Avian vision: A stable view of a moving world

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Two new studies provide the clearest evidence yet that eye position is actively controlled during avian flight. Pigeons dynamically balance image stabilisation, optic-flow processing and binocular vision, suggesting that gaze control is integral to navigation, obstacle avoidance and landing.

Birds are among the most visually accomplished vertebrates, yet a surprisingly basic question has remained unresolved: how do they direct their eyes during flight? The answer might seem obvious. As a bird moves through its environment the image projected onto its retinas sweeps across the visual field[1]. This motion can blur landmarks, obstacles, and landing targets. Imagine looking out of a fast-moving train: nearby objects rush past while distant features drift more slowly, generating a pattern of visual motion similar to the optic flow a bird would experience during flight. One might, therefore, expect flying birds to make compensatory eye movements to stabilise the visual scene. This would increase acuity and facilitate object recognition by reducing motion blur, and improve discrimination of moving objects. Alternatively, by keeping their eyes in a fixed position, the direction and magnitude of optic flow across the visual field would provide information about ground speed and travel direction. This is particularly valuable for animals in flight because mechanosensory systems encode motion within the air and inertial frames of reference[2,3]. Smaller-scale optic flow patterns can reveal the structure of the environment and the approach of nearby obstacles. Flying animals, therefore, face a strict trade-off between maintaining a stable view of the world and retaining the motion cues needed to monitor and regulate their movement through it. Yet two studies reported in this issue of *Current Biology*, by Ivo Ros and colleagues[4] and Anthony Lapsansky and colleagues[5], reveal a far more nuanced story. Rather than continuously moving their eyes or keeping them fixed, homing pigeons (*Columba livia*) switch between distinct visual strategies according to the demands of flight. Together, these two studies provide some of the clearest evidence yet that eye position in birds is an active component of flight control and navigation.

For decades, the role of vision in avian flight control was underestimated. Frosted-lens experiments in homing pigeons in the 1970s appeared to suggest that vision contributed little to navigation, steering and landing[6]. Subsequent behavioural studies — using previews of release locations — overturned this assumption, demonstrating that vision supports efficient navigation in familiar areas[7]. More recently, work on gap negotiation, obstacle avoidance and prey pursuit has shown that birds use visual information to guide flight over small scales[8–11]. Yet despite growing evidence that vision contributes to flight control, remarkably little is known about how birds direct their gaze while airborne.

Part of the difficulty has been technological. Birds move rapidly through three-dimensional environments, generate substantial aerodynamic forces and cannot support large additional masses during flight. Consequently, most previous studies of avian eye movements have focused on restrained or walking birds in the laboratory. By mounting miniature eye-tracking cameras on pigeons during natural flight, Ros *et al.*[4] and Lapsansky *et al.*[5] were able to overcome these limitations and now provide an unprecedented view of how birds deploy their eyes while moving through the world.

At first glance, the findings from these two studies appear difficult to reconcile. Ros *et al.*[4] report that pigeons maintain their eyes in a remarkably stereotyped position relative to the head during flight. Shortly after take-off, their eyes enter a consistent configuration just forward of the lateral direction. Although pigeons are capable of moving their eyes independently through angles of up to around 15°[12], eye movements during flight are typically restricted to around 1°, indicating that the birds actively stabilise their gaze while airborne. In contrast, Lapsansky *et al.*[5] describe slow eye movements during cruising flight and pronounced binocular convergence during landing. Are pigeons holding their eyes still, or are they moving them? The answer, it turns out, is both.

A key insight emerges when the behavioural contexts of the two studies are considered. The flights examined by Ros *et al.*[4] involved relatively short journeys close to the ground and among obstacles, where pigeons experienced extremely high rates of translational optic flow. In such situations, attempting to stabilise individual ground features through eye movements would be difficult, and likely of limited value. Features move rapidly through the visual field, and the most useful information may instead come from the optic-flow pattern itself. Under these conditions, pigeons appear to hold their eyes largely fixed, preserving the rich self-motion and looming obstacle information. Shifts in gaze are achieved primarily through head movements, consistent with previous studies showing that birds rely heavily on head saccades rather than continuous eye movements to redirect gaze[13,14].

The situation changes during longer-distance cruising flight. Lapsansky *et al.*[5] examined pigeons flying over kilometre-scale routes at greater heights, where the distance from the substrate means that optic-flow rates are substantially lower. The slowest rates of optic flow are found in the relatively featureless and expansive sky and along the distant horizon, while the fastest rates occur in the ventral field, where the ground moves rapidly beneath the bird. Here, pigeons exhibited slow eye movements whose velocity closely matched the translational optic flow occurring along the horizon, while leaving substantial optic-flow information available in the ventral field. The eye movements observed during cruising flight appear, therefore, to represent a compromise. By stabilising the horizon, pigeons may improve their ability to detect and identify distant landmarks useful for navigation, while still preserving strong optic-flow signals in the ventral visual field that could contribute to self-motion estimation.

While Lapsansky *et al.*[5] highlight the importance of small eye movements during cruising flight, the magnitude of these shifts is generally less than 5°; the eyes remain in roughly the same position. However, a dramatic departure from this configuration occurs during landing: the authors found that, as pigeons approach a perch, the eyes converge strongly towards the target. This suggests a transition to a fundamentally different visual mode. During most flight, the visual system appears organised around navigation and self-motion estimation. During landing, the critical problem becomes the analysis of a specific object whose successful interception determines whether the manoeuvre succeeds. For laterally eyed birds such as pigeons, converging the eyes substantially increases binocularity; binocularity is important for the accurate timing and placement of the bill and feet[15].

Combined, these findings show that pigeons dynamically reconfigure their visual system to shift the balance between image stabilisation and optic flow according to the information demands of the behavioural task (Figure 1). When flying close to the ground, pigeons appear to prioritise optic-flow cues associated with self-motion and the structure of the nearby environment. This likely facilitates speed regulation and obstacle avoidance. During longer-distance flights at height, individual landmarks become important for navigation by visual pilotage. Thus, rather than keep their eyes fixed, pigeons employ compensatory eye movements to stabilise distant features while retaining useful motion information elsewhere in the visual field. During landing, visual processing shifts towards perch fixation via strong binocular convergence. This might facilitate distance estimation through visual expansion of the target. Similar landing-related convergence occurs in Indian peafowls (*Pavo cristatus*)[16], while optokinetic stabilisation resembles that reported in hummingbirds[17] and *Drosophila*[18], suggesting a broadly conserved strategy for flight control.

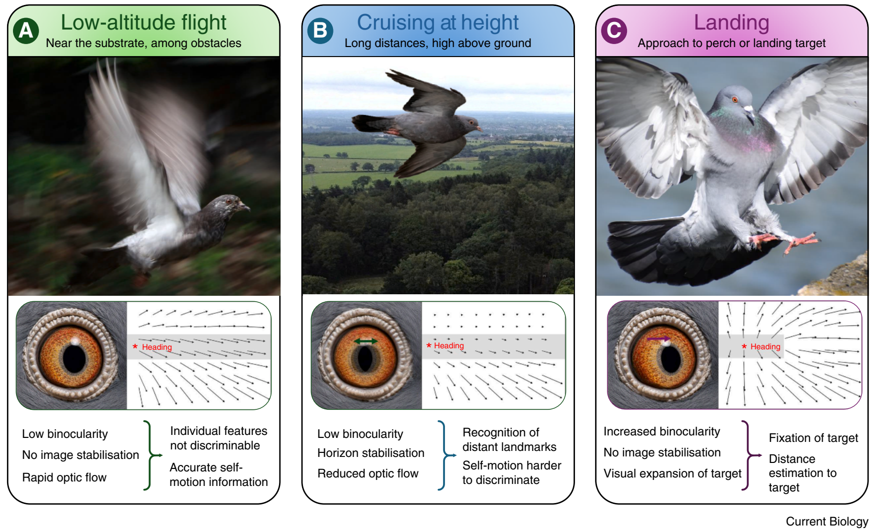

Figure 1. Pigeons show three distinct visual modes during different flight contexts.
Each panel illustrates the characteristic position of the right eye, the resulting optic flow field, and their functional implications. (A) During low-altitude flight close to the substrate, pigeons maintain their eyes in a lateral position. The proximity of surrounding surfaces generates high optic-flow velocities, including along the horizon (grey shaded band), which may blur individual features but provides reliable information about self-motion without the complications introduced by eye movements. (B) During long-distance cruising flight at height, pigeons make small divergent eye movements that approximately match optic-flow velocities along the horizon (grey shaded band). This compensates for retinal image motion, reducing motion blur and potentially improving the detection of distant landmarks used for visual pilotage. (C) During approach to a perch, the eyes adopt a converged position, increasing binocular overlap and centring the target and optic-flow field within the visual field (grey shaded region), which may facilitate distance estimation and landing control. Pigeon eye images were made using ChatGPT. Photo credits: (A) Hotcatssan/Wikimedia Commons (CC BY 4.0); (B) Alexis Lours/Wikimedia Commons (CC BY 4.0); (C) Tylwyth Eldar/Wikimedia Commons (CC BY-SA 4.0).

The wider implications extend beyond vision as a standalone system. One of the most intriguing findings reported by Ros *et al.*[4] is that the preferred eye position aligns closely with the principal axes of the vestibular system. Such alignment could simplify the brain's estimate of self-motion by bringing visual and vestibular signals into a common frame of reference, reducing the neural transformations required to combine these signals. This idea shifts attention away from the traditional view of eye movements as mechanisms for directing gaze towards objects, and instead suggests eye position itself may be part of a broader sensorimotor strategy.

Despite these advances, many questions remain. It is unclear how broadly these findings generalise across birds with different visual fields and ecological demands. Raptors pursuing agile prey[8], seabirds travelling over featureless oceans or flocking species monitoring neighbours[19] face very different visual challenges and information requirements. More complex aerial manoeuvres, obstacle-rich environments or intense target pursuit might reveal additional visual modes. With this in mind, the most important contribution of these studies is perhaps conceptual. For decades, the question of whether birds move their eyes during flight has been treated as a descriptive problem. The emerging answer suggests that the more interesting question is not whether eye movements occur, but why they occur and under what circumstances. Eye position emerges not merely as a consequence of flight behaviour, but as an active component of how birds acquire, organise and interpret sensory information.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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