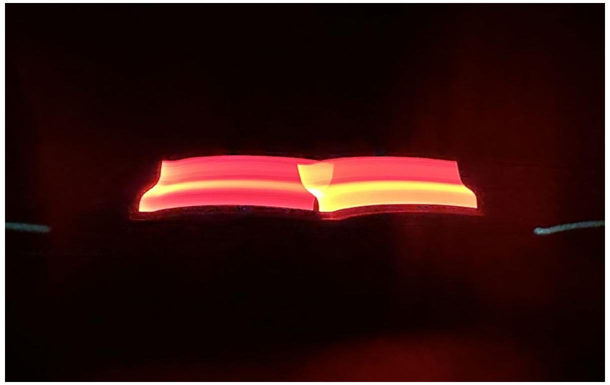
- Experiment using actual car tail lamps (Volvo XC60)
- Square wave modulation, duty cycle 50%
- Distance between lamps and observer ~8 m
- Five frequencies (100, 200, 600, 1000, 1800 Hz)
- 2IFC procedure with fixed modulation depths (six per frequency)
- Each setting is repeated six times, total number of trials = 6 x 6 x 5 = 180
- Plans to carry out experiments with modified settings using a smaller reference group



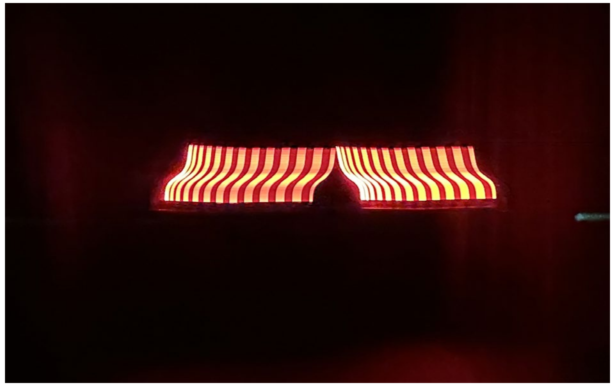
Phantom array effect in real-life applications (RISE)



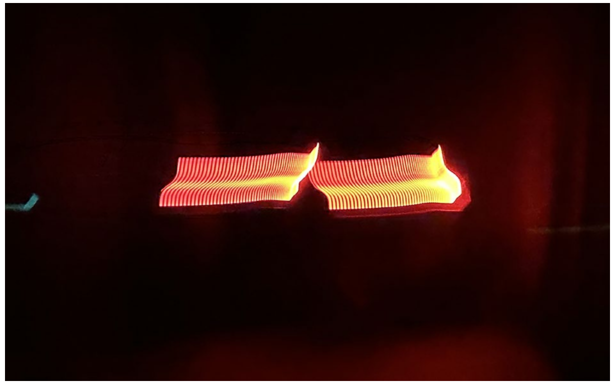
Constant output



200 Hz



1000 Hz



Summary

- The phantom array effect is a common TLM phenomenon
- In contrast to flicker and stroboscopic TLM effect, no established metric exists
- The effect can be seen at very high modulation frequencies (>15 kHz, Kang et al. 2023)
- The visibility is depending on many variables (frequency, geometry, waveform, modulation etc.)
- Several experiments contributing to the knowledge of the phantom array effect has been carried out within the MetTLM project
- A general model covering all aspect of the phenomenon will be challenging
- Possible solutions could be:
  - – specify standard conditions
  - – based on ”worst-case” situations
  - (– different models for different conditions)

Acknowledgements

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