



What is a penguin's-eye view on the world?

- Penguins need to see in an extremely challenging set of conditions, from air to water and from bright sunlight to the dim depths of the ocean.
- Dr Peter Hadden, an eye specialist from Auckland, New Zealand, has been working with Dr Jie Zhang of the University of Auckland to take a closer look.
- Penguin vision seems clearer than we thought and more adaptable than we can currently explain.
- This work will aid teaching, research, and veterinary practice for these much-loved birds.

Having less-than-perfect vision isn't uncommon in humans. Many people are nearsighted or farsighted and some are even both. But penguins have far greater challenges than us: they need to see while on land raising their chicks, and also while hunting for prey underwater in dark and gloomy oceanic depths.

Penguins have been flightless and living a semi-aquatic lifestyle for about 70 million years. We might expect their eyes to have evolved some interesting features to perform in this challenging range of conditions. John Darby, formerly of the Tūhura Otago Museum in Dunedin, New Zealand, asked Dr Peter Hadden, an eye surgeon based in Auckland, to take a look. Hadden teamed up with Dr Jie Zhang, an academic working down the road at the University of Auckland, to dive deep into penguin vision, using the latest techniques and equipment.

The oceans of the Southern Hemisphere are home to many penguins, which come in a large range of sizes and live in quite different habitats. It often surprises people to see penguins standing near sheep in New Zealand, or next to a giant tortoise at the Galápagos. Here, three very different species have been selected for study: shallow-diving Little Penguins (*Eudyptula minor*), Gentoo Penguins (*Pygoscelis papua*), and the well-known, relatively deep diving, King Penguins (*Pygoscelis papua*).

Measuring penguin eye structure

There are pros and cons to testing penguin vision. On the plus side, they have relatively large eyes compared to most flying birds, which find heavy eyes a disadvantage. King Penguins have eyes that are even larger than ours. The cons, of course, are that samples are hard to come by. For their study, the team worked with various birds in captivity or individuals that had to be rescued from the wild or had recently died.

Hadden and Zhang used the latest microCT scanners alongside more traditional dissection techniques to generate incredibly detailed illustrations of penguin head anatomy. These feature the beautiful ring of overlapping bones that surround the eye, the intricate system of muscles and fluid-filled cavities that work together to focus light

Getting clear measurements of eye function on a vet's table is hard enough, now try that with a swimming penguin!

onto the retina, and even the exact eye structure of the three different species of penguins.

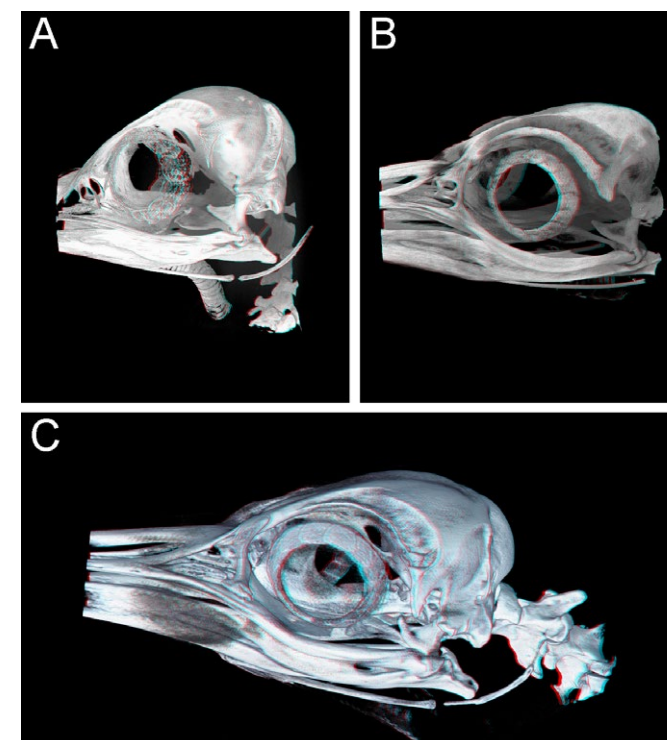
Where is the focusing power of a penguin eye?

When light enters the eye, the first layer it passes through is the transparent cornea. In humans, the cornea is like a domed outer window, and this is where much of the light is focused. However, the light-bending ability of this dome pretty much vanishes if the eye is submerged in a liquid, as anyone who has tried to retrieve a toy from the bottom of a swimming pool will tell you.

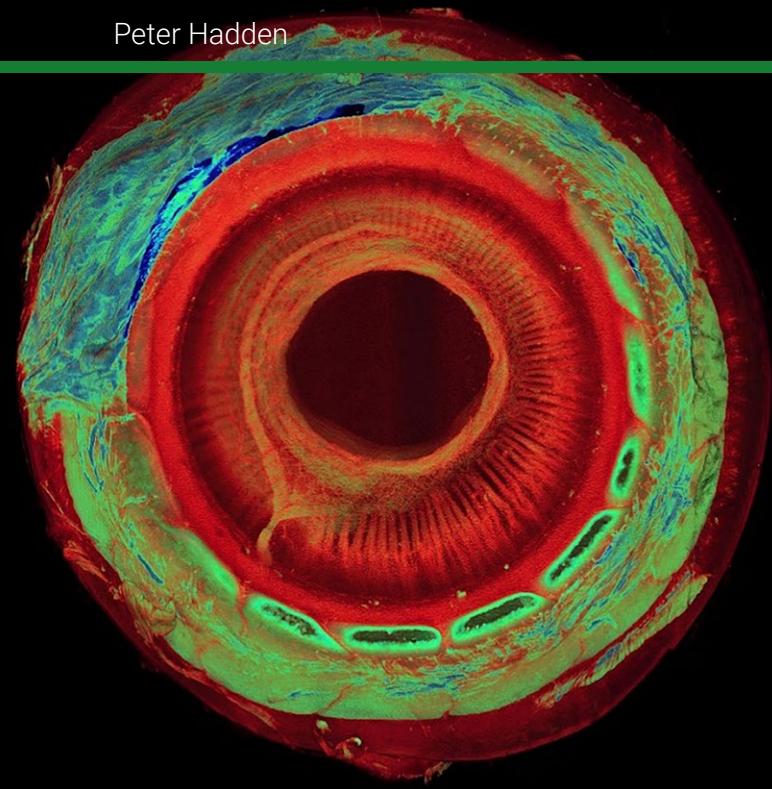
Not surprisingly, penguins don't seem to rely that much on their corneas to focus. The team found that the larger penguin species in particular have exceptionally flat corneas. Instead, most of the bending of light probably takes place in the lens, much more like what happens in fish eyes than in those of terrestrial animals. It is possible that the ring of bones surrounding the eye helps by providing a firm support to those muscles that change the shape of the lens, allowing for greater focusing power.

Adaptations for low light

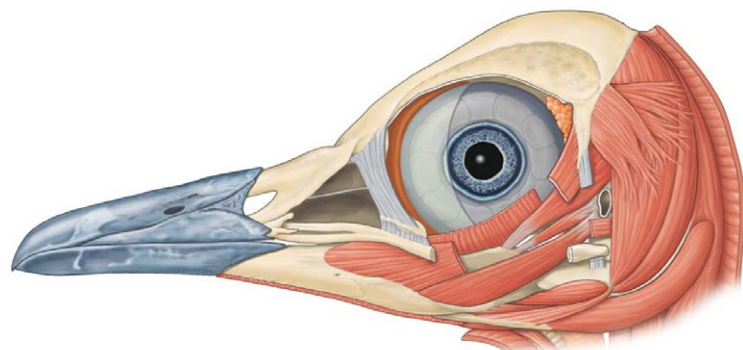
Light levels drop fast as you dive down after prey in the sea, especially in the darker winter months where, close to Antarctica, the days are very



Three-dimensional reconstructions of head micro-CT scans. (A) Little Penguin *Eudyptula minor*; (B) Gentoo Penguin *Pygoscelis papua*; (C) King Penguin *Aptenodytes patagonicus*. Use red-green glasses to view these images in three dimensions. From Hadden, PW, et al, (2022) *Micro-CT guided illustration of the head anatomy of penguins (Aves: Sphenisciformes: Spheniscidae)*. *Journal of Morphology*, 283, 827–851.



The intrinsic structure of the King Penguin *Aptenodytes patagonicus* iris, imaged with micro-CT. From Hadden, PW, Zhang, J. (2023) [An overview of the penguin visual system](#). *Vision*, 7(1), 1–24.



The left eye, skull and muscles of a Little Penguin *Eudyptula minor*. From Hadden, PW, et al. (2022) [Micro-CT guided illustration of the head anatomy of penguins \(Aves: Sphenisciformes: Spheniscidae\)](#). *Journal of Morphology*, 283, 827–851.

Penguins' eyes have evolved to work well both when they are on land and when underwater.

short. Even though most penguins, particularly the smaller ones, tend to dive in the daytime and dive deeper when it is lighter, many species are hunting in light levels equivalent to a starry night or darker. Most birds can see four primary colours, but all penguins sacrifice one of these to improve their ability to see in the gloom. Interestingly, Hadden found that Gentoo Penguins can see ultraviolet light.

The larger penguin species which tend to dive deeper have relatively large pupils to harvest more light, and the large King Penguin has been found to have unusual pale green oil droplets and more rod photoreceptors, which are particularly good at detecting small amounts of light.

Eyes in action

A closer look at the structure of the three penguin species has given us valuable data on the shape of their eyes, but the ultimate challenge is to measure this hardware in action in live birds. Some previous studies proposed that penguins might be a bit bleary when out on land, but Hadden, Zhang and team found penguins standing on land to have sharp focus.

Getting clear measurements of eye function on a vet's table is hard enough, now try that for a swimming penguin! It's difficult, but as it turns out, not entirely impossible. The researchers have managed to take focussing measurements of penguins as they approach the window of their tank when lured there with food. Snapping head shots while they zoom past is tricky, but well worth the effort. It is these measurements of eye function in living, conscious animals that can really tell us how the structure of the eye performs when the penguin is out and about.

Surprisingly, the team's readings have shown that penguins' eyes have evolved to work well both when they are on land and when underwater, and their eyes are able to focus in both physical environments. Finding out how penguins are achieving this remarkable level of accommodation will be a challenging next step.

The future

This innovative work on the imaging and recording of penguin eye structure and function is a welcome hop forward in our knowledge of these interesting and charismatic birds. Fascinating in their own right, these new insights will also aid future research efforts, improve teaching aids for vets, and allow for more accurate predictions of the challenges different penguins might face in an ever-changing future.

We might expect patterns of water clarity and prey distribution to shift in the future, and penguins are often caught in fishing nets that perhaps they can't see. Understanding the limitations of penguin vision for different species might help us predict the consequences of such change and reduce penguin mortality from things we have the power to change.

Personal response

What inspired you to conduct this research?

I have always been interested in animals. Because of this and my background as an eye surgeon, I was approached by John Darby, a well-known penguin expert from Dunedin, with a view to looking at how penguins see. I think it is very important because although some penguins are very common, others, particularly some species in New Zealand, are threatened and have declining populations. We need to understand how they see as they depend on sight for foraging and to avoid predation, including by human fishing nets. Hopefully understanding what and how they see can help us to help them.

Are you tempted to apply your skills to any other non-human animals?

I do hope that understanding penguin vision will help us understand other birds,

particularly other sea birds, which face similar challenges. I have been lucky enough also to have the opportunity to look at the eyes of some other native New Zealand animals, including birds such as the North Island Kākā *Nestor meridionalis*, South Island Takahē *Porphyrio hochstetteri*, and a reptile, the tuatara *Sphenodon punctatus*, which are also very interesting.

How might you further investigate the interesting ability of penguins to focus in such a wide range of conditions?

I would like to look at other penguins, in aquaria overseas and in the wild, as there are many species of penguin that live in other parts of both New Zealand and the world. If I'm lucky my research might lead to exotic travel opportunities! I would also like to look more closely at exactly how the lens changes shape so that it can accommodate different environments.

Details



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Collaborators

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Bio

Dr Peter Hadden is an eye surgeon from Auckland, New Zealand.

Further reading

Hadden, PW, Zhang, J. (2023) [An overview of the penguin visual system](#). *Vision*, 7(1), 1–24.

Hadden, PW, et al. (2022) [Micro-CT guided illustration of the head anatomy of penguins \(Aves: Sphenisciformes: Spheniscidae\)](#). *Journal of Morphology*, 283, 827–851.

Hadden, PW, et al. (2022) [Selected ocular dimensions of three penguin species](#). *Vision Research*, 201, 1–10.

Hadden, PW, et al. (2021) [Skeletal elements of the penguin eye and their functional and phylogenetic implications \(Aves: Sphenisciformes: Spheniscidae\)](#). *Journal of Morphology*, 282, 874–886.

