Exploring the contrast sensitivity function for two-photon vision 3879788

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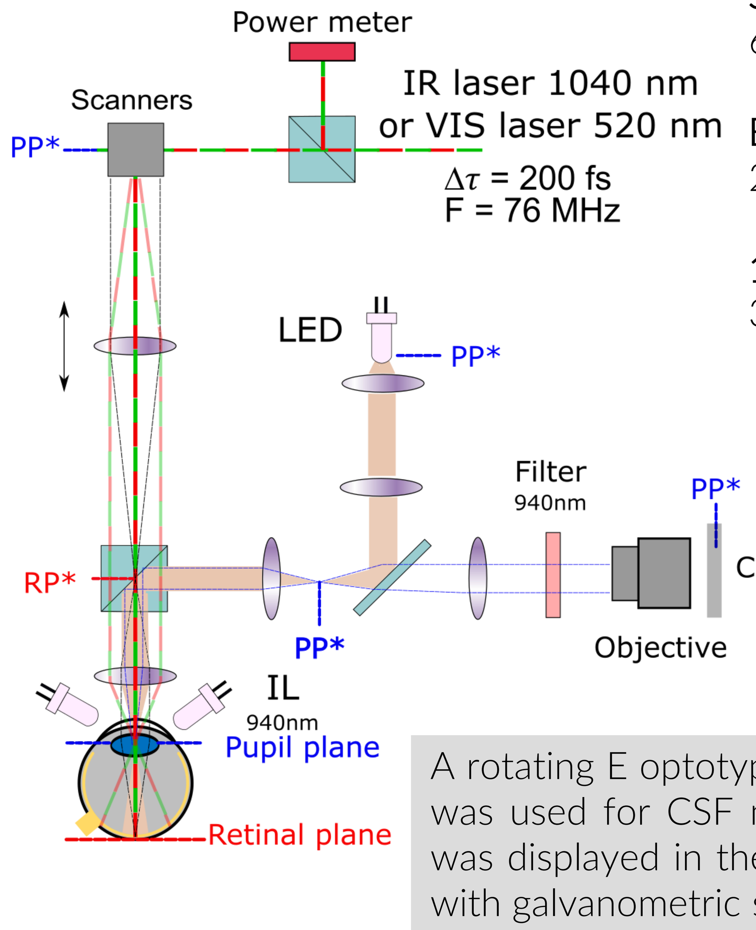
PURPOSE

Two-photon vision relies on the perception of pulsed near-infrared lasers as having colors like their half-wavelength counterparts. It is due to two photon absorption occurring in visual pigments (Palczewska, 2014). The detailed characteristics of the contrast sensitivity function (CSF) for two-photon vision remain unclear. Therefore, the purpose of this study is to obtain additional data on the CSF of two-photon vision and comparing it with one-photon CSF.

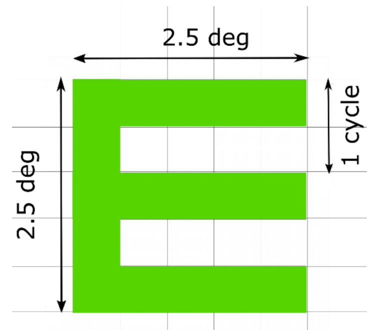
METHODS



Subjects:
6 healthy volunteers aged 24-46.

BCVA (best corrected visual acuity):
20/20 or better.

1% Tropicamid applied every
30 min. to paralyze accommodation



A rotating E optotype with 1 cpd of spatial frequency was used for CSF measurement. The letter stimulus was displayed in the subject's retina by fast scanning with galvanometric scanners.

Fig 1. Optical system. The IR and VIS beams were generated by a femtosecond laser (=200 fs, Frep=76 Hz). BS, beam splitter; CAM, camera; DM, dichroic mirror; GS, galvanometer scanners; IF, 940 nm bandpass filter; Li, lens; LED, white LED; OBJ, objective; PM, power meter; PP, pupil plane; PP*, conjugated pupil plane; RP, retinal plane; RP*, conjugated retinal plane.

- Scanning beam laser allowed to present stimuli of various angular sizes, corresponding to spatial frequencies: 1, 1.5, 2, 3, 6, 12, 18 and 24 cycles per degree (cpd).
- The homogenous background was obtained by Maxwellian view illumination with white LED, with luminance equal to 98 cd/m^2.

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METHODS

- A threshold stimulus brightness for each spatial frequency was determined by finding the minimum power of laser beam for which the subject was able to state the correct letter orientation in at least 4 of 5 trials.
- Next, contrast sensitivity was calculated according to the formula:

$$CS = \frac{background\ luminance}{threshold\ stimulus\ luminance}$$

- Considering that there is no luminance curve for two-photon vision, determining two-photon CSF required a non-standard approach.
- To determine the luminance of the infrared stimulus, a brightness adjustment method was used. It involved matching the power of the visible beam so that its brightness corresponded the threshold brightness for the infrared stimulus.

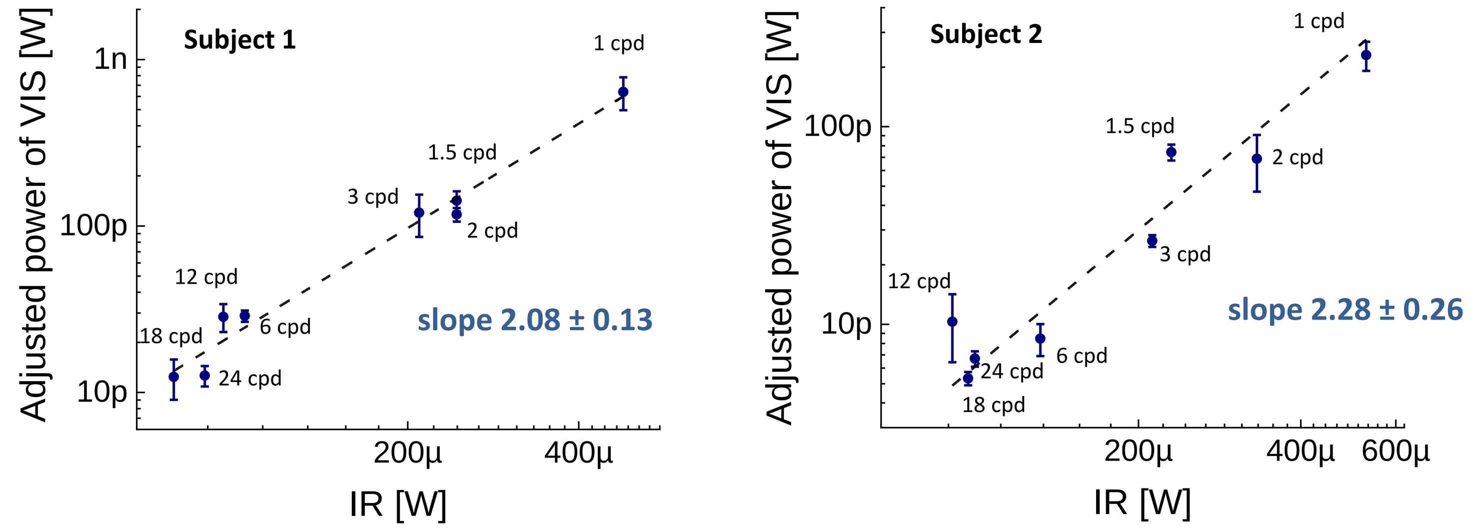

Fig 2. The adjustment relationship of the visible beam power, corresponding to the brightness of the stimulus with a specific infrared beam power. The quadratic relationship of the adjusted visible beam power to the infrared beam power emphasizes the nonlinear character of the two-photon vision.

- Contrast sensitivity was measured under photopic conditions and brightness was adjusted under scotopic conditions. Values were corrected for spectral sensitivity differences and the eye's sensitivity.

$$L_{corrected} = \frac{V\ (550\ nm)}{V'\ (520\ nm)} * L_{matched} = 0.51$$

- To account for the chromaticity of the presented optotype and to provide a reference CSF, additional measurements were made for the one-photon stimulus using a standard LCD screen, where the green optotype was displayed on a white background.

The study was approved by the Ethical Committee of the Medical College, NCI.

RESULTS

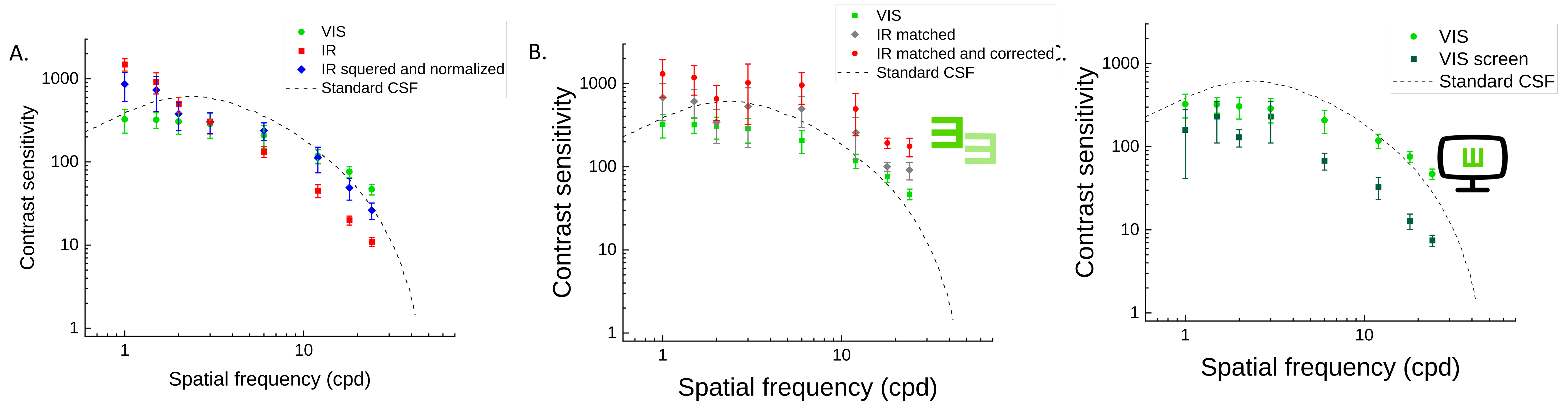

Fig 4. **A.** CSF for the visible stimulus (VIS), for the infrared stimulus normalized to the one-photon CSF for 3 cycles per degree (IR), and for the IR stimulus after the stimulus power was squared and also normalized to the one-photon CSF for 3 cycles per degree (IR squared and normalized). **B.** CSF obtained after the brightness adjustment method for the infrared (IR matched) beam and considering differences in the spectral sensitivity of the eye for different lighting conditions (IR matched and corrected). **C.** CSF for the visible beam using presented optical system (VIS) and under standard conditions using LCD monitor (VIS screen). A standard CSF is also included in the figures (Pappas, 2005).

- Comparison of CSF curves for visible and infrared stimuli shows that the two-photon CSF has a broader dynamic range than one-photon CSF. The IR threshold powers were squared to consider the quadratic dependence of beam power on brightness. This approach reduced the two-photon CSF range, although it was still greater than the one-photon CSF range.
- The brightness adjustment method allowed determination the subjective luminance of infrared stimuli. The method enabled the assessment of the CSF for two-photon vision and its comparison with the standard CSF. The results indicate that the CSF for the infrared stimuli has higher values than the CSF for VIS stimuli. The accuracy of the adjustment method depended on the size of the stimulus.
- The CSF for VIS stimuli displayed on LCD screens exhibited lower values compared to the ones projected in the optical system. The reduced sensitivity may be related to differences in the way the stimuli are presented: background has a lower brightness than the stimulus in case of the optical system and while for LCD screens, background has higher brightness than the stimulus.

CONCLUSIONS

- The determination of CSF for two-photon stimuli displayed against a visible background required a method to determine the luminance of the two-photon stimuli.
- After applying such method, the two-photon stimuli demonstrated better contrast compared to one-photon stimuli. It may be related to the more precise, well-localized, stimulation of photoreceptors in two-photon vision.
- Further studies are planned to determine the repeatability and reliability of the proposed brightness-matching method.
- The results show that applying two-photon vision to AR/VR displays can enable stimuli with better contrast and a broader dynamic range.

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