NEWS & VIEWS

BIOMECHANICS

Getting to grips with bird landing

Tree-dwelling birds can land on perches that vary in size and texture. Force measurements and video-footage analysis now reveal that birds rely on rapid and robust adjustments of their toe pads and claws to land stably.

ANDREW A. BIEWENER

Even casual observations of flying birds, bats and insects reveal the adept and seemingly effortless ability of these creatures to land and take off safely from a wide variety of surfaces, whether these are tree branches, telephone wires, flowers or rocks. By contrast, passenger aircraft usually require long, flat runways to accomplish the same feats, and, even so, accidents can occur during take-off or landing. With the rise in the use of aerial drones for a range of applications[1–4], and the challenge of improving the aerodynamics and energy efficiency of drones, given their small size[5], there is interest in developing drone design to boost their success in landing on a range of complex surfaces. Writing in *eLife*, Roderick *et al.*[6] report their analysis of how Pacific parrotlets (*Forpus coelestis*) land on different types of perch, providing insights into the landing approach taken by these birds.

Previous work[7] has examined how vertebrates such as birds, bats and terrestrial mammals grip surfaces, by studying their feet and claws. This work has relied mainly on approaches such as comparative morphological analyses to assess foot, toe and claw geometry, studies of animal motion (termed descriptive kinematics) or static tests of grip strength. Such methods have shown, for example, how claw shape varies depending on an animal's size and claw use during its usual patterns of movement in its natural surroundings. For example, claws that are commonly used for running on the ground and manoeuvring usually have greater depth and are less curved than claws typically used for climbing. However, what has been lacking are studies of the dynamics and the forces that enable an animal to use its feet and claws to establish a stable support on landing, such as when birds perch.

Pacific parrotlets are tree-dwelling birds native to mountain forests of Ecuador and Peru. Roderick *et al.* studied how these birds landed (Fig. 1) on seven natural or artificial perches of differing diameters and textures, including rough, soft and slippery surfaces. Branches of three types of tree were tested, including one called a silk floss (*Ceiba speciosa*), found in the birds' natural habitat.

To independently monitor the front and rear of the landing surface of a perch, the authors designed split perches so that each half was anchored separately to a force and torque sensor that recorded the timing and features of the landing force and the rotational force experienced by the birds; both forces are influenced by the landing approach. The authors also measured the squeezing forces produced by the birds' feet and claws on landing. Combining these measurements with close-up, high-speed video recordings of the landing movements of the bird's wings, body, legs, feet and claws provided detailed information about the landing events associated with achieving a stable perch (see videos from the paper at go.nature.com/2nbfhtq and go.nature.com/2perfs9).

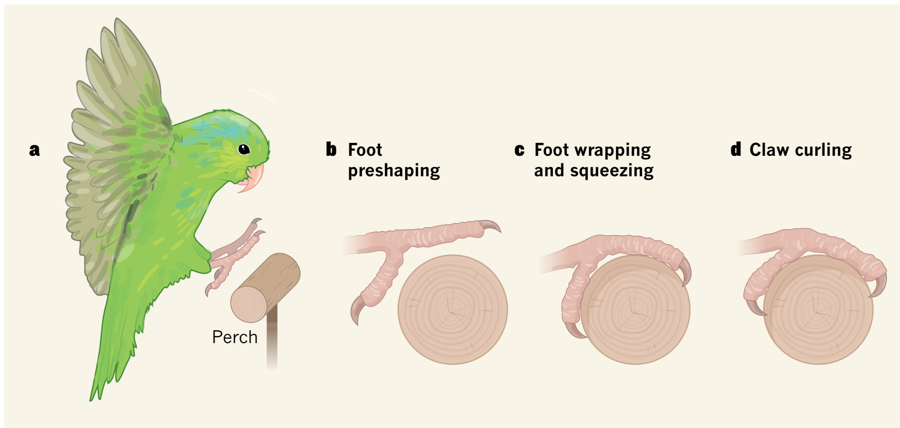

Figure 1 | How a Pacific parrotlet (*Forpus coelestis*) lands stably on a perch. Roderick *et al.*[6] analysed perching using methods to assess the forces that a bird encounters during landing, and by studying high-speed video recordings. **a**, When a bird is about to land, its wings, body and legs are positioned in the same, predictable way, consistent with earlier work[8,9] suggesting that birds use visual cues to position themselves for landing. At this stage, the bird's toes and claws are outstretched. **b**, When the bird is on the verge of making direct contact with the perch, its toes begin to close, in an event described as preshaping. **c**, When the bird's toes make contact with the perch, they wrap around it and squeeze it. **d**, The claws then begin to curl. This event can be superfast (1–2 milliseconds) if the perch surface is slippery.

The authors report that the birds approached their landing on any given perch in a consistent fashion in terms of the movements of their wings and legs, with the landing and rotational forces varying uniformly over the time frame of each landing process. Such a landing strategy is consistent with earlier work[8,9] indicating that birds and insects approach a landing target using visual cues to accurately position their body appropriately for the estimated time when they will make contact with the landing surface.

This initial predictive phase of landing is followed by a rapid adjustment phase. It probably involves what is termed proprioceptive feedback from sensors in the bird's skin, muscles and joints, and communication with the nervous system, as the bird squeezes the perch, dragging its toe pads and claws across the perch's surface to achieve a stable grasp. Using laser scans and indentation tests to assess changes in the properties of the perch surface, Roderick and colleagues could relate the friction experienced by the birds' toes and claws to the animals' gripping movements, and showed how the movements of the bird's claws are adjusted to anchor the claws to perches of differing diameters and surface features.

The birds curled their claws more on perch surfaces that were difficult to grasp, such as those of large diameter or that generated low friction on landing, than on easier perches. During this grasping phase, the friction forces experienced by the toes (which are fairly consistent for a given perch type) are subsequently reinforced and are accompanied by less predictable, but higher gripping forces exerted on the perch surface by the claw tip. This strategy provides a stable safety margin for gripping the perch that is comparable to analogous safety margins achieved by snakes[10] and robots[11], and is greater than the safety margins used by humans to grasp small objects[12]. Once stabilized on the perch, birds relax their grip, avoiding the unnecessary continued energy cost of muscle activation.

A limitation of Roderick and colleagues' work is that it did not investigate the role of the nervous system in controlling how gripping establishes a stable landing. The authors report superfast (1–2 milliseconds) initial anchoring movements of the claws, which suggests that these might be rapid, intrinsic, elastic mechanisms that do not involve neural control. However, these superfast movements are followed by longer-lasting adjustments in toe and claw movements that probably help to establish the stable grasp allowing birds to then relax their grip. These slower adjustments probably require proprioceptive feedback through the nervous system. Such feedback control could be evaluated by recording muscle activation and force patterns over the course of landing and perching. Inhibiting the activity of the mechanosensory receptors in a bird's toe pads with an anaesthetic would offer a way to determine whether the loss of sensory feedback from toe pads affects these foot movements and the bird's landing ability.

The landing flights in this study were short and were made between perches on the same horizontal level. However, Pacific parrotlets probably fly to perches above or below the animal's current location when foraging. It would therefore be interesting to examine whether body orientation and landing forces vary depending on the trajectory of landing flights. Perhaps such flights might show less consistent patterns in the early stages of the landing process than were found by the authors. Nevertheless, Roderick and colleagues' detailed biomechanical analysis provides an important road map for future work on how feet, toes and claws enable animals to grip surfaces stably. ■

Andrew A. Biewener *is in the Department of Organismic and Evolutionary Biology, Harvard University, Massachusetts 01730, USA.*
e-mail: abiewener@oeb.harvard.edu

1. Cory, R. & Tedrake, R. in *AIAA Guidance, Navigation and Control Conf. Exhibit* https://doi.org/10.2514/6.2008-7256 (2008).
2. Pope, M. T. & Cutkosky, M. R. in *Biomimetic and Biohybrid Systems* (eds Lepora, N. F. *et al.*) 288–296 (Springer, 2016).
3. Kalantari, A., Mahajan, K., Ruffatto, D. & Spenko, M. in *2015 IEEE Int. Conf. Robot. Automation* 4669–4674 (IEEE, 2015).
4. Desbiens, A. L., Asbeck, A. T. & Cutkosky, M. R. *Int. J. Robot. Res.* **30**, 355–370 (2011).
5. Tennekes, H. *The Simple Science of Flight: From Insects to Jumbo Jets* (MIT Press, 2009).
6. Roderick, W. R. T., Chin, D. D., Cutkosky, M. R. & Lentink, D. *eLife* **8**, e46415 (2019).
7. Sustaita, D. *et al. Biol. Rev.* **88**, 380–405 (2013).
8. Lee, D. N., Davies, M. N. O., Green, P. R. & Van Der Weel, F. R. *J. Exp. Biol.* **180**, 85–104 (1993).
9. Wagner, H. *Nature* **297**, 147–148 (1982).
10. Byrnes, G. & Jayne, B. C. *Biol. Lett.* **10**, 20140434 (2014).
11. Estrada, M. A., Hawkes, E. W., Christensen, D. L. & Cutkosky, M. R. *2014 IEEE Int. Conf. Robot. Automation* 4215–4221 (IEEE, 2014).
12. Westling, G. & Johansson, R. S. *Exp. Brain Res.* **53**, 277–284 (1984).

MICROFLUIDICS

Dissolving without mixing

Microfluidic devices have revolutionized biological assays, but complex set-ups are required to prevent the unwanted mixing of reagents in the liquid samples being analysed. A simpler solution has just been found. SEE LETTER P.228

ROBERT HOŁYST & PIOTR GARSTECKI

On page 228, Gökçe *et al.*[1] report a clever solution to a fundamental problem in microfluidics: a simple and inexpensive method for delivering a liquid to multiple dried reagents that doesn't mix all the reagents together. By considering diffusion, convection (the flow along a channel) and capillary forces, the authors designed a microfluidic structure that produces a complicated, yet highly reproducible, liquid flow that first passes around dried spots of reagents and then back over them. This dissolves the dried reagents, but minimizes unwanted dispersal within the flow.

The 1990s saw an explosion of interest in microfluidics, driven by a vision of liquid-handling systems that were faster, simpler and smaller than existing devices being used in chemistry and biology. The fluid dynamics of liquids in microfluidic channels is fascinating: streams of distinct liquids typically flow side by side without turbulence or mixing[2], unlike liquid flows at larger scales. Convection in these systems can be tuned to rates similar to those of diffusion, which opens up a way to control the concentration gradients of chemical reagents across parallel streams. Surprisingly, it was also found that the flow of immisicible liquids, which involves highly complex surface-tension forces, produces regular patterns of equally sized microdroplets in microchannels[3].

The ratio of the surface area of a microchannel-confined liquid (that is, the surface area bounded by the channel walls) to its volume is large, allowing heat and mass to be rapidly transferred to such liquids. Moreover, the flow of the liquid can be tightly controlled. Taken together, these features make microfluidics devices a useful platform for studying chemical reactions and biological processes. For example, miniature water droplets suspended in an oily continuous phase in microchannels can be used as reactors for chemical or biological processes.

The advent of microfluidics and droplet technologies led to breakthroughs in the life sciences. For example, these technologies have enabled digital assays[4] that can measure the concentration of specific genes in a sample without calibration. They are also key to the single-cell genetic-sequencing techniques[5] currently used in the Human Cell Atlas, a project that aims to characterize every cell type in the human body[6]. Furthermore, microfluidics technologies are powering a wave of new point-of-care systems that bring diagnostic assays closer to the patient's bedside[7].

But a fundamental problem remains. In most applications, the microfluidic assay must run multiple analytical reactions on the same liquid sample. Each reaction requires a different reagent, which is dried and pre-stored on the cartridge before the sample is added. These reagents should not mix with each other, because this would ruin the assay. But mixing is hard to avoid once the sample has been added, because of dispersion effects in the liquid. Several solutions to this problem have been proposed, always involving two steps — one to deliver the sample to the reagents, and the other to isolate the microchambers in which the reagents are stored from each other. The second step typically either uses an immiscible liquid as a barrier, or the microchambers are enclosed by solid walls, but either option complicates the design, manufacturing and use of these systems.

Gökçe *et al.* have tackled the problem in a much simpler way. They prepared a straight section of channel that is divided into two along its length by a shallow barrier, and deposited dried spots of reagents in one of the resulting halves (Fig. 1). They then introduced a sample liquid so that it filled the other half of the channel, before changing direction to bend around the end of the barrier and fill the portion of the channel containing the dried spots. Once the whole channel has been filled, the resulting solution of reagents is released through a valve so that it can enter the next section of the microfluidic system. This produces a solution that has an approximately uniform concentration of reagents throughout