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

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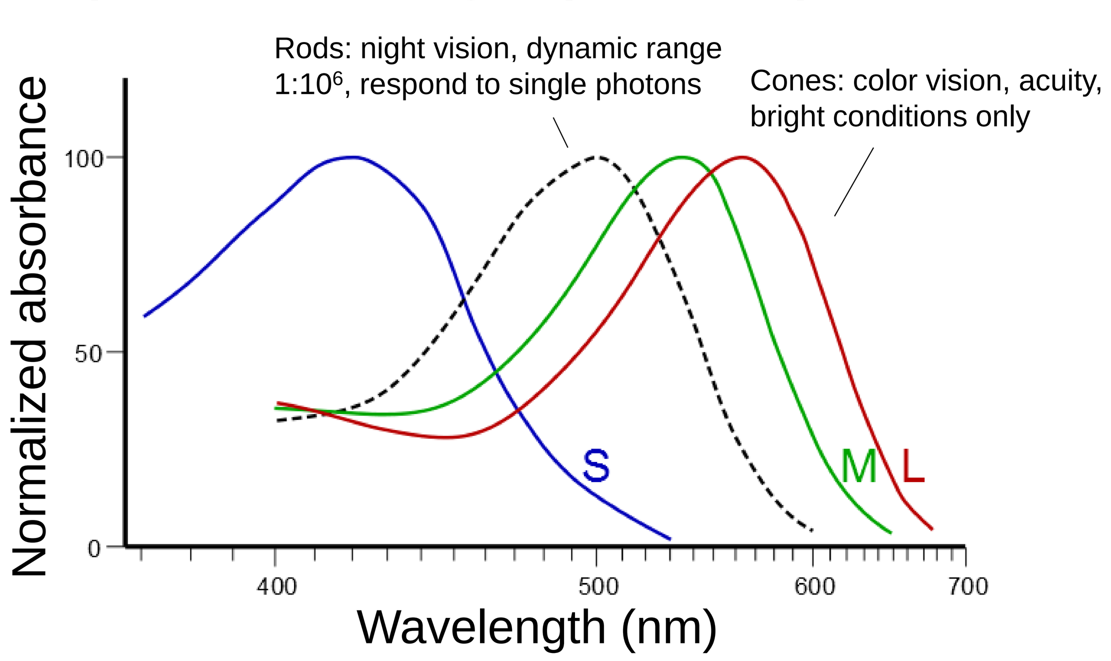
Can you see a single photon?

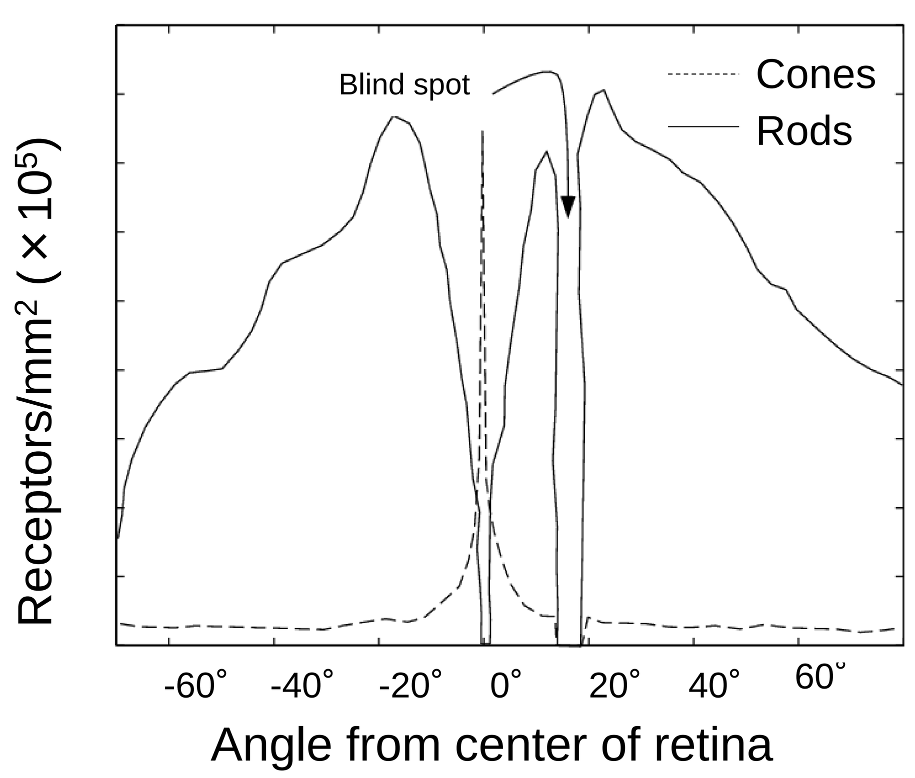
Psychological and physiological research has suggested that the threshold for vision may be as low as one photon [1]. Previous studies have estimated the detection threshold with classical sources and model-fitting methods [2, 3]. **Here we attempt to directly characterize the lower limit of human vision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

Spectral sensitivity of photoreceptor cells [4]



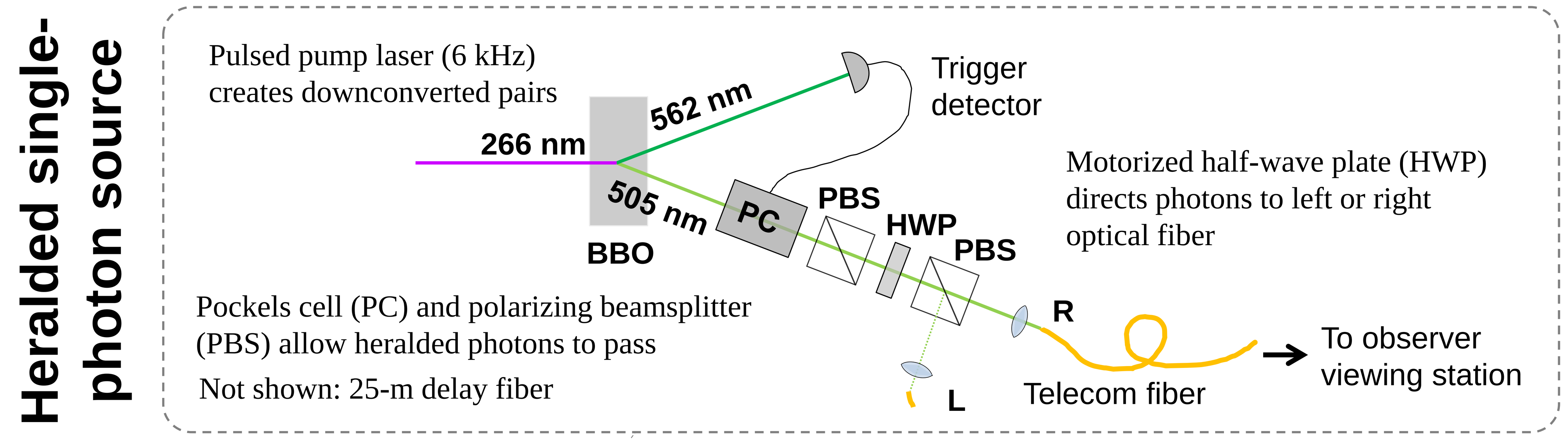
Our source produces heralded single photons at 505 nm, near the peak of rod sensitivity.

Density of photoreceptor cells [5]



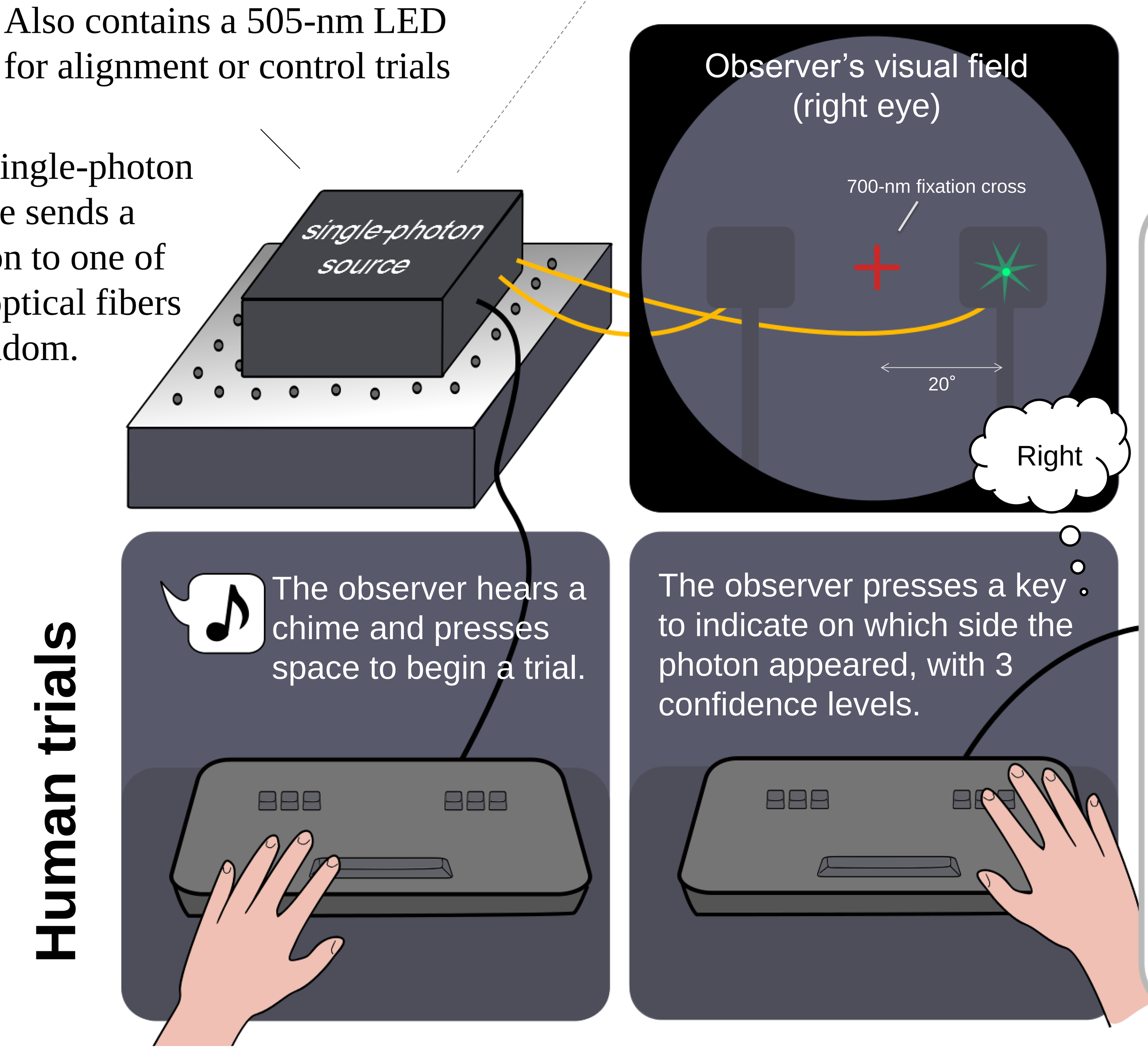
A custom viewing station delivers photons to 20° on the left or right side of an observer's retina, where the rods are most dense.

Experimental design



Also contains a 505-nm LED for alignment or control trials

The single-photon source sends a photon to one of two optical fibers at random.



× **300** single-photon trials
\+ **50** brighter LED trials to maintain focus and alignment

- Computer records the observer's choice and correct answer
- Is the average accuracy of many observers different from the 50% expected from random guessing?
- Forced-choice design eliminates the artificial threshold caused by an observer's bias against false positive responses

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

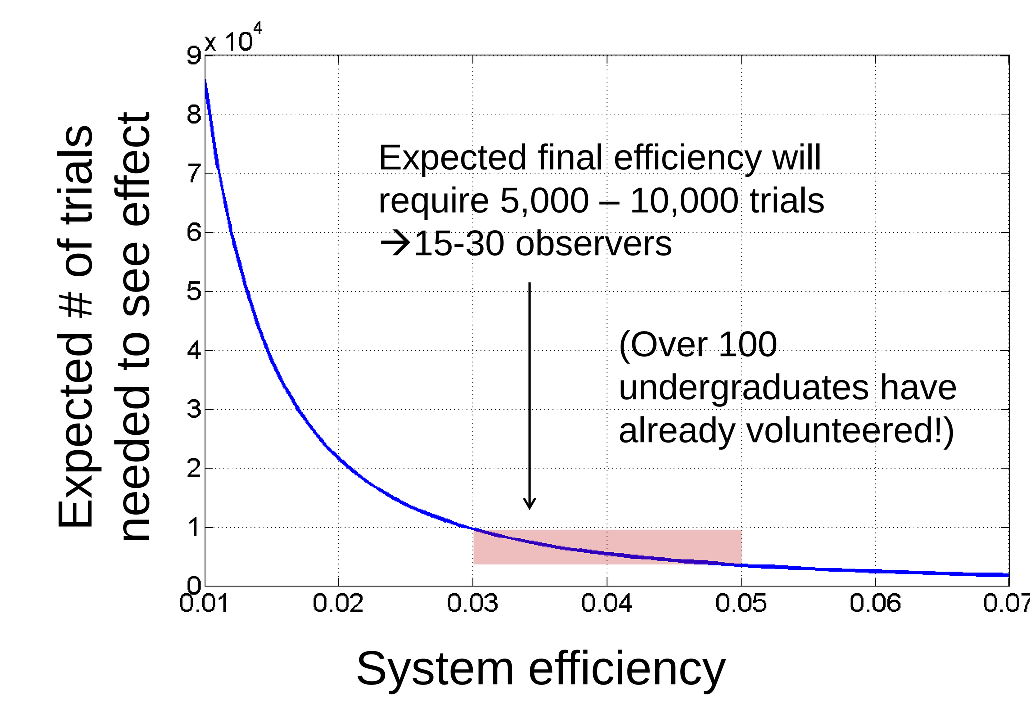
Testing the source. The single-photon source has been tested successfully with single-photon detectors in place of a human observer.

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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