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# Surroundings influence developing biology of the eye

**In a virtual reality study involving zebrafish, researchers from the University of Konstanz and King's College London have discovered that the development of the eye is influenced by what the fish see during the early stages of life – and this, in turn, alters their behaviour.**

The environment in which animals grow up impacts their physical development and their behaviour later in life. Researchers have now demonstrated the extent of this influence in a study involving young zebrafish, which has been published in the journal "Neuron". The surroundings did not only influence the form and the electrical activity of the eyes' neurons, but also how the fish navigated later on. Neuroscientists from King's College London and the University of Konstanz first exposed the animals to specific stimuli in a virtual reality environment, and then examined and observed them. The study shows that zebrafish growing up surrounded by horizontal stripes develop neurons that differ in shape and response properties from those of their conspecifics growing up surrounded by vertical stripes. As a result, their behaviour later in life changes, too.

## Zebrafish in a VR environment

Stripes are highly salient visual features which all animals use to make sense of what they are looking at. Zebrafish prefer to swim towards vertical stripes, such as seaweed growing vertically from the bottom. The reason for this has not yet been definitively established, but one possibility is that this is their way of seeking out places that can offer them shelter. To determine whether this behaviour is innate or shaped by the early environment, the researchers conducted a study using a virtual reality (VR) behavioural test they had developed. The fish were divided into two groups and, during the first five days of their lives, exposed to an environment characterized either solely by horizontal stripes or solely by vertical ones. In the next step, the researchers investigated whether the respective environment had any effect on the structure of the eye.

They visualized the neurons in the retina through a microscope and found that the neurons in the two groups were shaped differently. The neural activity transmitted from the retina of the eye to the brain, too, was adapted to the stripes that the fish had seen in the first few days after birth.

"At birth, neither the eyes nor the brain of humans or fish are fully developed. Although many neurons are already present, they are being refined through a process known as plasticity right up to adulthood," comments Robert Hindges, lead author of the study and a developmental neurobiologist at King's College London. "We were very surprised and fascinated to discover such pronounced experience-dependent plasticity in a primary sensory organ – the retina".

## The way of seeing influences the behaviour

As the study progressed, all the fish had to find their way around both VR strip worlds –horizontally and vertically. "We wanted to find out how these changes in the eye might affect the actual behaviour of the fish", explains Phoebe Reynolds, first author of the study. "We developed a novel behavioural test in virtual reality in which the fish can demonstrate a preference for stripes of specific orientations. This allowed us to test whether their innate preference was influenced by the environment in which they had grown up".

Armin Bahl from the Centre for the Advanced Study of Collective Behaviour at the University of Konstanz led the behavioural experiments in the study. He explains: "The experimental setup in the VR environment is based on our observations of structural and functional changes in the retina. It was entirely unclear whether these characteristics would also affect the ability to distinguish between striped patterns during the orientation phase. We were therefore very surprised when it became apparent that the animals' rearing conditions did indeed have a major influence on their subsequent behaviour. The fish usually tend to swim towards the vertical stripes, but those who only knew horizontal stripes, did so much less frequently. They clearly adapted their swimming behaviour to the changed surroundings."

## It's the structure of the eye that makes the difference

What is particularly fascinating from a biological point of view is the fact that not only the animals' behaviour changes, but also the physical structure of the eye. There were changes in the retina, a structure at the back of the eye that is responsible for detecting light and basic visual processing. Through genetic manipulation, the researchers succeeded in isolating the role retinal plasticity plays in this context. Without the influence of retinal plasticity, the fish from both environments behaved the same, demonstrating that the changes in the biology of the eye drive their behaviour.

These research results add to a growing body of evidence showing that the retina pre-processes the visual scene before passing it on to the brain for further processing. This is in keeping with studies in humans that have shown that people who grow up in different visual environments perceive optical illusions differently. Until now, however, it was not known that these changes are being at least partially driven by changes in the earliest stage of visual processing, namely in the retina. The current study on zebrafish is the first study to show that this pre-processing is dependent on the visual environment in which the retina and the fish are developing.

**Publication:**
P. Reynolds, D. Marchi, Y. T. Ling, K. Slangewal, M. Capelle, Z. Chalakova, A. Bahl, R. Hindges (2026): Early visual experience elicits cellular and functional plasticity in the retina and alters behaviour, Neuron, DOI: 10.1016/j.neuron.2026.05.001

**Professor Armin Bahl** is a project leader at the Centre for the Advanced Study of Collective Behaviour and head of the laboratory for neural information processing and behaviour in the Department of Biology at the University of Konstanz. His research focuses on how animals integrate information provided by their sensory organs and make decisions, and how the nervous system effortlessly carries out these calculations and ultimately controls behaviour.

The **Centre for the Advanced Study of Collective Behaviour at the University of Konstanz** is an interdisciplinary research centre that studies the principles behind the collective behaviour of animals and other systems.

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