The effect of defocusing on the contrast sensitivity function for two-photon vision

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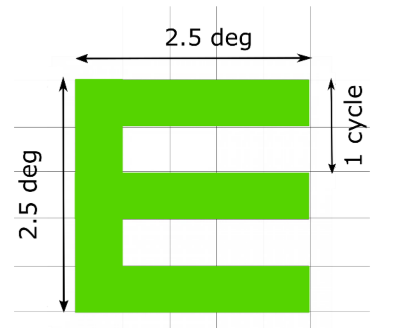
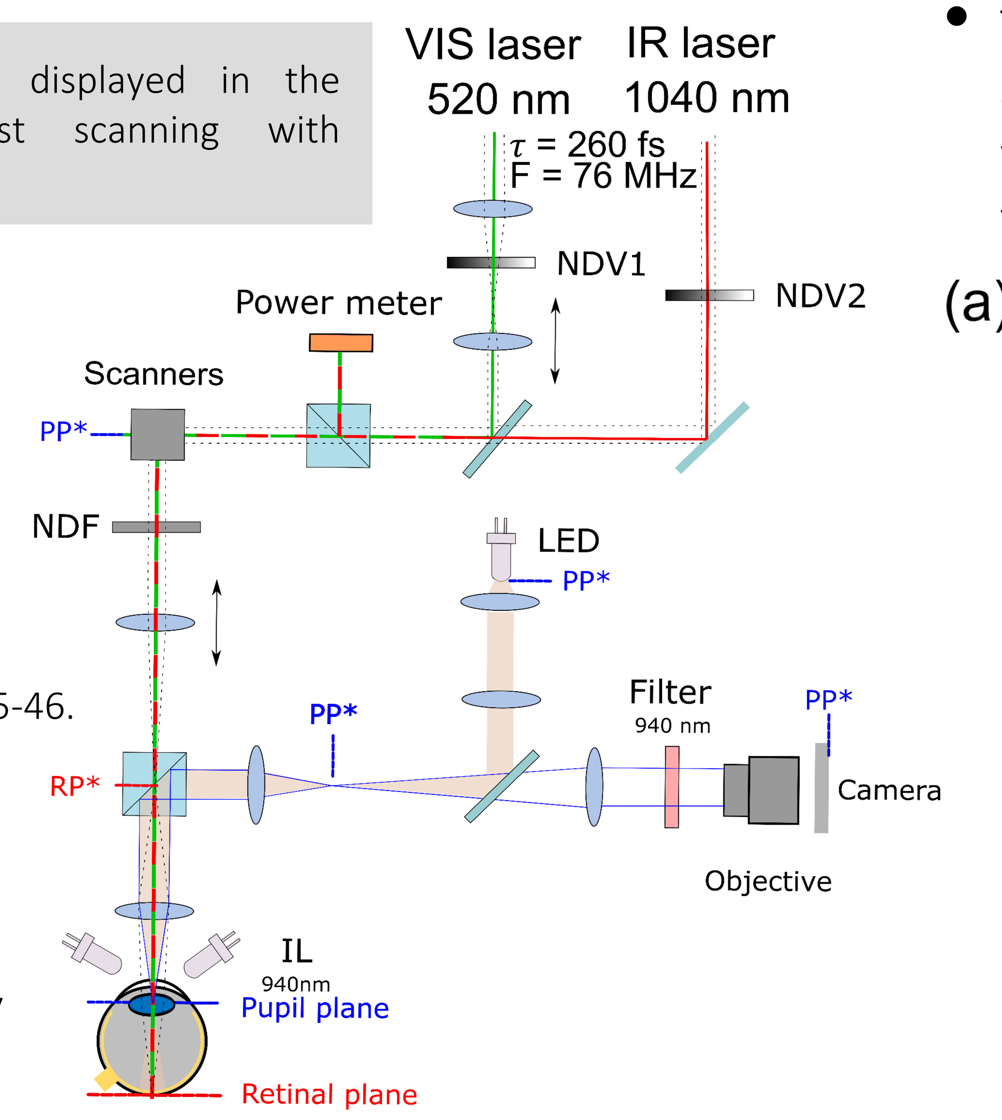
PURPOSE

One of the possible applications of two-photon vision is its implementation in retinal displays. This study aims to investigate the effect of **defocusing on contrast sensitivity for two-photon vision**, enabling a better assessment of the potential application of the phenomenon in Augmented Reality (AR) technology.

METHODS

The letter stimulus was displayed in the subject's retina by fast scanning with galvanometric scanners.





Subjects:
6 healthy volunteers aged 25-46.

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

1% Tropicamid applied every 30 min. to paralyze accommodation

Fig 1. Optical system. The IR and VIS beams were generated by a femtosecond laser (τ=240 fs, F=76 MHz). LED, white light emitting diode; NDF, neutral density filter; NDV, neutral density gradient filter ; 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, 3, 6, 12 and 24 cycles per degree (cpd).

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METHODS

- A threshold stimulus luminance for each spatial frequency was determined by finding the minimum power of the 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 luminous efficiency function 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 brightness of the two-photon stimulus at the determined contrast threshold.

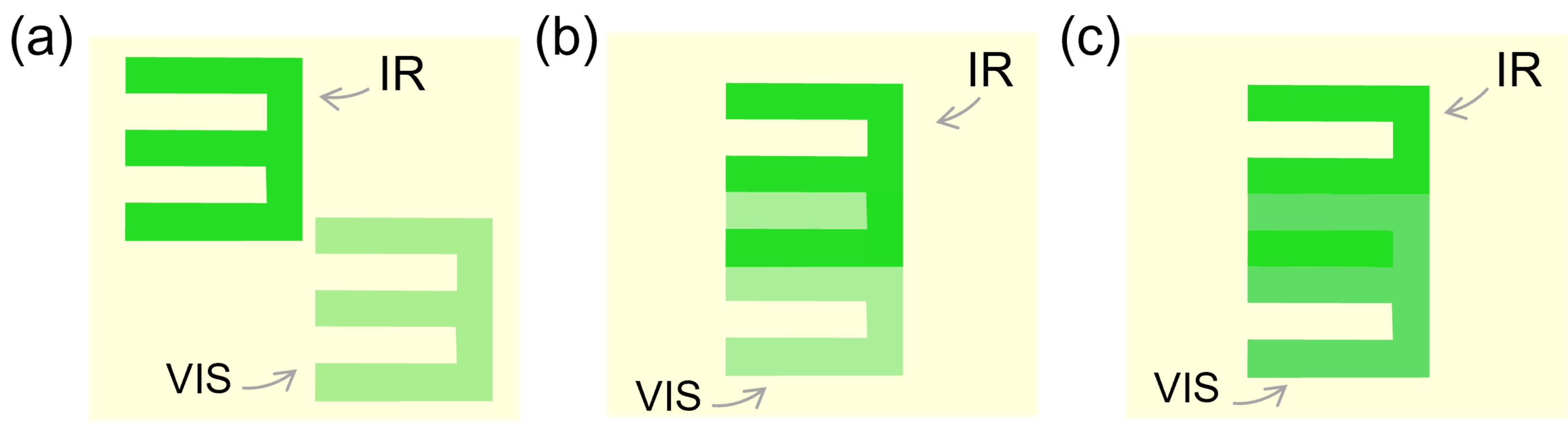

Fig 2. Schematic representation of the simultaneous display of stimuli in the brightness adjustment method. **(a)** Two stimuli were simultaneously presented on the white background - an infrared stimulus (IR) of determined and constant luminance and a second, visible stimulus (VIS). **(b)** The position of the visible stimulus was found for which the two presented stimuli were located as presented in the scheme. **(c)** The power of the visible stimulus was adjusted until the two stimuli obtained subjectively the same luminance.

- To evaluate **defocusing effects**, the procedure was performed with the optimal refractive correction for each subject and with an additional defocusing of +1.00 diopters.

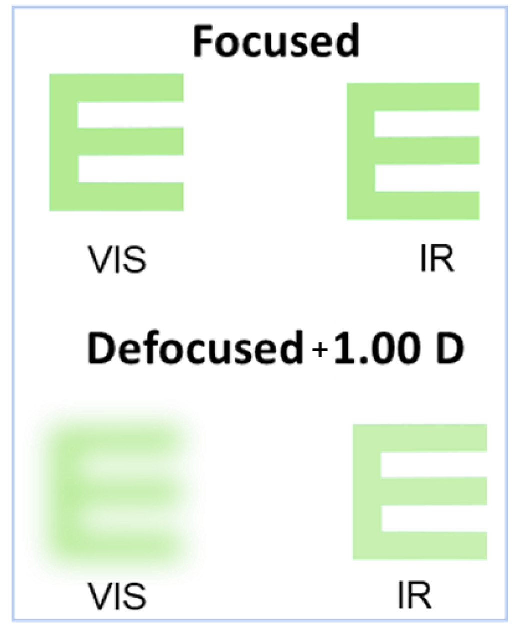

Fig 3 Visualization of the effect of defocusing on image blurring for the visible stimulus (VIS) and changes in stimulus brightness for the Infrared stimulus (IR).

The study was approved by the Ethical Committee of the Collegium Medicum, NCU.

RESULTS

- The obtained values of CSF for two-photon vision under optimal focusing are higher than values of CSF for standard one-photon vision. The average ratio two-photon to one-photon is (1.77 ± 0.25) indicating the advantage of two-photon vision (Fig. 4a). The similar values of contrast sensitivity for high spatial frequency are due to resolution limit of the optical system determined by the diameter of stimulating beams (1 mm).
- By defocusing at +1.00D, the CSF for two-photon vision is also higher compared to standard vision, and the average two-photon to one-photon ratio is equal to 2.44 ± 0.28 (Fig. 4b).
- Defocusing affected the decrease in CSF compared to CSF under optimal focusing for the visible beam, particularly for high spatial frequencies, as expected (Fig 4c). The average CSF impairment over all spatial frequencies for one-photon vision was 37% (from 10 to 72%).
- Defocusing caused the reduced brightness of the two-photon stimuli, so a decrease in CSF for the infrared beam compared to CSF at optimal focusing was observed (by 22% on average for all spatial frequencies). However, no negative defocusing effects were observed for the highest spatial frequency (Fig 4d).

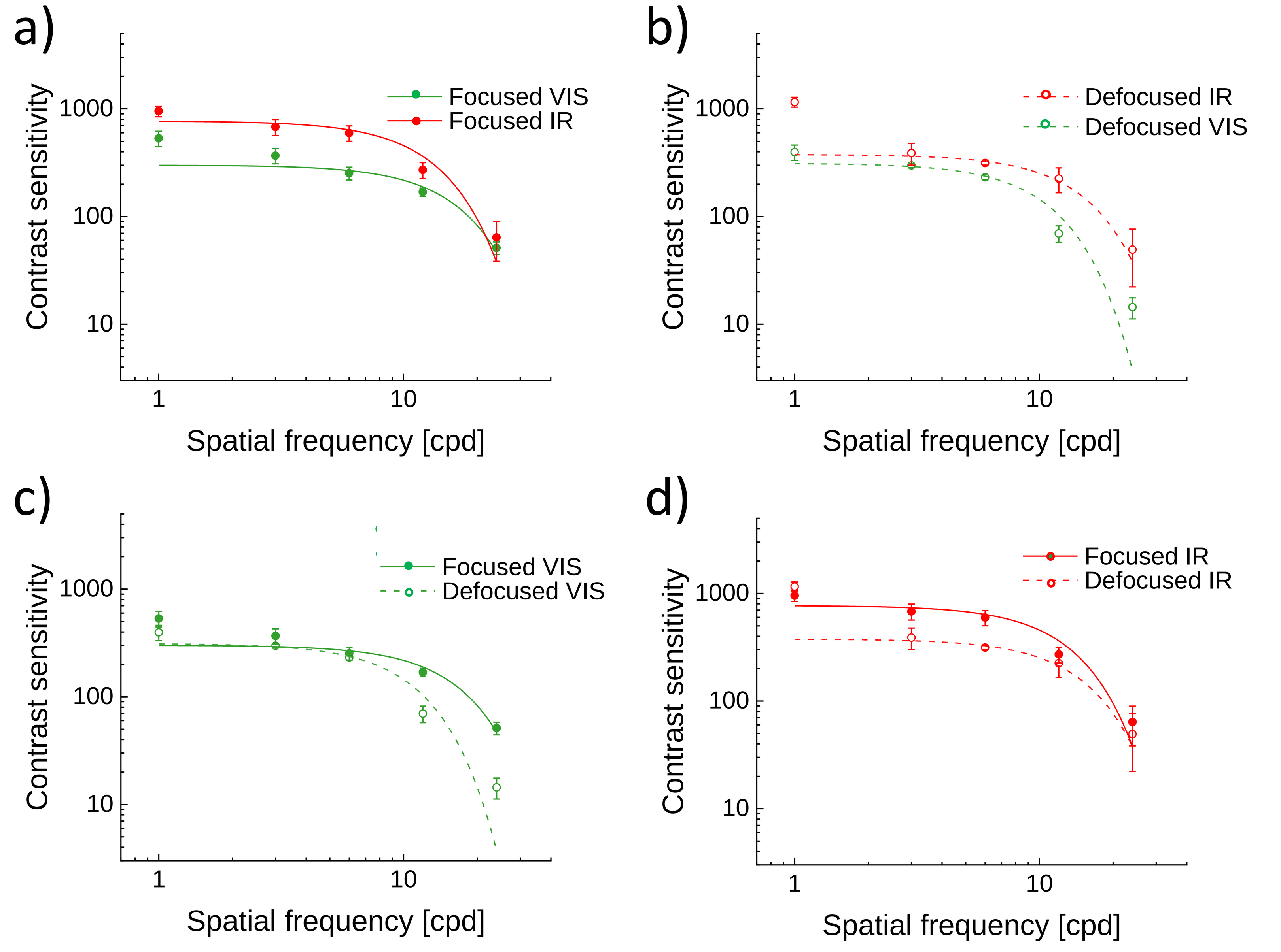

Fig 4. **(a)** CSF for one-photon (green) and two-photon (red) vision under optimal focusing conditions. **(b)** CSF for one-photon (green) and two-photon (red) vision under +1.00 D defocusing conditions. **(c)** Comparison of CSF for visible beam for optimal focusing and for defocusing. **(d)** Comparison of CSF for infrared beam for optimal focusing and for defocusing. Function of a difference of Gaussians was used to adjust the CSF curves (Rohaly and Buchsbaum, 1989).

CONCLUSIONS

- The results show that contrast sensitivity for two-photon vision is higher compared to standard one-photon vision under optimal focusing and under defocus of +1 diopters.
- In the two-photon vision, the quadratic dependence of brightness on power reduces the blurring of the image, which significantly improves the contrast sensitivity for stimuli of high spatial frequencies.
- The CSF conservation under defocusing may be advantageous for applying the two-photon vision in retinal displays and augmented reality (AR) technology, particularly in resolving the accommodation-vergence conflict.

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