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Humans can see single photons

Scientists at the Rockefeller University in New York and the Research Institute of Molecular Pathology (IMP) in Vienna have combined a quantum light source with sophisticated psychophysics experiments to show for the first time that humans can see a single photon incident on their eye. The journal Nature Communications publishes the details in its current issue.

Despite investigations for over seventy years, the absolute limit of human vision had remained elusive. Previous historical studies had established that dark-adapted human subjects are capable of reporting dim light flashes that contain as few as five to seven photons. However, whether the human eye would be capable of detecting a single photon had remained an open question. Now, for the first time, a team headed by Alipasha Vaziri, Associate Professor and head of the Laboratory of Neurotechnology & Biophysics at Rockefeller University and Adjunct Investigator at the Research Institute of Molecular Pathology (IMP), has shown that humans can indeed detect a single photon that impinges on the eye.

Remarkable precision in adverse environment

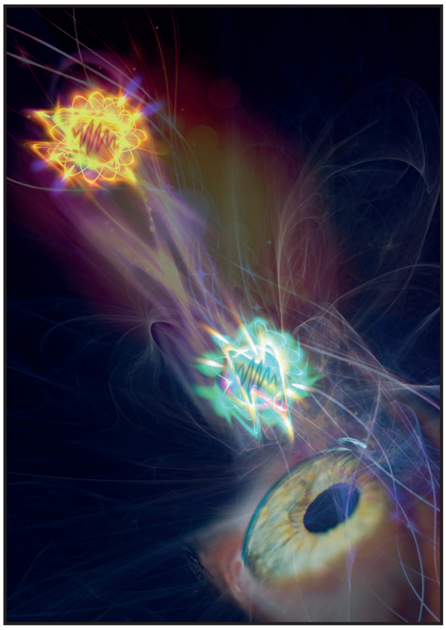
This significant observation shows how far evolutionary pressure can drive optimization. ‘If you imagine this, it is quite remarkable: a photon, the smallest physical entity with quantum properties of which light consists of, is interacting with a biological system consisting of billions of cells, all in a warm and wet environment. The response that the photon generates survives all the way to the level of our awareness, so that we can report on it - despite the ubiquitous background noise. These conditions are the opposite of what one usually associates with quantum experiments. Any man-made detector would need to be cooled and isolated from noise to behave the same way’, Alipasha Vaziri comments.

Another unexpected finding of the study was the observation that the probability of the single photon perception was enhanced by an earlier photon within a time window of a few seconds. So far it remains unclear what the functional role of such a mechanism could be and how it is mediated. One of the next steps for this project will therefore be to explore the biological mechanisms underlying this effect.

Quantum light source used to produce single photons

The main challenges with prior experimental attempts have been the lack of appropriate technologies as well as the non-ideal psychophysical procedures. ‘It is not trivial to design states of light that contain exactly one or any other number of photons. This is because the number of photons in a classical light source such as that from a lamp or a laser follow certain statistical distributions. Thefeore, by attenuating the light, one can only reduce the mean number of photons that a light pulse contains but the exact number of the photons in each given instance is inherently undetermined.’ explains Alipasha Vaziri, who is a quantum physicist by training.

The lack of light sources that can generate an exact number of photon states has been the main problem for many years. To overcome it, Vaziri’s team built a light setup that is often used in quantum optics and quantum information-studies. It is based on the so called “Spontaneous Parametric Down-Conversion” or SPDC, a process in which a high-energy incoming photon decays in a non-linear crystal into two lower energetic quantum-entangled photon pairs. Because this process must obey the conservation of energy, the two photons are always generated together and have complementary colors. In the experimental setup, one of them was sent to a detector and



Artist’s interpretation of an entangled photon-pair entering the human eye. (Copyright: IMP) the other one to the subject's eye. In this way, whenever there was a "click" on the detector, the scientists knew that exactly one photon was sent towards the subject's eye.

First evidence for detection of single photons

In this context, an unprecedented psychophysics protocol called "two-alternative forced-choice" (2AFC) was combined with the above quantum light source. In this procedure, the subjects are repeatedly asked to choose between two time intervals, one of which contains a single photon while the other one is a blank. The gathered data from more than 30,000 trials with this sophisticated set-up demonstrated that humans can indeed detect a single photon incident on their eye with a probability significantly above chance.

As a result of the study, a number of fundamental questions arise from the observations, such as 'How can a biological system achieve such sensitivity? How does it achieve this in the presence of noise? Is the mechanism unique to vision or could it tell us something more general on how other systems could have evolved to detect weak signals in the presence of noise?' remarks Alipasha Vaziri about the next steps of the project.

Original Publication

Jonathan N. Tinsley, Maxim I. Molodtsov, Robert Prevedel, David Wartmann, Jofre Espigulé-Pons, Mattias Lauwers and Alipasha Vaziri: Direct Detection of a Single Photon by Humans. Nature Communications 7, 19 July, 2016. doi:10.1038/ncomms12172

About the IMP

The Research Institute of Molecular Pathology (IMP) in Vienna is a basic biomedical research institute largely sponsored by Boehringer Ingelheim. With over 200 scientists from 37 nations, the IMP is committed to scientific discovery of fundamental molecular and cellular mechanisms underlying complex biological phenomena. Research areas include cell and molecular biology, neurobiology, disease mechanisms and computational biology.

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