Determining the lower limit of human vision using a single-photon source

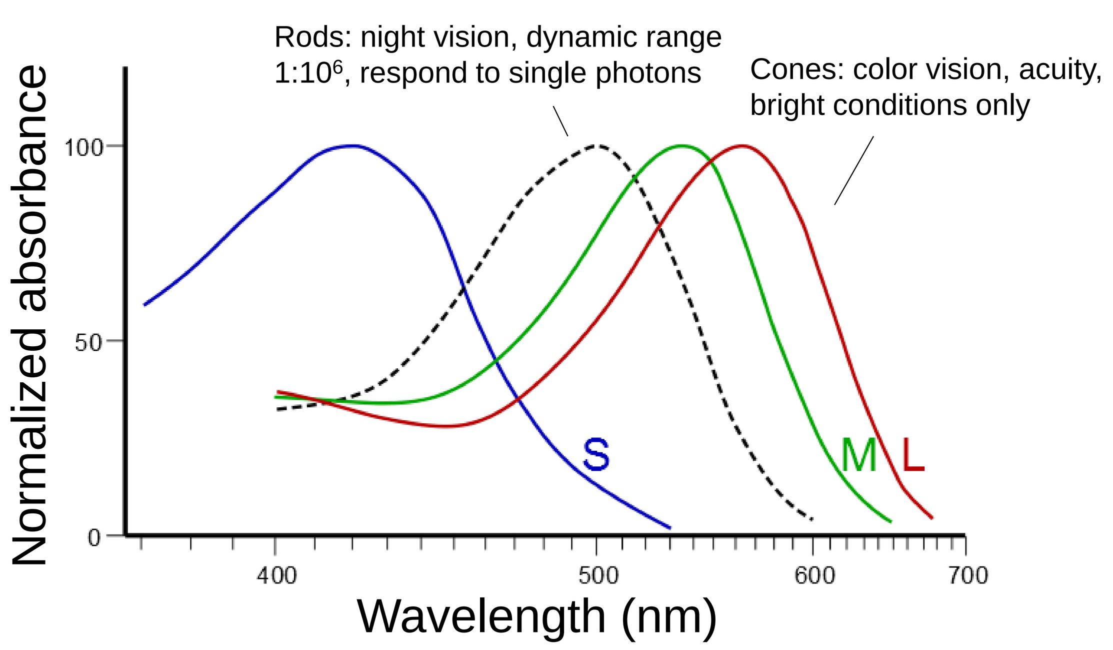
Rebecca M. Holmes, Bradley G. Christensen, Whitney Street, Cory Alford, R. Frances Wang, Paul G. Kwiat

Department of Physics and Department of Psychology, the University of Illinois at Urbana-Champaign

Can you see a single photon?

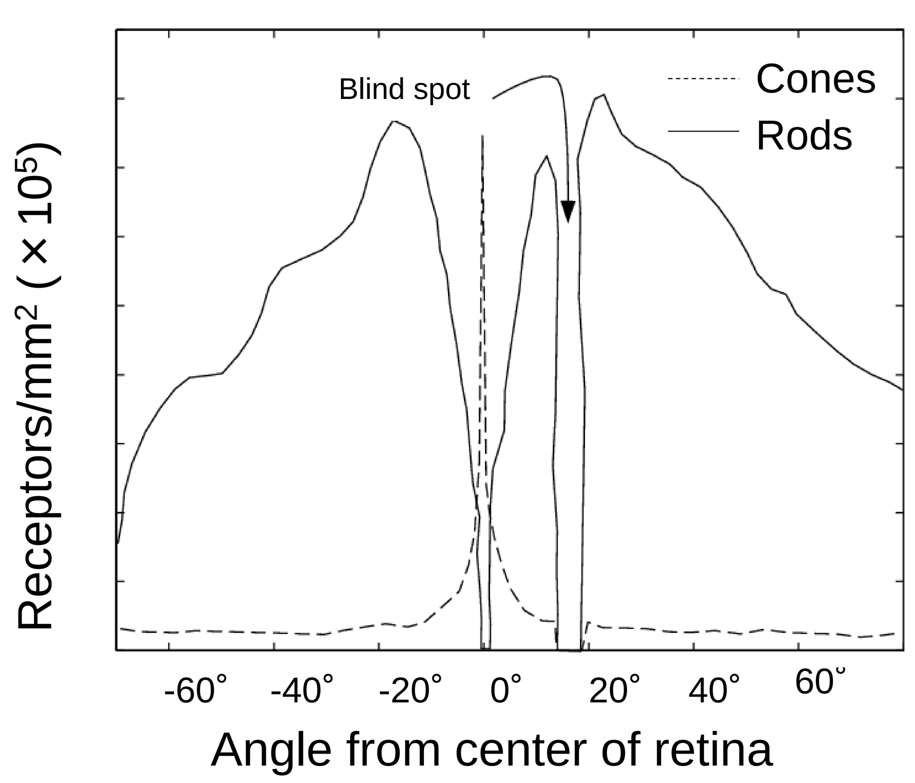
Psychological and physiological research has suggested that the threshold for vision may be as low as one photon [1]. Previous studies have estimated the detection threshold with classical sources and model-fitting methods [2, 3]. **Here we attempt to directly characterize the lower limit of human vision using a true source of single photons.**

Spectral sensitivity of photoreceptor cells [4]



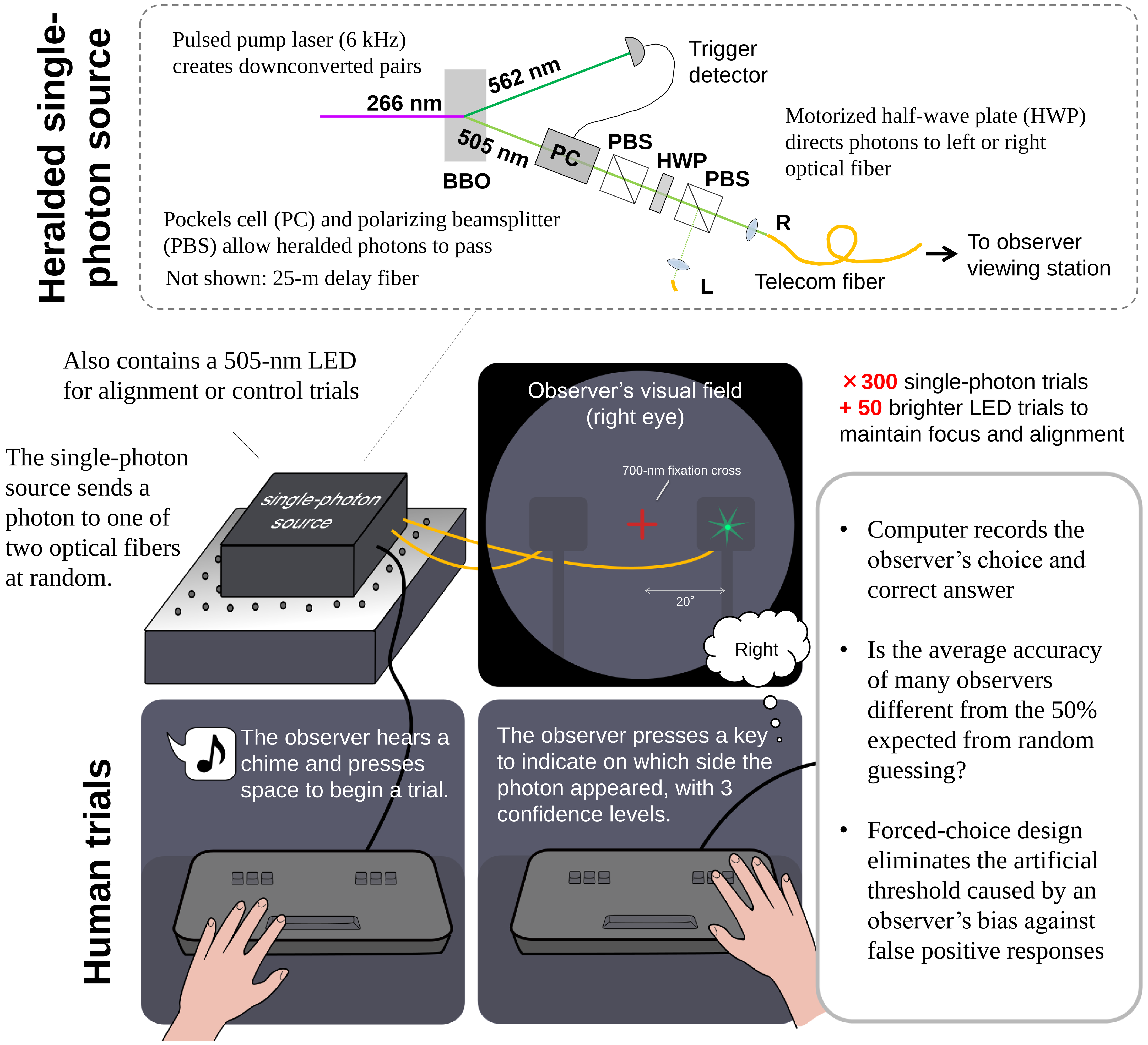
Our source produces heralded single photons at 505 nm, near the peak of rod sensitivity.

Density of photoreceptor cells [5]



A custom viewing station delivers photons to 20° on the left or right side of an observer's retina, where the rods are most dense.

Experimental design



Results

Control trials with a 505-nm LED. Each observer completed 300 trials with a mean of 30 ± 3 photons at the cornea in each trial.

The efficiency of the eye is ~10%, so ~3 photons are absorbed in each trial. Vision at this level has not previously been directly demonstrated.

LED trials

Observer	Proportion of correct responses
A	0.58 ± 0.03
A II	0.55 ± 0.03
B	0.53 ± 0.03
C	0.55 ± 0.03
D	0.51 ± 0.03

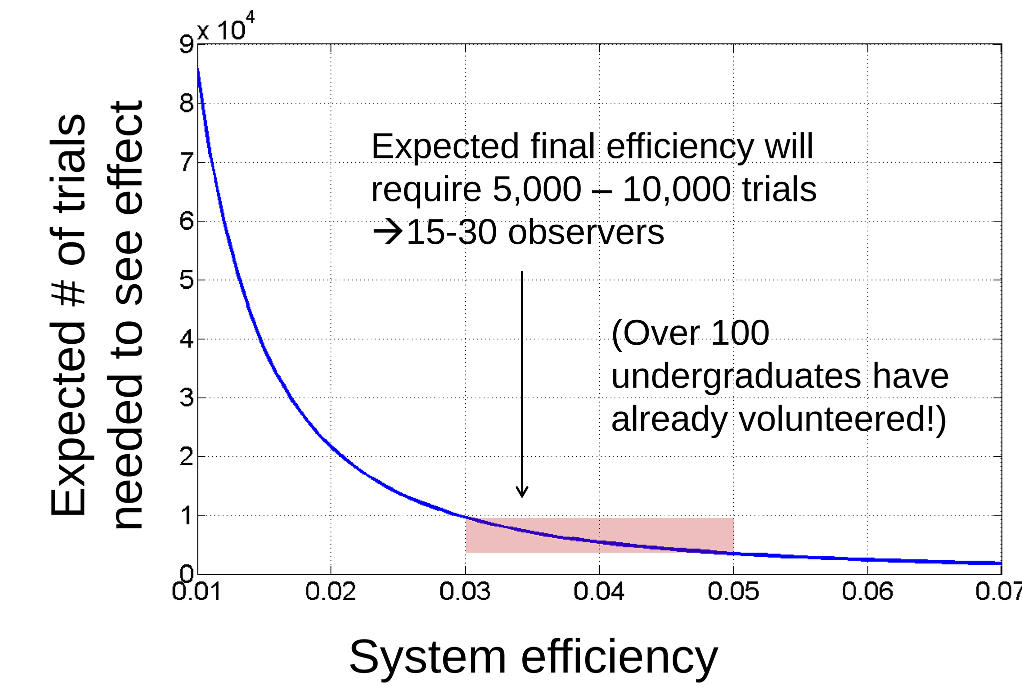
Testing the source. The single-photon source has been tested successfully with single-photon detectors in place of a human observer.

Efficiency of the source. The heralding efficiency of the downconversion collection was optimized and measured to be 67%. Losses in the rest of the system reduce this efficiency:

- 12% loss in delay fiber
- ~10% loss in Pockels cell and polarizing beam splitter
- ~10% loss in final fiber coupling

The quantum efficiency of the eye is uncertain and is estimated to be 6-10% [6], leaving a total system efficiency of 3-5%.

Required # of trials vs. system efficiency



Next steps: quantum mechanics and human perception

We are beginning human trials with the single-photon source. If humans can see single photons, we plan to investigate quantum effects via the visual system:

- Superposition states: does an observer perceive them the same as statistical mixtures? [7]
- Observer as detector in a Bell test of non-locality

References

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Acknowledgments

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Contact: rholmes4@illinois.edu