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PRACTICAL TOOLS

HawkEar: A bird-borne visual and acoustic platform for eavesdropping the behaviour of mobile animals

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Abstract

1. Unoccupied aerial vehicles (UAVs; drones) offer mobile platforms for ecological investigation, but can be impractical in some environments and the resulting noise can disturb wildlife.
2. We developed a mobile alternative using a bird-borne platform to record the behaviour of other animals in the field. This unit consists of a lightweight audio and video sensor that is carried by a trained Harris's hawk *Parabuteo unicinctus*.
3. We tested the hypothesis that our bird-borne platform is a viable option for collecting behavioural data from mobile animals. We recorded acoustic and video data as the hawk flew through a dense group of Brazilian free-tailed bats *Tadarida brasiliensis* emerging from a cave, with a test case of investigating how echolocation calls change depending on spatial position in the bat group.
4. The HawkEar platform is an alternative for collecting behavioural data when a mobile platform that is less noisy and restrictive than traditional UAVs is needed. The design and software are open source and can be modified to accommodate additional sensor needs.

KEYWORDS
animal-borne tag, bats, collective behaviour, falconry, hawk, silent monitoring system, UAV

1 | INTRODUCTION

As technology becomes smaller, more affordable and increasingly powerful, its applications to wildlife monitoring continue to expand, leading to new insights into animal population sizes, distribution and migration (McGowan et al., 2017; Wang et al., 2019). For example, passive acoustic sensing can reveal the occurrence and behaviour of cryptic animals, quantify biodiversity, estimate population density and detect illegal hunting or logging (Gibb et al., 2019; Hill et al., 2018; Katsis et al., 2022; Kloepper et al., 2016; Marques et al., 2013), and camera traps can monitor wildlife health, highlight inter- and intra-species interactions and behaviour, and estimate population size and density (Keim et al., 2019; O'Connell et al., 2011; Preti et al., 2021; Smith et al., 2020). Over the past decade, unoccupied aerial vehicles (UAVs, also called drones) have increased in popularity as a mobile alternative for both ecological and behavioural investigation (Corcoran et al., 2021; Fu et al., 2018; Han et al., 2015; Wang et al., 2019). By equipping drones with cameras, acoustic sensors and sample collection devices (Kloepper & Kinniry, 2018; Madden et al., 2022; Pirotta et al., 2017; Shelare et al., 2021), fine-scale data can be remotely gathered from a specific region of interest, reducing both the risk to the human investigator and disturbance to species. Despite the advantages of UAV mobility, one concern is the noise of the device, which can impact both humans and wildlife (Schad & Fischer, 2022; Schäffer et al., 2021; Wich et al., 2021). The noise of a UAV can vary greatly according to type, size, number of rotors, payload and flyover speed (Ramos-Romero et al., 2023; Schäffer et al., 2021), with even fixed-wing UAVs generating noise (Harvey & O'Young, 2018), making it challenging to both predict animal response to UAV flights (Mo & Bonatakis, 2022), control for changes in background noise for acoustic experiments and capture the natural (i.e. non-disturbed) behaviour of wild animals.

A potential solution to the noise problem with UAVs is to explore alternative, quieter mobile platforms for recording animal behaviour. Many species of raptors have evolved quiet or even silent flight to aid in prey capture (Clark et al., 2020), so here we explore the use of a trained raptor to carry acoustic and visual sensors safely and quietly through a group of mobile animals, using echolocating bats as a test case. Falconry has been developed and practiced across different cultures worldwide for thousands of years (Epstein, 1943; Kenward, 2009) and is considered an Intangible Cultural Heritage of Humanity (UNESCO, 2024). In the United States, falconry is regulated at the federal (Falconry Standards and Falconry Permitting, 2008) and state level. Practitioners must pass a detailed examination, pass a state-mandated equipment and facilities inspection and serve a two-year apprenticeship under a mentor. Despite its long history, falconry and the use of falconry techniques have yet to be considered as an alternative mobile platform for research, excepting cases where the raptor itself forms the subject of study (Brighton et al., 2017, 2021; Kane et al., 2015; Kane & Zamani, 2014). For scientific research purposes, falconry techniques may be used in the training of raptors, capitalizing on their predatory nature to observe behaviours of animals or across landscapes that may be impossible to observe otherwise.

Motivated by the need for a mobile and less noisy sensor platform than a UAV, we developed a multimodal (video and acoustic) bird-borne platform for recording the behaviour of wild animals. Here, we report on the electronic components of the sensor and regulatory and ethical considerations for falconry. We also demonstrate a case-study using our platform to record the behaviour of bats undergoing collective motion.

2 | METHODS

2.1 | Falconry and animal care

For this project, a captive-bred female Harris's hawk *Parabuteo unicinctus* was purchased from a breeder and trained using standard falconry practices. Our female Harris's hawk weighed ~900 g, and in line with the standard ethical convention that temporary added payloads should not exceed 5% of body weight (Fair & Jones, 2010), this gave us a target payload of <45 g. The hawk was trained to fly between two people over a distance of 50–100 m using a variable food reward schedule (Pryor, 2019) to maximize the number and frequency of the point-to-point flights.

2.2 | Onboard recording unit

The onboard recording unit consisted of a 4k video sensor (4K WIFI Hidden Camera, MateCam, Huizhou City, China), an ultrasonic recording microphone (Knowles SiSonic MEMS Microphone, Itasca, IL, USA), a PIC32 microcontroller (Mouser Electronics, Mansfield, TX, USA) and custom-printed housing. The complete unit weighed 43.4 g with dimensions of 75 × 30 × 20 mm for the back unit and 40 × 40 × 11 mm for the head unit and was designed to be worn with the microphone and camera on the head of the hawk while most of the weight (battery, microcontroller, microSD card) was carried on the back of the hawk. Figure 1a shows an overview to the onboard unit electronics.

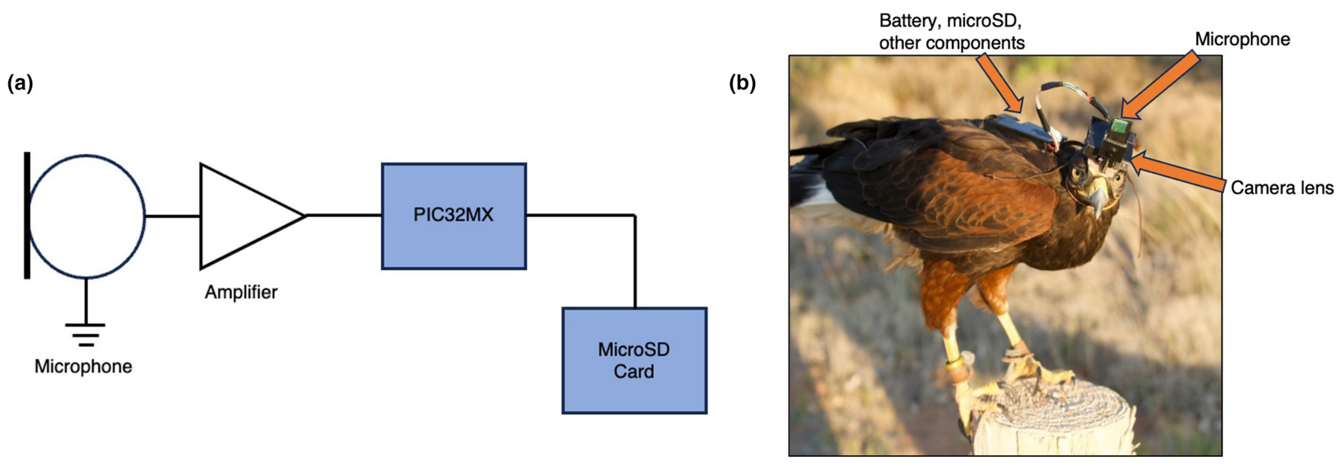

FIGURE 1 Details of the HawkEar unit. (a) Block diagram of the components for the audio and video recording, (b) image of the assembled unit as carried by the trained Harris hawk.

The audio sensor had a flat frequency response between 10 and 100 kHz and was AC coupled into an amplifier (AD8338, Analog Devices, Wilmington, MA) with programmable gain control. The coupling capacitors at the input and output to the chip are designed to be a first-order bandpass filter from 10 to 100 kHz, which allows for live annotation of the recordings using human speech and/or clap signals. Given the manufacturer specifications of our components, the gain settings used during deployment, and assuming bats are echolocating between 100 and 120 dB re: 20 μPa at 0.1 m (Jakobsen et al., 2013) in an environment with no background noise, our platform should be capable of detecting bats up to approximately 25 m distance. HawkEar board designs, code and details on construction and programming can be found in the data repository (Kloepper et al., 2024).

The video sensor was modified from an off-the-shelf camera in which we removed WIFI and battery components to reduce weight and wired to receive power from the same battery controlling the audio recordings. Besides these alterations, the camera was used with the original manufacturer components and design, recording onto a separate microSD card from the audio unit.

The back unit was powered by a 3.7 V, 40 mAh battery with a MOLEX connector (Molex, Lisle, IL, USA), which was housed in a custom-printed case and attached to a TrackPack (Marshall Radio Telemetry, Salt Lake City, UT, USA). The head unit was designed to be attached using hook and loop fasteners to the hawk's custom-made leather hood. Figure 1b illustrates the completed unit attached to the hawk. The designs for the printed cases can also be found in the data repository (Kloepper et al., 2024).

2.3 | Field testing

Field testing of the unit occurred in July 2022 at the Jornada Caves, New Mexico, USA, which is a remote cave site located on private land with a cave housing approximately 600,000 Brazilian free-tailed bats (*Tadarida brasiliensis*) (Kloepper et al., 2016). The work was conducted under New Mexico Scientific Collecting Permit Authorization #3651, IACUC approval through the University of Cincinnati (2022), and a New Mexico Master-level falconry permit issued to P. Domski. The use of onboard instrumentation and falconry protocols was approved by the Animal Welfare and Ethical Review Board of the Department of Zoology, University of Oxford, in accordance with University policy on the use of protected animals for scientific research, permit no. APA/1/5/ZOO/NASPA. This work was considered not to pose any significant risk of causing pain, suffering, damage or lasting harm to the animals concerned. Field testing was approved by the University of Oxford's Animal Care and Ethical Review Committee in relation to its potential impact on wild animals. More information on specific animal husbandry along with field-specific welfare considerations can be found in the data repository (Kloepper et al., 2024).

The motivation for the field testing was to test two hypotheses: First, that the HawkEar can obtain relevant video and acoustic data from even dense aggregations of mobile species; and second, to test the hypothesis that that during operation, the HawkEar is quieter compared to a UAV. To collect these data, we flew the hawk through the bats during evening emergence from the cave. Once the bats emerged from the cave, they flew down the middle of a recessed canyon in a horizontal column, allowing the handlers to position themselves in such a way that the hawk flew from one side of the canyon to the other, with its flight path crossing that of the bat stream (Figure 2a). When a handler was present on either side of the canyon, the hawk was trained to fly from handler to handler; when only one handler was present the hawk flew across the canyon and circled back again through the column, landing back at its starting point. The position of the hawk relative to the column of bats was obtained from both the onboard video unit and from three fixed video cameras (Lumix DMC0FZ1000/2500, Panasonic Corporation, Osaka, Japan) positioned around the canyon edge. The video cameras and acoustic recorder were synchronized by clapping hands <1 m from the microphone and within view of all cameras. This provided an acoustic and visual marker that enabled us to synchronize all recorders to within 0.033 s of each other, corresponding to the inverse frame rate of our video cameras.

For each pass of the hawk, we used the monitoring cameras to identify periods in which the hawk was stationary (just prior to or after a flight) or flying but outside of the bat swarm and corresponding noise (just after flight takeoff or prior to landing), and extracted a 500 millisecond audio file from each period. We then calculated the total acoustic energy (in dB) within each audio file using Raven Pro v 1.6.5 (as described in Charif et al., 2010), and quantified the difference in energy between the stationary and flight time periods to determine how much the noise level increases when the HawkEar is in flight operation. Direct comparison of these results to a UAV is challenging because it is not feasible to fly a UAV into a dense column of emerging bats without risking high levels of mortality and/or avoidance, so for comparison, we used the data from a previous experiment in which bat echolocation signals during roost re-entry were captured by a UAV equipped with a thermal camera and ultrasonic microphone modified to reduce UAV noise by 11 dB to facilitate passive acoustic recording ('The Chirocopter', Fu et al., 2018). Similar to our procedure for the HawkEar, we quantified the increase in noise of the UAV during hovering operation compared to when it was stationary and rotors were turned off. We compared the increase in operation noise levels between the HawkEar and the UAV using an independent t-test with equal variances not assumed using SPSS v. 28.0.1.0 (IBM, Armonk, NY).

3 | RESULTS

We extracted 23 passes from the flights where the hawk flew through the centre of the bat column. An example spectrogram of calls recorded from the onboard microphone as the hawk flew through the column is found in Figure 3a, and an example frame from the onboard video camera is depicted in Figure 3b. Surprisingly,

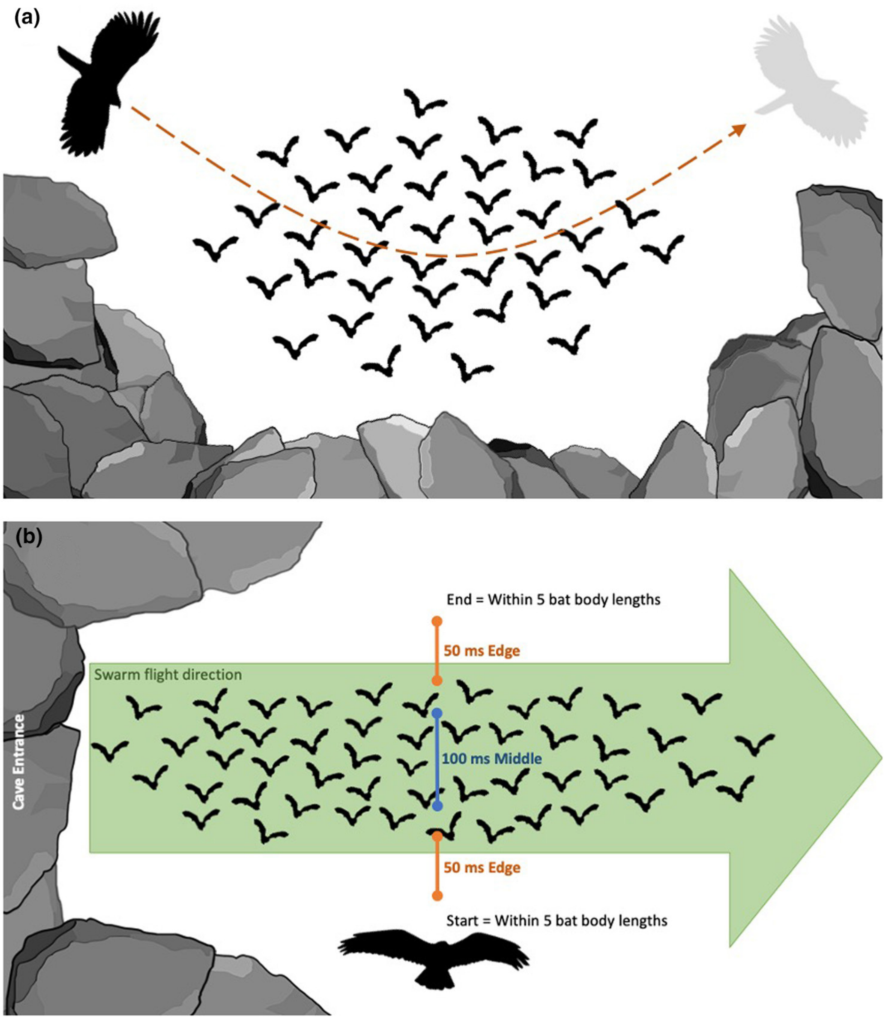

FIGURE 2 Illustration of the flight path of the hawk. (a) The hawk flew from one side of the canyon, dipping into the column of bats, either crossing the stream once or twice depending on number of handlers (see text). (b) As the hawk flew across the column, the HawkEar collected data from different spatial positions within the column.

in the presence of the hawk we observed no avoidance or change in flight behaviour by the bats, with some bats flying directly into the hawk.

While the hawk occasionally collided with the wings of the bats due to the density of the emerging column, the hawk appeared unaffected by the dense bat column and willingly flew through the column. From this cross-section of the swarm, we could examine questions prohibitive with drone flights such as how the swarm soundscape changes according to spatial position within the group (Figure 3c). During flight operation, the HawkEar was significantly quieter than the UAV, $t(39)=-12.013$, $p<0.001$, with the HawkEar increasing total acoustic energy by 0.078 ± 0.23 dB during flight and the UAV increasing by 6.34 ± 2.21 dB when in flight mode.

4 | DISCUSSION

We developed an onboard audio and video recording unit that is compact and lightweight enough to be carried by a hawk while significantly decreasing the noise of the platform compared to a UAV and retaining the functionality needed to acquire behavioural data. Our platform reduced noise by over 6 dB compared to The Chirocopter (Fu et al., 2018), but since the Chirocopter was modified to reduce reception of UAV noise by 11 dB, the equivalent reduction in flight operation noise of the HawkEar is closer to 17 dB. This reduction in noise can allow our platform to capture acoustic signals that may be otherwise masked by UAV noise and result in fewer negative impacts to wildlife that are typically disturbed by UAVs (Schad & Fischer, 2022; Wich et al., 2021). As a result, the HawkEar may be more likely to record the natural behaviour of a species compared to a UAV. Furthermore, because our platform involves a gliding bird as opposed to propellors that spin at thousands of rotations per minute, we captured audio and video data from the middle of a dense column of flying animals that would be otherwise prohibitive with a multirotor UAV.

We created this platform with a specific application in mind—recording the acoustic and flight behaviour of bats in dense groups—but with the underlying motivation of a need for a less-noisy alternative to a UAV that can record audio and video of mobile animals. With modification in raptor training, this system can be extended for many applications in which a mobile, quiet platform is needed. For example, although we trained our hawk to fly 50–100 m each time, raptors can easily be trained to fly longer distances. Raptors are not typically trained for a singular activity as in our experiment,

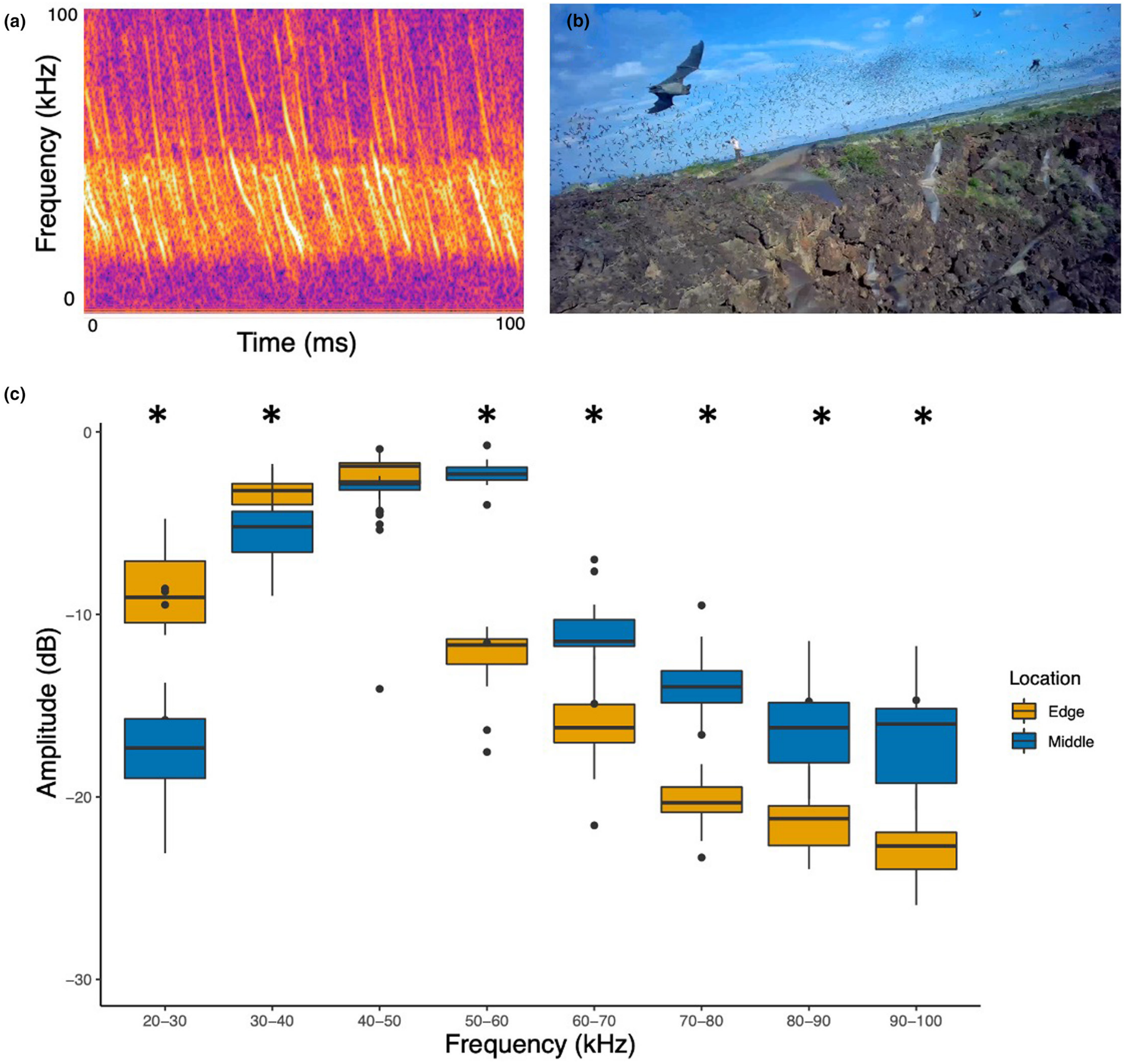

FIGURE 3 Example data recorded by the HawkEar unit. (a) Sample spectrogram recording from inside the column ('middle' condition), (b) sample video frame recorded from inside the column, (c) example of how the platform can obtain data previously inaccessible by UAVs, including examining changes in relative acoustic energy for different frequency bands according to spatial position in the group (edge versus middle of the column). Asterisks indicate statistically significant differences ($p < 0.05$) in Wilcoxon signed rank tests on paired samples.

but are instead trained worldwide for the sport of falconry which includes hunting and avian pest abatement. For many applications, in particular abatement, falconry activity must be performed from sunrise to sunset, and abatement falconers maintain multiple birds to carry out the work on rotation, with each bird flown for a limited duration depending on weather conditions. Scaling up this approach for scientific purposes can, therefore, be possible by using multiple birds in a similar fashion. With a scaled-up approach, potential use cases could include recording the antipredator behaviour of animals that are common prey of hawks and falcons, such as smaller birds (Griesser, 2008; Møller et al., 2015) or mammals (Hanson & Coss, 1997; Macedonia & Evans, 1993; Sherman, 1985). The same approach could also be used to make acoustic recordings in habitats that prohibit most UAV flights, such as acoustic biodiversity (Sueur et al., 2008) transects in dense forest canopies, across regions in controlled airspace in which UAV flight is prohibited (Stöcker et al., 2017) or in areas where dense population makes UAV flight a safety risk.

It is important to emphasize that we collaborated with a licensed falconer in experimental design and training from the inception of our project. By doing so, we ensured that our approach was ethical, feasible and manageable given the challenges of working with a live animal. Raptor propagation (breeding) and training is federally allowed in the United States (Falconry Standards and Falconry Permitting, 2008; Raptor Propagation Permits, 2011) and any applicant for a raptor propagation or training permit must have proper facilities, undergo random inspections, file annual reports and obtain state licensing, if applicable. Readers are encouraged to research country, state and/or institutional animal care procedures and guidelines, which applies both the scientific falcon and any target or incidental study species. Additional regulations may vary among countries. For example, in the United States, falconry can only be performed by a licensed falconer (North American Falconers Association, 2023), and there are restrictions against transporting raptors across state lines. Finally, the weight of the sensor relative to the bird should also be factored, with a combined sensor and harness not exceeding 5% of the raptor's weight (Fair & Jones, 2010). The weight guideline and biddability of a species should be primary factors in selecting which raptor to select for the platform.

In essence, our platform can be considered a form of bio-logging, similar to devices worn by animals to measure ecological or physiological data (Chung et al., 2021), including birds that carry devices to collect video data on behaviour of conspecifics (Michel et al., 2021; Tremblay et al., 2014; Troscianko & Rutz, 2015) or cyber-enhanced rescue canines (Ohno et al., 2019). One distinctive feature of our approach is that we designed a lightweight tag to collect both acoustic and video data. As electronics continue to be miniaturized, the potential for falconry to provide an alternative to UAV platforms may extend to a wider range of ecological investigations. Sensors, including thermal cameras, lidar, multi-spectral imagery and gas analysers, are currently used with UAVs for a wide array of investigations. These sensors could easily be modified into animal-borne tags suitable for falconry, as we provide our detailed sensor design and associated code found in the data repository (Kloepper et al., 2024).

We make no attempt to claim that the HawkEar can completely replace UAVs and must acknowledge some of the limitations with our approach. First, flying a raptor may not be feasible in all environments, especially for applications in which a pre-planned flight route or hovering is required. Second, the possibility exists that wild birds may mob the raptor, which would influence the ability of the HawkEar platform to collect unbiased data of species in their natural environment. Finally, as UAV technology continues to accelerate, it is our hope that soon we will have a quiet UAV with no spinning rotors, similar to a glider, that may make the need for alternative platforms obsolete and increase opportunities for mobile passive acoustic monitoring.

AUTHOR CONTRIBUTIONS

L. N. Kloepper and G. K. Taylor conceived of the ideas and designed the methodology in consultation with R. L. Stevenson and P. Domski. L. N. Kloepper, G. K. Taylor, R. L. Stevenson, P. Domski and D. Vanderelst collected the data; L. N. Kloepper and K. Eveland analysed the data and led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts to disclose.

DATA AVAILABILITY STATEMENT

Board and case designs, code to program and run the HawkEar, and acoustic data from field testing available via the Dryad Digital Repository https://doi.org/10.5061/dryad.cjsxksncc (Kloepper et al., 2024).

STATEMENT ON INCLUSION

We conducted our research in the United States, collaborating with authors from various disciplines and regions. All authors actively participated in the early stages of research and study design to ensure that the diverse range of perspectives they bring to the table were taken into account from the beginning.

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