THE UNIVERSITY of EDINBURGH
Edinburgh Medical School

Biomedical Sciences

Title of Assessment:

The Nobel Prize in Physiology or Medicine 1981 - D.H Hubel and T.N Wiesel "for their discoveries concerning information processing in the visual system"

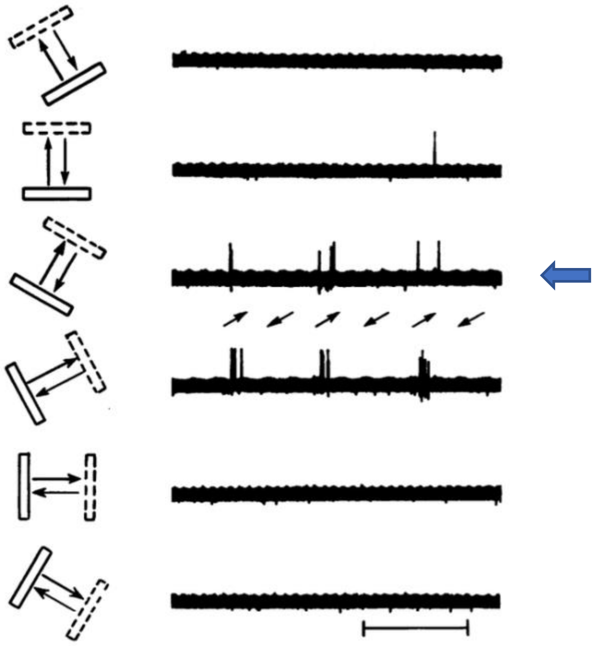
By the time of the David Hubel and Torsten Wiesel's research, surprisingly little was known about the visual system structure and functioning. Most of the knowledge was based on behavioural observations made by experimental psychologists, which lack an explanation of neuronal mechanisms underlining mammals' perception (Wurtz, 2009). Although it is important to note that Kuffler's work on discharge patterns from retinal receptive fields (Kuffler, 1953) had an impact on the first Hubel and Wiesel's research, it was them who enabled us for the first time to understand the complex, cell by cell pathway in visual perception as well as the importance of the visual system development during the earliest stages of life. Thanks to these findings, they were awarded the Nobel Prize in Physiology or Medicine in 1981 "for their discoveries concerning information processing in the visual system" and this essay briefly presents the key points of some of these discoveries as well as their implications.

First experiments and key findings

In their experiments involving stimulation and viewing of the retina, Hubel and Wiesel used a multibeam ophthalmoscope designed by Talbot & Kuffler in 1952. (Hubel & Wiesel, 1959) The most breakthroughs discovery for future work of the two researchers was, indeed, done by an accident when they were changing a slide in the ophthalmoscope. The movement of the slide's edge caused the firing of the cat's visual cortex cell, moreover, the movement had to be in one particular direction. (Hubel, 1981) As a result, they studied 45 anaesthetised cats to map out receptive fields (RF) of the retina, which cause the cortical cells to fire in the response to the light stimuli. (Hubel & Wiesel, 1959) Long narrow rectangles of light ('slits') or contracting edges were found to be the most effective stimuli. (Hubel & Wiesel, 1963a) From the experiment, it was clear that the stimulus had to be of the particular size, shape and orientation in order to trigger the activity of cortical cells. In addition, "a moving spot of light often produced stronger responses than a stationary one, and sometimes a moving spot gave more activation for one direction than for the opposite." (Hubel & Wiesel, 1959) One of the implications is that the visual system is better adapted for movement, since it is more responsive to moving spot. The Fig 1. illustrates an example of the recording. These findings were crucial in explaining the specificity and complexity of visual information processing.

Fig 1. Records of electric impulses from cell activated by ipsilateral eye (eye on the same side as the hemisphere from which the unit was recorded). The arrows represent the direction of a stimulus movement. Activity was recorded for the movement of a stimulus with an oblique orientation in up-right direction but there was no activity for the movement in down-left direction. This shows high specificity required for visual information processing.

Source: (Hubel & Wiesel, 1959)



In the same study, receptive fields were divided into excitatory "on" and inhibitory "off" to the light stimuli. In general, when opposite fields were triggered, no response was recorded, however, when two "on" or two "off" fields were triggered, summation occurred, giving stronger response than a single RF. However, this straightforward antagonism/synergism mechanism did not always apply e.g. in some cases the "on" and "off" fields triggered jointly were reinforcing the response. Further research explained it through the distinction between 'simple' and 'complex' cells. (Hubel & Wiesel, 1962) This division depicts different levels of cortical cells organization in the visual pathway. 'Complex' cells represent higher order and possibly process impulses received from many 'simple' cells, which explains an unexpected response pattern. Furthermore, the arrangement of these fields might explain the specificity of retinal input required. Further research was built upon these principles.

Importance of the early visual system development

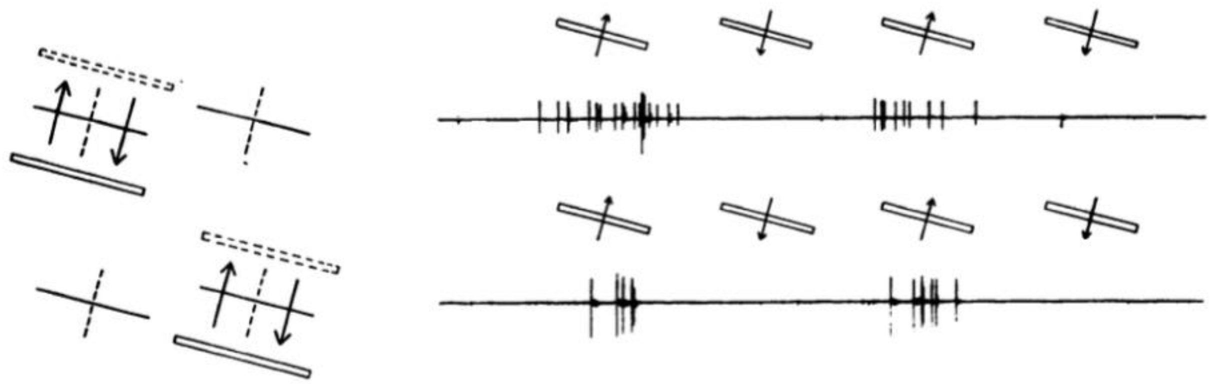
The work of Hubel and Wiesel has also practical implications for humans. They studied an influence of visual deprivation on the development of visual system in kittens. The outcomes were presented in the series of three papers in 1963. In the first experiment, they sutured the right eyes of cats in different age and for the different time. According to the results, 2-3 months without visual stimuli caused significant atrophy in kittens, however, no changes were noted in an adult cat, (Hubel & Wiesel, 1963b) which had already developed visual system. This implies that first months of life are crucial for a proper vision development. The outcome was consistent with a common knowledge at the time. Notwithstanding, before the research, it was thought that exposure to visual stimuli enables the formation of the neuronal connections. In fact, it is the other way around and the lack of visual stimuli causes the disruption of the connections that already exist and are innate to mammals. This was shown in the second paper, in which 8- and 16-days-old kittens, which had no previous exposure to any visual stimuli, had remarkably similar responses of cortical cells to those of adult cats. (Hubel & Wiesel, 1963c) Moreover, as a control, one kitten had right eye covered by a translucent occluder until it was 19-days-old, while the left eye was uncovered. As Fig. 2 shows, both eyes were responsive to stimuli, which once again proves the innateness of mammals' visual perception tool.

Fig. 2 Recording of cortical cells activity of 19-days-old kitten from (A) left eye, which remained uncovered; (B) right eye, which was covered by translucent occluder from the time of normal eye-opening in cats until the cat was 19-days-old. The activity of both eyes can be seen when stimulated by an oblique slit movement in right-up/left-down direction. However, records from the right eye are slightly weaker. This shows that deprivation of visual stimuli causes deterioration of neuronal connections, which seem to be present at birth.

Source: (Hubel & Wiesel, 1963c)

A

B



Since it was known that an early visual deprivation causes deterioration of neuronal connections, a new question has arisen. Is the recovery possible and if yes then to what extent? It was found that although slight recovery in some of the striate cortex cells could be observed during first three months, the cells' responses were abnormal. Therefore, it was concluded that "the animals' capacity to recover from the effects of early monocular or binocular visual deprivation [...] is severely limited, even for recovery periods of over a year". (Hubel & Wiesel, 1965)

Another substantial question that should come to the mind of everyone reading Hubel and Wiesel's studies on cats is whether this might apply to humans. As an answer to this, research on primates, particularly monkeys, was conducted and gave similar results (Hubel, 1979) and thus this is very likely to apply to humans as well. The whole work of these Nobel Prize winners sheds a new light on the approach towards surgeries on infants diagnosed with congenital cataracts (Ziganshina, 2017). As long as it was thought that visual pathway is acquired with time, surgeons were waiting until any impairments will stabilize naturally before performing a surgery. Meanwhile, described research entails the need for taking immediate action in order to recover infants' proper visual system before it is too late.

Future perspectives

Despite a huge progress in explaining visual pathways in mammals, some aspects remain unexplained. Widely described responses to slits of light are not enough to explain curve recognition. This is where other disciplines may come into play. Some modern mathematical models dealing with this problem are directly built upon Hubel and Wiesel's work (Dobbins et al., 1989), which shows a long-term impact of their research. Moreover, the idea of visual processing in a sequence of cells of a neuronal pathway contributed to the concept of explaining vision as an information processing system (Marr, 2010). This theory divides complex problem - vision - into small steps – cell by cell processing- which in turn has greatly influenced computational neuroscience, artificial neural network research and apparently is one of the cornerstones for cognitive science field.

Conclusion

Described discoveries of structure and function of the visual system, as well as their implications for the current vision treatment are just a small, nevertheless strikingly important part of Hubel and Wiesel's research. Thanks to the work of these two, the inquiry in the visual field of neuroscience has exploded, leading to remarkable enhancement of our general understanding of the visual system as well as prompting an interdisciplinary enquiry. What is more, their history teaches us that even accidental discoveries, if noticed and appropriately interpreted may bring ever new impact to next generations.

Word count: 1249

References

Dobbins A, Zucker S & Cynader M (1989). Endstopping and curvature. *Vision research* 29(10), 1371-1387.

Hubel D (1979). The Visual Cortex of Normal and Deprived Monkey. *American Scientist.* 532-543. Available at: http://www.jstor.org/stable/27849434 [Accessed October 28, 2017].

Hubel D (1981). Nobel lecture: Evolution of ideas on the primary visual cortex, 1955-1978: a biased historical account.

Hubel D & Wiesel T (1959). Receptive fields of single neurones in the cat's striate cortex. *The Journal of Physiology* 148, 574-591.

Hubel D & Wiesel T (1962). Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. *The Journal of Physiology* 160, 106-154.

Hubel D & Wiesel T (1963). Shape and arrangement of columns in cat's striate cortex. *The Journal of Physiology* 165, 559-568.

Hubel D & Wiesel T (1963). Effects of Visual Deprivation on Morphology and Physiology of Cells in The Cats Lateral Geniculate Body. *Journal of Neurophysiology* 26, 978-993.

Hubel D & Wiesel T (1963). Receptive Fields of Cells in Striate Cortex of Very Young, Visually Inexperienced Kittens. *Journal of Neurophysiology* 26, 994-1002.

Hubel D & Wiesel T (1965). Extent of recovery from the effects of visual deprivation in kittens. *Journal of Neurophysiology* 28(6), 1060-1072.

Kuffler S (1953). Discharge patterns and functional organization of mammalian retina. *Journal of Neurophysiology* 16(1), 37-68.

Marr D (2010). *Vision. A Computational Investigation into the Human Representation and Processing of Visual Information*. MIT Press, Cambridge, MA.

Wurtz R (2009). Recounting the impact of Hubel and Wiesel. *The Journal of Physiology* 587, 2817-2823.

Ziganshina D (2017). David H. Hubel and Torsten N. Wiesel's Research on Optical Development in Kittens | The Embryo Project Encyclopedia. *Embryoasuedu*. Available at: http://embryo.asu.edu/handle/10776/12995 [Accessed October 27, 2017].

Fig 1. - Hubel D & Wiesel T (1959). Receptive fields of single neurones in the cat's striate cortex. *The Journal of Physiology* 148, 574-591.

Fig 2. - Hubel D & Wiesel T (1963c). Receptive Fields of Cells in Striate Cortex of Very Young, Visually Inexperienced Kittens. *Journal of Neurophysiology* 26, 994-1002.