

# Towards Modelling the Visibility of the Phantom Array Effect

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## TOWARDS MODELLING THE VISIBILITY OF THE PHANTOM ARRAY EFFECT

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### Abstract

The phantom array effect is the least studied temporal light artefact (TLA) among the three defined in TR 249:2022 by CIE Technical Committee 1-83 "Visual Aspects of Time-Modulated Lighting Systems." Models that predict the visibility of both flicker and the stroboscopic effect have been detailed by the CIE and the IEC.

When it comes to the phantom array effect, its visibility in real-life situations is most often described as 'in an otherwise dark environment', during 'night driving conditions', and from a 'backlight of a car at night'. Thus, almost all laboratory investigations on the phantom array effect adopted experimental conditions with bright light sources in a dark room (i.e., < 1 lx). Multiple psychophysical investigations have studied the phenomenon qualitatively or quantitatively. Variables that have been employed in these studies can be categorized as: 1) individually related characteristics: the age and gender of the observer, and maybe also the saccade speed (i.e., variations around the average speed determined by the size of the saccade amplitude); 2) characteristics of the light modulation: the time-averaged luminance/illuminance for direct/indirect viewing conditions, the temporal frequency, the modulation depth, the shape of the waveform, the duty cycle, and the chromaticity of the light source; and 3) characteristics of the viewing geometry: foveal or peripheral observance, the size of the light source (i.e., the subtended visual angle), the spatial distribution of the light source (i.e., with sharp or smooth edges), the saccade amplitude (which usually is fixed in an experimental setting), and the relative motion of the light source to the observer. Some of these studies measured the visibility of the phantom array effect, but others asked the observers to rate the noticeability and/or annoyance of the phantom array effect.

The results of all these investigations can be summarized as follows. The visibility of the artefact did not depend on the observer's gender, but did depend on the age; younger observers were reported to be more sensitive to the phantom array artefact. It was concluded that a higher luminance/illuminance, a higher modulation depth, and a smaller size of the light source resulted in higher visibility of the artefact. The shape of the waveform also played a role. The square waveform was more visible than the sinusoidal waveform for the same duty cycle, modulation depth, and temporal frequency. The visibility of the phantom array effect was also colour dependent, with blue light resulting in a lower sensitivity than red, green, and white light. Not all studies drew consistent conclusions regarding the effect of temporal frequency. Some studies concluded that the phantom array effect became less visible when the frequency increased, while others showed a band-pass-shaped curve, with a peak at around 600 Hz. Combining all these results would facilitate the determination of a visibility model, but not all studies measured visibility nor used the same protocol, and hence not all data can straightforwardly be combined.

In addition, substantial individual differences in visibility of the phantom array effect were found. These differences can be partly attributed to age, maybe partly to differences in executing the experimental task, and maybe also to individual differences in eye movements. In CIE TN 008:2017 (prepared by CIE Reportership 3-32 of Division 3 "Interior Environment and Lighting Design"), it was also pointed out that eye movements differ greatly in pattern and velocity. Since the phantom array effect is visible as a consequence of an interaction between an observer's eye movements and the temporal light modulation, measuring the actual eye movements while measuring the visibility of the artefact may show added value in explaining individual differences in seeing the phantom array effect. On the other hand, it is known from the literature that the average saccade speed is related to the saccade amplitude with a maximum speed of about 500 deg·s<sup>-1</sup>. So, how far small fluctuations around the average speed determine individual differences in viewing the artefact still has to be explored. Only a limited number of studies recorded the eye movements of the observers during the experiment, and

thus there is a lack of in-depth analysis of the relationship between the visibility of the phantom array effect and variations in eye movements. Recording and reporting eye movement data using an eye-tracking device would facilitate understanding to what extent including eye movements in the visibility model of the phantom array effect is needed.

Some researchers discuss their findings in terms of contrast, i.e., the ratio between the target (the light source) and the background (the surrounding). Expressing the visibility of the phantom array effect in terms of the contrast of the average luminance of the light source with the background luminance does not allow them to conclude whether a change in sensitivity is due to a change in the absolute luminance level of the light source or in its contrast with the background. Thus, to disentangle these two effects, one needs to systematically change the luminance of the light source independently of the luminance of the background.

In summary, designing a visibility model for the phantom array effect requires more systematic data on the visibility threshold, measured in a consistent way, including its dependency on the modulation frequency. These measurements should disentangle the effect of the average luminance of the modulated light source and the luminance of the background. In addition, the effect of specific eye movements can be established. Therefore, we are currently designing a set of psychophysical experiments using a two-interval forced-choice (2IFC) procedure to determine at which modulation depth the phantom array effect becomes just visible. This visibility threshold will be measured systematically as a function of temporal frequency, and for different values of the luminance of the light source and luminance of the background. The eye movement data will be recorded simultaneously during these experiments. First results will be presented at the CIE Symposium on the Measurement of Temporal Light Modulation in October 2022.