Received: 6 October 2021 | Accepted: 30 November 2021

DOI: 10.1111/2041-210X.13789

Methods in Ecology and Evolution | BRITISH ECOLOGICAL SOCIETY

PRACTICAL TOOLS

BoomBox: An Automated Behavioural Response (ABR) camera trap module for wildlife playback experiments

Meredith S. Palmer[1] | Chris Wang[2] | Jacinta Plucinski[2] | Robert M. Pringle[1]

[1]Department of Ecology and Evolutionary Biology, Princeton University, Princeton, NJ, USA

[2]FreakLabs, Kamogawa, Japan

Correspondence
Meredith S. Palmer
Email: mspalmer@princeton.edu

Funding information
High Meadows Environmental Institute; Cameron Schrier Foundation; National Science Foundation, Grant/Award Number: DEB-1457697, IOS-1656527 and #1810586

Handling Editor: Miguel Acevedo

Abstract

1. Camera traps (CTs) are a valuable tool in ecological research, amassing large quantities of information on the behaviour of diverse wildlife communities. CTs are predominantly used as passive data loggers to gather observational data for correlational analyses. Integrating CTs into experimental studies, however, can enable rigorous testing of key hypotheses in animal behaviour and conservation biology that are otherwise difficult or impossible to evaluate.
2. We developed the 'BoomBox', an open-source Arduino-compatible board that attaches to commercially available CTs to form an Automated Behavioural Response (ABR) system. The modular unit connects directly to the CT's passive infrared (PIR) motion sensor, playing audio files over external speakers when the sensor is triggered. This creates a remote playback system that captures animal responses to specific cues, combining the benefits of camera trapping (e.g. continuous monitoring in remote locations, lack of human observers, large data volume) with the power of experimental manipulations (e.g. controlled perturbations for strong mechanistic inference).
3. Our system builds on previous ABR designs to provide a cheap (~100USD) and customizable field tool. We provide a practical guide detailing how to build and operate the BoomBox ABR system with suggestions for potential experimental designs that address a variety of questions in wildlife ecology. As proof-of-concept, we successfully field tested the BoomBox in two distinct field settings to study species interactions (predator–prey and predator–predator) and wildlife responses to conservation interventions.
4. This new tool allows researchers to conduct a unique suite of manipulative experiments on free-living species in complex environments, enhancing the ability to identify mechanistic drivers of species' behaviours and interactions in natural systems.

KEYWORDS
acoustic cues, animal behaviour, Arduino open-source development platform, Automated Behavioural Response system, behavioural ecology, camera trap modification, playback experiment, species interactions

1 | INTRODUCTION

Understanding how species interactions influence wildlife coexistence, space use and population dynamics is fundamental to behavioural, population and community ecology (Lima & Dill, 1990, Pringle et al., 2019; Werner & Peacor, 2003). Examining the ways these relationships change in response to anthropogenic pressures underlies numerous related questions in conservation biology (Gaynor et al., 2018; Suraci et al., 2019; Wilson et al., 2020). Yet, rigorously studying animal behaviour and species interactions in free-ranging wildlife populations can be prohibitively difficult, particularly if the environment is complex and hard for observers to navigate or if the focal species are small, rare, nocturnal, cryptic or sensitive to human presence (Brown et al., 2013; Hughey et al., 2018; Wearn & Glover-Kapfer, 2017).

Camera traps (CTs; also called trail cameras or remote cameras) are valuable tools in ecology and conservation, providing a non-invasive automated means of monitoring wildlife populations (Burton et al., 2015; O'Connell et al., 2010). These devices collect images or videos when triggered by the heat and/or motion of passing animals (Wearn & Glover-Kapfer, 2017) and operate continuously to gather data on diverse wildlife communities while minimizing potentially disruptive effects of direct human observation (Burton et al., 2015; Caravaggi et al., 2020). To date, CTs have been used overwhelmingly in a strictly observational context, providing valuable correlational inferences but not experimentally testing mechanisms that underlie species interactions and behavioural decisions (Caravaggi et al., 2020; Smith et al., 2020). Indeed, despite the crucial role of manipulations for mechanistic inference in ecology, experimental field studies have been a steadily shrinking fraction of the literature over the last 30 years (Anderson et al., 2021).

Playback experiments, performed by exposing focal animal(s) to a sensory (typically audio) cue and monitoring animals' subsequent response, are a powerful approach for investigating drivers of wildlife behaviour (Atkins et al., 2019; Falls, 1992; Suraci et al., 2019). This method has been used on a wide variety of taxa to study responses to potential predators (Hettena et al., 2014), competitors (Deecke, 2006; Suraci et al., 2016; Webster et al., 2012), mates (McComb et al., 1993; Pfefferle et al., 2008) and anthropogenic disturbance (Francis & Barber, 2013; McComb et al., 2014). A key drawback to playback experiments, however, is the necessity of having a human experimenter present. This can disrupt natural behaviours (Brown et al., 2013; Falls, 1992) and limit the types of animals that can be studied (Suraci et al., 2017). Logistical difficulties in amassing sufficient sample sizes for rare, cryptic animals have meant that such experiments are rarely used to study elusive or endangered species (Suraci et al., 2017; Suratissa, 2021).

Recently, an experimental design combining these two methods has been developed that provides the ability to directly manipulate and evaluate the behavioural responses of free-ranging animals (Suraci et al., 2017). The Automated Behavioural Response (ABR) system automatically deploys an audio cue when triggered by a remote CT, which then captures the animal's response to the stimulus. This approach combines the benefits of camera trapping with the power of experimental manipulations to provide data critical for establishing causal mechanisms. The ABR design can capture responses of multiple focal species to a set of cues and generate sufficient sample sizes to evaluate ecological hypotheses that would be untestable using standard methods (Suraci et al., 2017). This approach has been used to understand wildlife responses to anthropogenic disturbance (Smith et al., 2017) and explore species interactions (Epperly et al., 2021), with the potential for widespread application such as addressing questions of animal intelligence, interguild and intraguild interactions, and human–wildlife conflict (see Practical Guide for further discussion).

To facilitate such experiments, we present the 'BoomBox': a modular attachment for off-the-shelf CTs that allows the user to conduct novel ABR experiments using readily accessible CT technology. The BoomBox integrates the ABR directly with the camera's own passive infrared (PIR) sensor, creating a single trigger source that synchronizes audio cue and response recording. Variables including delay and duration of the cue can be programmed using freely available Arduino software, while volume, playlists and other settings can be adjusted dynamically in the field. We build upon previous designs to create open-source hardware built with low-cost commercially available components to maximize accessibility and minimize price (~100USD per unit). With their small size, modularity, durability and power efficiency, these devices are easy to transport and set up in the field and can operate continuously for months at a time. The BoomBox can easily be modified with additional sensors (e.g. motion, range, external PIR) to address a wide range of research questions. Code and hardware designs to tailor performance of the device to address project-specific issues (e.g. collecting additional metadata, broadcasting different cues day vs. night) are being curated as part of an active online support network (see 'Data Availability Statement').

Here, we provide a technical description of the device along with a supporting Practical Guide for constructing and deploying the BoomBox ABR. To demonstrate its potential to conduct experiments on a variety of species under a range of environmental conditions, we describe the successful deployment of the BoomBox in two distinct habitat types (open and wooded savannas) to study the responses of large herbivores (30–1,825 kg), mesocarnivores (6–20 kg), and primates (10–35 kg) to competitor and predator cues. We evaluate the quality of the resultant data and provide suggestions for maximizing BoomBox ABR performance under different scenarios.

2 | DESIGN AND ASSEMBLY

2.1 | Hardware

The BoomBox module contains a custom-built Arduino-based circuit board encased within protective weather-proof plastic housing (Figure 1; Table 1). The BoomBox attaches to the CT mainboard, interfacing with the CT's own PIR sensor. Incoming PIR sensor signals wake

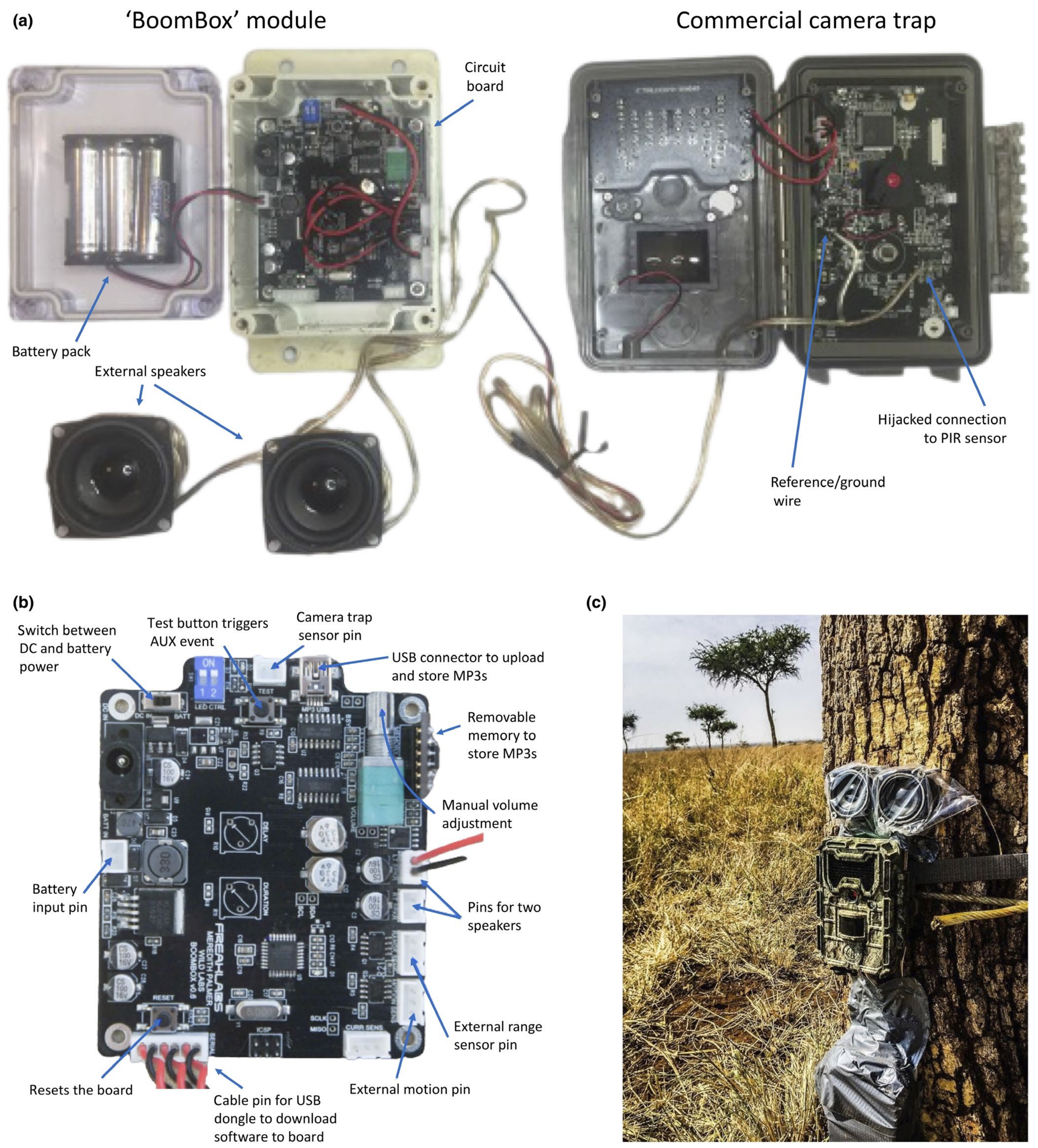

FIGURE 1 Overview of the BoomBox ABR. (a) The BoomBox module consists of a circuit board and battery pack encased in durable IP65 rated plastic housing. The BoomBox connects to two external speakers and to the PIR sensor on the circuit board of a commercial CT. (b) Design of the BoomBox circuit board. (c) BoomBox ABR deployed in the field (Grumeti Game Reserve, Tanzania)

up the camera to take pictures or video when motion is detected; connecting to this signal means that the playback is triggered directly by the CT itself (Video S1). The BoomBox can wake up within fractions of a millisecond and produce audio cues within ~3 milliseconds of being triggered. As commercial CTs tend to use identical or highly similar PIR processing chips, the BoomBox can be connected to most commonly used models. In the Supporting Information, we detail instructions for attaching the BoomBox to Bushnell (TrophyCam, Core Low Glow), Spypoint (Force-Dark), Browning (Strike Force Pro) and Reconyx (Hyperfire) CTs (Videos S2–S5).

Attached to the BoomBox are speakers that can be positioned at varying distances from the CT depending on the length of speaker wires

TABLE 1 BoomBox ABR (a) equipment, specifications and (b) component costs (USD, 2021). Note that total cost does not include equipment for manufacturing and assembly (e.g. PCB fabrication, soldering iron, solder, wire strippers)

(a) BoomBox ABR specifications	
Power consumption	0.8 mA in sleep mode
Audio format	MP3
Speakers	2-inch, 4 ohm, 5W speakers
Batteries	3× AA
Operating temperature range	0–70°C; 32–158°F
Amplifier	3W channel stereo amplifier IC PAM8403
MP3 decoder IC	YX6100
Enclosure	115 × 90 × 55 mm
Enclosure rating	IP65
	Dust-proof and rain-proof
Weight	500 g (without batteries); 575 g (with batteries)

(b) BoomBox ABR component costs	
Discrete components (resistors, capacitors, diodes)	$10.00
Connectors (JST, USB)	$4.00
Transistors	$2.00
Volume Knob	$2.00
Serial memory	$3.00
MP3 Decoder + Amplifier	$5.00
Microcontroller	$3.00
Power supply	$10.00
Enclosure	$10.00
Cable gland	$1.00
Cable harness	$6.00
Crimped wires	$3.00
Speakers	$10.00
USB programming interface	$5.00
Printed circuit board (PCB)	$2.00
Total	**$76.00**

used (Figure 1). The BoomBox circuit board incorporates an YX6100 MP3 integrated circuit binary decoder. The output of the MP3 decoder travels to a stereo amplifier that generates a maximum of 3W to each speaker channel, which represents a balance between loudness and the amount of power that can be supplied by 3 AA batteries. Circuit board designs and block diagrams are provided in the Supporting Information.

The MP3 decoder interfaces with a 16-MB memory chip (similar to a microSD) that can be pre-programmed with audio playlists and easily exchanged in the field. The number of audio files the chip can hold depends on their length and quality, but on average, 15 min of MP3 audio is supported. Each time the BoomBox is triggered, a single audio file is played; through subsequent trigger events, MP3s in the playlist are cycled through sequentially or randomly. The decibel level of the playback can be manually adjusted using a tuning dial on the circuit board (Figure 1).

A battery pack (3 AA) is encased within the plastic housing. To extend field longevity, we optimized the system to use minimal power when the camera is not being triggered. The BoomBox consumes 0.8 mA in sleep mode, 38 mA when idle, and up to 1 A when active. Depending on the frequency of triggers, batteries last 1.5–3.5 months (see 3. Field Testing).

The CT can be programmed to video-record animal responses to playbacks according to the manufacturer directions. Depending on the make and model, video length can be set between 10 and 120 s. If other CT brands are used, we advise users to ensure that the specific model captures audio as part of video recording to verify that the ABR was successfully triggered. Users can define 'idle' or 'quiet' periods on most CTs such that repeated triggers within a short amount of time do not trigger repeated captures (e.g. to prevent collecting data on individual(s) remaining in front of the CT for extended periods). This same idle period can be defined in the BoomBox (see below) such that audio is only produced when the CT is set to record.

2.2 | Software

The BoomBox is programmed using Arduino IDE (Integrated Development Environment), an open-source software development platform (v.1.8.13; https://www.arduino.cc/en/software/). We created custom libraries and sketches (programs), available at https://github.com/freaklabs/BoomBox. The main sketch keeps the system asleep until triggered by the PIR sensor, upon which the system wakes up, plays an MP3 and returns to sleep. Here, users define parameters, including the number of audio files on each memory chip, video length, and idle period between trigger events, and choose to use random or sequential playlists. Users also set the latency between when the PIR sensor is triggered and the audio cue is played (either instantly or allowing baseline animal activity to be captured before cue exposure). The test sketch ensures that the hardware is working and the device has been assembled correctly. Information on uploading sketches and troubleshooting code can be found in the Practical Guide.

2.3 | Cost

We relied on inexpensive, commonly available electronic components. For example, we used a low-cost MP3 decoder designed for interactive toys and a stereo audio amplifier made for Bluetooth speakers. This reduces the cost of the overall module while ensuring that the necessary components are widely accessible (Table 1b).

3 | FIELD TESTING

3.1 | Test locations

We tested the BoomBox in two field settings, Grumeti Game Reserve in Tanzania (open savanna) and Gorongosa National Park in Mozambique (woodland savanna). These deployments aimed to examine behavioural responses of large mammalian herbivores, mesocarnivores, and primates to extant and reintroduced predators. BoomBoxes were active from August to October 2019 and June to August 2021 in Grumeti and Gorongosa, respectively. Full site and project descriptions can be found in the Supporting Methods.

3.2 | Setup

We used Bushnell Trophy Cams (HD Aggressor Model 119877B), attached to trees or posts at a height of 0.5–1.0 m facing open areas or animal trails (Figure 1c). The BoomBox module was secured at the base of the supporting structure. Speakers were positioned near the CT to direct animal attention to the camera for behavioural response recording. Ten-second audio cues of predator or bird (control) vocalizations were programmed to play immediately when triggered (0s delay). Playbacks were field adjusted to broadcast at a consistent peak sound pressure level of 80 dB at 1 m as measured by the Arduino Science Journal iPhone application and cycled sequentially through a pre-randomized playlist after each trigger event. Videos were 30 s long with a 1-min idle period. See Supporting Methods for full methodology.

3.3 | Success metrics

Following Suraci et al. (2017), we calculated (a) *proportion triggered*—proportion of video recordings where the audio triggered as programmed (i.e. with correct delays); (b) *proportion observable*—proportion of successful triggers where animal responses are discernible and (c) *overall success rate*—proportion of trials where the playback was successful and behavioural data could be collected. We recorded any issues that arose during field deployment, including scenarios that resulted in playback or camera failure.

4 | RESULTS

We recorded thousands of ABR videos of focal species (Table S1; Videos S6–S11). Across both sites, we gathered an average of 24.6 'successful' captures/ABR/week (range: 0–97.3 captures/ABR/week). Footage was obtained of 41 species (33 in Grumeti, 25 in Gorongosa), representing 76% and 81%, respectively, of terrestrial mammals >2 kg that occur at each site (Figure 2; Table S1). Only the smallest and rarest species in each system were not captured during our sampling periods.

In 80.3% and 91.7% of cases for Grumeti and Gorongosa, respectively, audio was triggered as programmed. Failures resulted entirely from human error, specifically, mismatch between the length of 'idle period' programmed into the CT versus the BoomBox. Behavioural responses were observable in 87.3% (Grumeti) and 95.2% (Gorongosa) of the successful trials. Undiscernible cases included far-off nighttime captures where only eyeshine was visible or situations where animals were so close to the camera that only small portions of their bodies were observable. Overall success rate was therefore 70.1% and 87.3% for each site, respectively, with the caveat that the number of usable trials could be improved by first deploying a 'pilot period' to optimize device settings (Section 4.1).

4.1 | Lessons learned

We recommend using the first week of each deployment to adjust PIR sensitivity, video quality and length, and sound settings to maximize

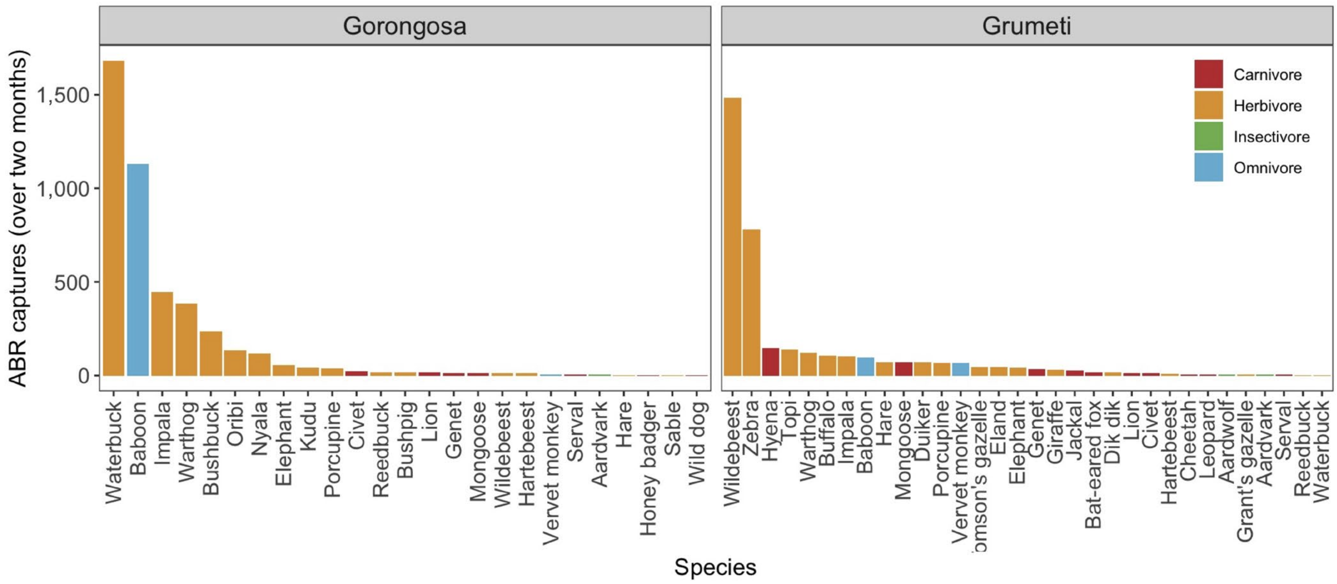

FIGURE 2 Successful ABR captures by species over the 2-month pilot deployments at Gorongosa National Park and Grumeti Game Reserve. Species are color-coded by trophic guild

longevity without sacrificing data quantity or quality. At both test locations, lower sensitivity and longer delays between triggers prevented SD cards from filling up on misfires (e.g. moving vegetation) and repeated triggers of the same animal(s). These settings may also help reduce animal habituation to audio cues. The lowest video quality (640 × 360 pixels/frame) was sufficient to quantify behavioural responses of greatest interest to most ecologists (e.g. flight, inspection, vigilance, bunching). In >85% of cases, these responses could be captured in ≤30 s. After optimization, the BoomBox ABR could perform >300 trials (~4 weeks) before requiring new batteries. The devices proved robust to dirt, heavy rains, insect infestation and high temperatures (27–32°C). For suggestions on experimental design and deployment strategies, see Practical Guide.

5 | DISCUSSION

ABRs enable robust inferences about free-ranging animals' responses to stimuli that simulate ecologically meaningful phenomena, such as the presence of potential predators. Overall, the BoomBoxes generated sufficient sample sizes (in many cases, >100 trials/treatment for focal species; Table S1) for powerful statistical hypothesis testing. In addition, they enabled the study of rare and cryptic species (e.g. African wild dog *Lycaon pictus*, aardvark *Orycteropus afer*; Videos S12 and S13). Features including cue playlists, sound levels, delay between trigger event and cue production, and cue length can be manually adjusted and adapted with software, creating the flexibility to tailor and reuse the unit for a variety of experimental designs. The device's low cost (Table 1) makes this method accessible to students, researchers and conservationists with modest budgets.

BoomBoxes operated with high success across habitat types, surviving a gauntlet of rugged field conditions. With CT usage increasing in ecosystems worldwide (Burton et al., 2015), our findings suggest that the BoomBox could be deployed widely to study terrestrial vertebrate species. While other remote playback recording devices exist that are triggered by animal-borne devices or cues generated by specific taxa (e.g. triggered by RFID detectors: Lendvai et al., 2015; Rafiq et al., 2021, VHF transmitters: Gottwald et al., 2021, ultrasonic bat calls: Gottwald et al., 2021)—which represent key advantages under specific circumstances—another significant benefit of CT-playback integration is that multiple individuals and species can be studied during a single deployment without needing to invasively capture and tag animals. We note, however, that the same limitations that exist for CTs exist for the BoomBox (e.g. animals that are larger or warm blooded are more likely to trigger the camera) given that the CT PIR sensor is used to trigger both devices. Similarly, as with any playback experiment, animals may become habituated to repeated cue exposure and, as such, we recommend keeping experiment duration short. For instance, we did not notice herbivore habituation over a period of 2 months, but future studies may wish to quantify habituation effects to pinpoint optimal experiment duration.

There are numerous questions in ecology and conservation biology that can be tested with ABRs, such as how animals respond to conspecifics, novel stimuli or human activity (see Practical Guide for in-depth discussion of potential questions and experimental scenarios). BoomBoxes can be deployed at areas of special interest, such as at waterholes or carcasses, to understand interactions at important resources. They can also be paired with other methods, such as CT surveys, weather stations or biologgers, to contextualize how the environment or individual condition modulates behavioural decision-making. For some purposes, these devices could be baited or otherwise positioned to maximize detection (Suraci et al., 2017).

5.1 | Future developments

We aim to continuously improve the BoomBox based on user needs and feedback. To enhance basic functionality, we are currently updating the hardware, with a larger enclosure, more batteries, a realtime clock, and microSD cards, and the software, to enable longer device life and collection of additional metadata. Special user-requested modifications are also under development, including separate daytime/nighttime playlists and wireless speakers that can be placed within the environment to produce directional cues. We are performing pilot studies to expand the number of commercial CTs compatible with the BoomBox and to enable the circuit board to connect to a wider variety of sensors and peripheral devices (e.g. temperature, humidity, audio). These updates will expand the functionality of the BoomBox to suit a wider range of research needs. A larger goal of the BoomBox project is to create a platform that will cause a CT capture to trigger additional events beyond audio playback, such as collecting environmental data, starting a lighting pattern or actuating a device like a valve or a motor. For example, 'BoomBox Disco' generates loud noises and flashing lights when elephants and bushpigs are detected to scare them away from community crops (piloted in Odzala-Kokoua Park, Congo). We hope that by releasing our design open source, we will stimulate other modifications of this device to suit a wide variety of purposes.

ACKNOWLEDGEMENTS

We thank Scientific Services at Grumeti and Gorongosa for research permissions and field support. We are grateful to S. O'Donnell and the WILDLABS.NET community for facilitating this collaboration. Research was funded by the National Science Foundation (PRFB-1810586, IOS-1656527, DEB-1457697), the Cameron Schrier Foundation and the High Meadows Environmental Institute at Princeton University.

CONFLICT OF INTEREST

Prefabricated BoomBox boards/kits can be obtained from FreakLabs (owned by J.P. and C.W.). However, all information necessary to independently construct the hardware and software is provided in Data Availability and Supporting Information.

AUTHORS' CONTRIBUTIONS

M.S.P. and R.M.P. conceived the idea; J.P. and C.W. designed the hardware and software; M.S.P. collected and analysed the data and led the manuscript writing. All authors contributed critically to drafts.

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1111/2041-210X.13789.

DATA AVAILABILITY STATEMENT

The Practical Guide for constructing and deploying the BoomBox can be downloaded from https://freaklabs.org/technology/boombox. Hardware designs, Arduino libraries and sketches can be accessed at https://github.com/freaklabs/BoomBox and in the Zenodo Repository (Palmer et al., 2021).

ORCID

Meredith S. Palmer https://orcid.org/0000-0002-1416-1732
Robert M. Pringle https://orcid.org/0000-0001-7487-5393

REFERENCES

Anderson, S. C., Elsen, P. R., Hughes, B. B., Tonietto, R. K., Bletz, M. C., Gill, D. A., Holgerson, M. A., Kuebbing, S. E., McDonough MacKenzie, C., Meek, M. H., & Veríssimo, D. (2021). Trends in ecology and conservation over eight decades. *Frontiers in Ecology and the Environment*, *19*(5), 274–282. https://doi.org/10.1002/fee.2320

Atkins, J. L., Long, R. A., Pansu, J., Daskin, J. H., Potter, A. B., Stalmans, M. E., Tarnita, C. E., & Pringle, R. M. (2019). Cascading impacts of large-carnivore extirpation in an African ecosystem. *Science*, *364*(6436), 173–177.

Brown, D. D., Kays, R., Wikelski, M., Wilson, R., & Klimley, A. P. (2013). Observing the unwatchable through acceleration logging of animal behavior. *Animal Biotelemetry*, *1*(1), 1–16. https://doi.org/10.1186/2050-3385-1-20

Burton, A. C., Neilson, E., Moreira, D., Ladle, A., Steenweg, R., Fisher, J. T., Bayne, E., & Boutin, S. (2015). Wildlife camera trapping: A review and recommendations for linking surveys to ecological processes. *Journal of Applied Ecology*, *52*(3), 675–685.

Caravaggi, A., Burton, A. C., Clark, D. A., Fisher, J. T., Grass, A., Green, S., Hobaiter, C., Hofmeester, T. R., Kalan, A. K., Rabaiotti, D., & Rivet, D. (2020). A review of factors to consider when using camera traps to study animal behavior to inform wildlife ecology and conservation. *Conservation Science and Practice*, *2*(8), e239. https://doi.org/10.1111/csp2.239

Deecke, V. B. (2006). Studying marine mammal cognition in the wild: A review of four decades of playback experiments. *Aquatic Mammals*, *32*(4), 461–482. https://doi.org/10.1578/AM.32.4.2006.461

Epperly, H. K., Clinchy, M., Zanette, L. Y., & McCeery, R. A. (2021). Fear of large carnivores is tied to ungulate habitat use: Evidence from a bifactorial experiment. *Scientific Reports*, *11*(1), 1–11.

Falls, J. B. (1992). Playback: A historical perspective. In P. K. McGregor (Ed.), *Playback and studies of animal communication* (pp. 11–33). Plenum Press.

Francis, C. D., & Barber, J. R. (2013). A framework for understanding noise impacts on wildlife: An urgent conservation priority. *Frontiers in Ecology and the Environment*, *11*(6), 305–313. https://doi.org/10.1890/120183

Gaynor, K. M., Hojnowski, C. E., Carter, N. H., & Brashares, J. S. (2018). The influence of human disturbance on wildlife nocturnality. *Science*, *360*(6394), 1232–1235.

Gottwald, J., Lampe, P., Höchst, J., Friess, N., Maier, J., Leister, L., Neumann, B., Richter, T., Freisleben, B., & Nauss, T. (2021). BatRack: An open-source multi-sensor device for wildlife research. *Methods in Ecology and Evolution*, *12*(10), 1867–1874. https://doi.org/10.1111/2041-210X.13672

Hettena, A. M., Munoz, N., & Blumstein, D. T. (2014). Prey responses to predator's sounds: A review and empirical study. *Ethology*, *120*(5), 427–452. https://doi.org/10.1111/eth.12219

Hughey, L. F., Hein, A. M., Strandburg-Peshkin, A., & Jensen, F. H. (2018). Challenges and solutions for studying collective animal behaviour in the wild. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *373*(1746), 20170005. https://doi.org/10.1098/rstb.2017.0005

Lendvai, A. Z., Akçay, Ç., Weiss, T., Haussmann, M. F., Moore, I. T., & Bonier, F. (2015). Low cost audiovisual playback and recording triggered by radio frequency identification using Raspberry Pi. *PeerJ*, *3*, e877. https://doi.org/10.7717/peerj.877

Lima, S. L., & Dill, L. M. (1990). Behavioral decisions made under the risk of predation: A review and prospectus. *Canadian Journal of Zoology*, *68*(4), 619–640. https://doi.org/10.1139/z90-092

McComb, K., Pusey, A., Packer, C., & Grinnell, J. (1993). Female lions can identify potentially infanticidal males from their roars. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *252*(1333), 59–64.

McComb, K., Shannon, G., Sayialel, K. N., & Moss, C. (2014). Elephants can determine ethnicity, gender, and age from acoustic cues in human voices. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(14), 5433–5438. https://doi.org/10.1073/pnas.1321543111

O'Connell, A. F., Nichols, J. D., & Karanth, K. U. (Eds.). (2010). *Camera traps in animal ecology: Methods and analyses*. Springer Science & Business Media.

Palmer, M. S., Wang, C., Plucinski, J., & Pringle, R. M. (2021). Data from: BoomBox: An Automated Behavioral Response (ABR) camera trap module for wildlife playback experiments. In Methods in Ecology and Evolution. *Zenodo*. https://doi.org/10.5281/zenodo.5745491

Pfefferle, D., Heistermann, M., Hodges, J. K., & Fischer, J. (2008). Male Barbary macaques eavesdrop on mating outcome: A playback study. *Animal Behaviour*, *75*(6), 1885–1891. https://doi.org/10.1016/j.anbehav.2007.12.003

Pringle, R. M., Kartzinel, T. R., Palmer, T. M., Thurman, T. J., Fox-Dobbs, K., Xu, C. C., Hutchinson, M. C., Coverdale, T. C., Daskin, J. H., Evangelista, D. A., Gotanda, K. M., Man in 't Veld, N. A., Wegener, J. E., Kolbe, J. J., Schoener, T. W., Spiller, D. A., Losos, J. B., & Barrett, R. D. (2019). Predator-induced collapse of niche structure and species coexistence. *Nature*, *570*(7759), 58–64.

Rafiq, K., Appleby, R. G., Edgar, J. P., Radford, C., Smith, B. P., Jordan, N. R., Dexter, C. E., Jones, D. N., Blacker, A. R. F., & Cochrane, M. (2021). WildWID: An open-source active RFID system for wildlife research. *Methods in Ecology and Evolution*, *12*(9), 1580–1587. https://doi.org/10.1111/2041-210X.13651

Smith, J. A., Suraci, J. P., Clinchy, M., Crawford, A., Roberts, D., Zanette, L. Y., & Wilmers, C. C. (2017). Fear of the human 'super predator' reduces feeding time in large carnivores. *Proceedings of the Royal Society B: Biological Sciences*, *284*(1857), 20170433. https://doi.org/10.1098/rspb.2017.0433

Smith, J. A., Suraci, J. P., Hunter, J. S., Gaynor, K. M., Keller, C. B., Palmer, M. S., Atkins, J. L., Castañeda, I., Cherry, M. J., Garvey, P. M., Huebner, S. E., Morin, D. J., Teckentrup, L., Weterings, M. J. A., & Beaudrot, L. (2020). Zooming in on mechanistic predator–prey ecology: Integrating camera traps with experimental methods to reveal the drivers of ecological interactions. *Journal of Animal Ecology*, *89*(9), 1997–2012. https://doi.org/10.1111/1365-2656.13264

Suraci, J. P., Clinchy, M., Dill, L. M., Roberts, D., & Zanette, L. Y. (2016). Fear of large carnivores causes a trophic cascade. *Nature Communications*, *7*(1), 1–7. https://doi.org/10.1038/ncomms10698

Suraci, J. P., Clinchy, M., Mugerwa, B., Delsey, M., Macdonald, D. W., Smith, J. A., Wilmers, C. C., & Zanette, L. Y. (2017). A new Automated Behavioural Response system to integrate playback experiments into camera trap studies. *Methods in Ecology and Evolution*, *8*(8), 957–964. https://doi.org/10.1111/2041-210X.12711

Suraci, J. P., Clinchy, M., Zanette, L. Y., & Wilmers, C. C. (2019). Fear of humans as apex predators has landscape-scale impacts from mountain lions to mice. *Ecology Letters*, *22*(10), 1578–1586. https://doi.org/10.1111/ele.13344

Suratissa, D. M. (2021). The falling out man and the wild-a review of influential factors, causes, impacts, and strategies for minimizing human-wildlife conflict. *Tropical Agricultural Research and Extension*, *24*(2). https://doi.org/10.4038/tare.v24i2.5527

Wearn, O. R., & Glover-Kapfer, P. (2017). Camera-trapping for conservation: A guide to best-practices. *WWF Conservation Technology Series*, *1*(1), 2019–2104.

Webster, H., McNutt, J. W., & McComb, K. (2012). African wild dogs as a fugitive species: Playback experiments investigate how wild dogs respond to their major competitors. *Ethology*, *118*(2), 147–156. https://doi.org/10.1111/j.1439-0310.2011.01992.x

Werner, E. E., & Peacor, S. D. (2003). A review of trait-mediated indirect interactions in ecological communities. *Ecology*, *84*(5), 1083–1100.

Wilson, M. W., Ridlon, A. D., Gaynor, K. M., Gaines, S. D., Stier, A. C., & Halpern, B. S. (2020). Ecological impacts of human-induced animal behaviour change. *Ecology Letters*, *23*(10), 1522–1536. https://doi.org/10.1111/ele.13571

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Palmer, M. S., Wang, C., Plucinski, J., & Pringle, R. M. (2021). BoomBox: An Automated Behavioural Response (ABR) camera trap module for wildlife playback experiments. *Methods in Ecology and Evolution*, 00, 1–8. https://doi.org/10.1111/2041-210X.13789