Can humans count photons?

Single photons at the retina? Single photons at the cornea?

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Physics/Neuro 141

Week 4

Sakitt, 1965

Frame Title

- Human subjects were asked to rate both blanks and very dim flashes of light under conditions of complete dark adaptation. The ratings used were 0, 1, 2, 3, 4, 5, and 6.
- The stimulus was a 29’ disk. It was a 16 msec blue-green flash corresponding to either 66 or 55 photons on the average at the cornea, hereafter called the strong and weak stimuli.

Definitions

- i = the rating (i = 0, 1, 2, 3, 4, 5 or 6).
- $p_i(S)$ = probability of saying i when the strong stimulus is presented.
- $p_i(W)$ = probability of saying i when the weak stimulus is presented.
- $p_i(B)$ = probability of saying i when the blank stimulus is presented.
- $P_i(S)$ = cumulative probability of saying i or greater when the strong stimulus is presented.
- $P_i(W)$ = cumulative probability of saying i or greater when the weak stimulus is presented.
- $P_i(B)$ = cumulative probability of saying i or greater when the blank stimulus is presented.
- QC = average number of quanta (scotopically equivalent to 507 nm) at the cornea per flash.
- N_i = number of times that the rating i was given.
- $a(S)$ = average number of rod signals due to the strong stimulus.

Number of trials (N_i) on which each rating was given for each stimulus.

- For each stimulus the mean rating i was calculated:

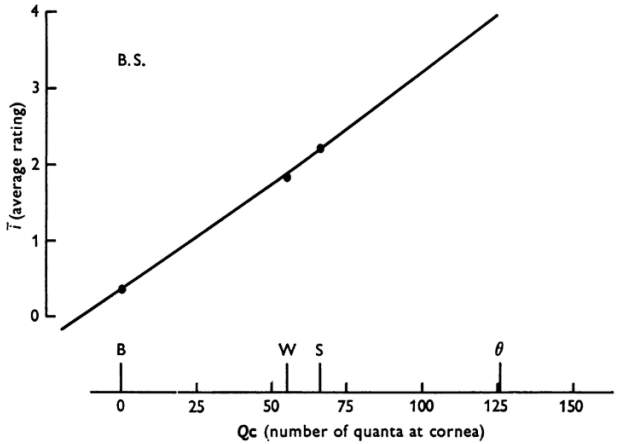
$$\langle i \rangle = \sum_{i=0}^{6} i p_i$$

- And the mean square rating i^2 was calculated:

$$\langle i^2 \rangle = \sum_{i=0}^{6} i^2 p_i$$

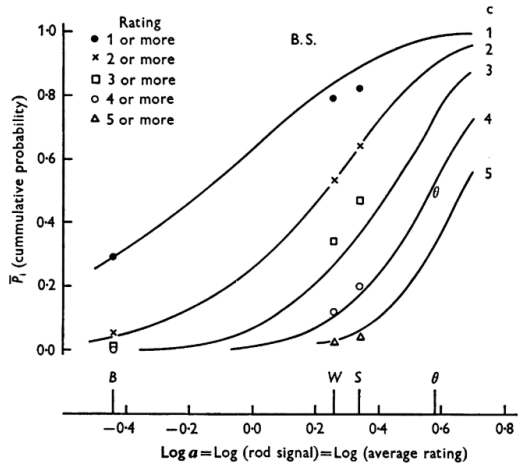
Signal	N_0	N_1	N_2	N_3	N_4	N_5	N_6	$\sum N_i$	$\langle i \rangle$	$\langle i^2 \rangle - \langle i \rangle^2$
Strong	70	75	66	109	63	12	5	400	2.19	2.22
Weak	83	104	78	87	36	11	1	400	1.82	1.93
Blank	566	192	33	9	0	0	0	400	0.36	0.38

Single-photon perception



Plots i, the average rating against Q_c, the average number of quanta at the cornea

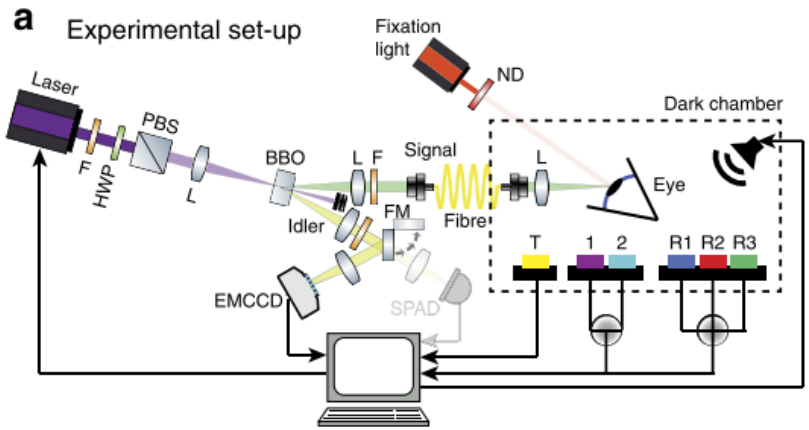
Single-photon perception



- The experimental points are the cumulative probabilities *P* giving a rating *i* or more.
- The abscissa is the log of the rod signal which is the same as the log of the average rating.
- The points labelled B, W and S are at the values of *a* for the blank, weak and strong stimuli respectively.
- The symbol θ refers to the absolute threshold as described in the text. The smooth curves are theoretical cumulative Poisson probabilities $P(\bar{c}, a)$ that *c* or more rod signals occur when *a* is the average number occurring.

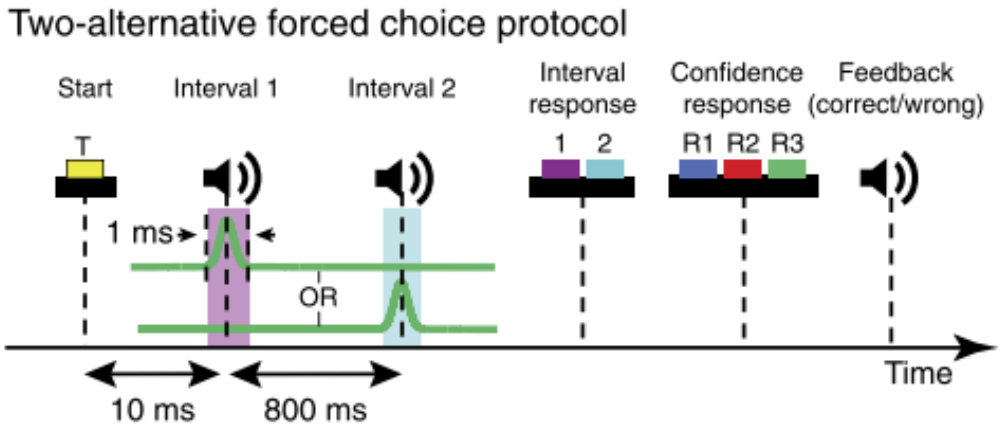
Tinsley, 2016

Design of quantum optical single-photon light source.



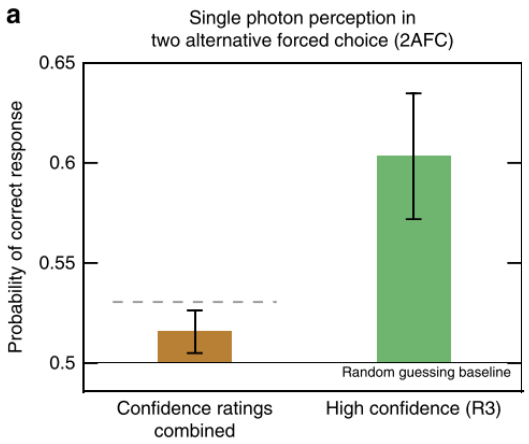
- To probe the absolute limit of light perception, we built a single-photon quantum light source with sub-Poissonian photon number statistics based on spontaneous parametric down-conversion (SPDC).
- SPDC is a quantum optical technique in which correlated pairs of photons (called signal and idler) are produced probabilistically from a higher energetic pump photon in a non-linear crystal following energy and momentum conservation.
- By detecting one of the photons (idler) and sending the other (signal) to the observer's eye, our SPDC source allowed us to create an effective single-photon light source with a sub-Poissonian photon number distribution.

Two-forced alternative forced choice test



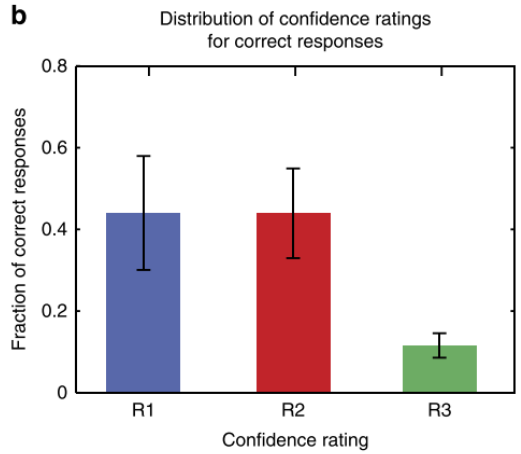
- On the triggering of a trial, the subject was presented with two intervals, each heralded by a sound.
- One of the two intervals was pseudorandomly chosen to trigger a possible single photon from SPDC around the peak rod sensitivity, while the other interval was a 'blank'.
- After the second interval the subject indicated which of the two intervals they thought contained the stimulus photons (interval response) and provided a confidence rating (R1–R3).

Single-photon perception



- Averaging across subjects' responses and ratings from a total of 30,767 trials, 2,420 single-photon events passed post-selection.
- We found the averaged probability of correct response to be 0.516 $\pm$ 0.010 (P= 0.0545).
- Therefore, sbjects could detect a single photon with a probability above chance.

Distribution of confidence ratings for post-selected single-photon events in which the stimulus was correctly identified



- Next we investigated the distribution of subjects' confidence ratings.
- As expected, given the weak stimulus, the distribution of confidence ratings for correct responses was dominated by low confidence R1 and R2 responses.
- Considering only the answers with the high-confidence R3 rating, we found that the probability of providing the correct response was significantly elevated compared with all responses (0.60 ± 0.03, $P=0.0010$), which demonstrates that subjects indeed detected a single photon in the high-confidence trials