Applicant: [redacted]
Organisation: [redacted]
Funding Sought: **£13,829.80**
Funding Awarded: **£13,829.80**

# LRB18/1010

**Elephant Seismology: Linking noise, terrain and elephant behaviour**

For African elephants, the savannah terrain is more than a habitat. It is also a platform over which they send and receive information in the form of ground-based, or seismic, vibrations. They generate these vibrations in two ways. Their huge size means they generate vibrations through the ground every time they move around. But in addition, vibrations are caused by loud and low-pitched vocalisations made by the elephants. Both types of vibrations are modelled to propagate over the kilometre scale in the elephant's natural habitat.

Still, there are unanswered questions on how seismic information transfer is influenced by physical factors within the elephant's ecosystem, which this project aims to explore further. It will aim to answer several questions. Firstly, are some types of vibrations, like those generated by other elephants, more worthy of a response? How big does the ground motion have to be to get a response? How does human-generated noise, such as from cars, influence behavioural responses? And finally, does the type of physical terrain influence behavioural responses?

The proposed project aims to answer these questions by playing custom-generated seismic vibrations to wild elephants in the field in Kenya. It will monitor elephant responses to changing seismic vibration volume and type (e.g. mimicking elephant-generated vocalisation versus weight drop) over changing noise levels and terrains.

These questions are important for understanding how elephants interact with their environment and other animals in their ecosystem. For instance, if elephants are found to be highly sensitive to seismic vibrations, this opens up the possibility that they can communicate and gather information about the savannah ecosystem over long distances. This could include the possibility of finding a mate kilometres away, or detecting distant animal movements or rainfall.

Moreover, elephants may have preferred terrains to send or receive this information. [redacted]

These questions are also important for understanding how human noise pollution may affect elephants, reducing the range and scope of information transfer. This has implications for captive and wildlife management strategies, as well as captive elephant welfare.

## PRIMARY APPLICANT DETAILS

**Title** [redacted]
**Name** [redacted]
**Surname** [redacted]
**Organisation** [redacted]
**Tel (Work)** [redacted]
**Email (Work)** [redacted]
**Address** [redacted]
[redacted]

## CONTACT DETAILS

**Name** [redacted]
**Surname** [redacted]
**Email (Work)** [redacted]

## CONTACT DETAILS

**Name** [redacted]
**Surname** [redacted]
**Email (Work)** [redacted]

# Section 1 - Your Part A Application

**Employment History**

**Please note if you do not know the exact day, select the 1st day of the month e.g. March 2005: 01/03/2005**

| Start Date | End Date | Position | Organisation | Additional Info |
|---|---|---|---|---|
| [redacted] | [redacted] | [redacted] | [redacted] | *No Response* |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| *No Response* | *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* | *No Response* |

**Please specify:**

*No Response*

**Education History**

**Please note if you do not know the exact day, select the 1st day of the month e.g. March 2005: 01/03/2005**

| Start Date | End Date | Qualification | Organisation | Additional Info |
|---|---|---|---|---|
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | *No Response* |

| | | | | |
|---|---|---|---|---|
| *No Response* | *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* | *No Response* |

**Research Grants/Fellowships Awarded**

| Date | Details | Amount Awarded (£) | Additional Info |
|---|---|---|---|
| July 2015 | [redacted] | £8,778.00 | [redacted] |
| October 2015 | [redacted] | £4,010.00 | [redacted] |
| July 2014 | [redacted] | £124,000.00 | [redacted] |
| October 2016 | [redacted] | £117,000.00 | [redacted] |
| October 2017 | [redacted] | £3,000.00 | [redacted] |
| *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* |

**Conference Participation**

| Conference Name | Details |
| --- | --- |
| Society of Experimental Biology | Gothenburg, July 2017 |
| Invertebrate Sound and Vibration | Frankfurt, September 2017 |
| Biotremology | Upcoming, 2018 |
| *No Response* | *No Response* |
| *No Response* | *No Response* |
| *No Response* | *No Response* |
| *No Response* | *No Response* |
| *No Response* | *No Response* |
| *No Response* | *No Response* |
| *No Response* | *No Response* |

**Other Awards/Achievements/Skills**

| |
| --- |
| [redacted] |
| [redacted] |
| [redacted] |
| [redacted] |
| [redacted] |
| *No Response* |
| *No Response* |
| *No Response* |
| *No Response* |
| *No Response* |

**Summary of Publication Record**

8 first author articles, 1 first author book chapter, 2 first author reviews, 3 articles as other author, 2 first author articles under review

Published first author publications:

[redacted]

**Professional Membership**

British Ecological Society, British Arachnological Society, Society of Experimental Biology, Association for the Study of Animal Behaviour

**Additional Information**

[redacted]

**Summary Project Details**

| **Total project cost: £** | **Amount requested from BES: £** |
| --- | --- |
| 13,829.80 | 0.00 |

**Project title:**

Elephant Seismology: Linking noise, terrain and elephant behaviour

**Project lay summary:**

For African elephants, the savannah terrain is more than a habitat. It is also a platform over which they send and receive information in the form of ground-based, or seismic, vibrations. They generate these vibrations in two ways. Their huge size means they generate vibrations through the ground every time they move around. But in addition, vibrations are caused by loud and low-pitched vocalisations made by the elephants. Both types of vibrations are modelled to propagate over the kilometre scale in the elephant's natural habitat.

Still, there are unanswered questions on how seismic information transfer is influenced by physical factors within the elephant’s ecosystem, which this project aims to explore further. It will aim to answer several questions. Firstly, are some types of vibrations, like those generated by other elephants, more worthy of a response? How big does the ground motion have to be to get a response? How does human-generated noise, such as from cars, influence behavioural responses? And finally, does the type of physical terrain influence behavioural responses?

The proposed project aims to answer these questions by playing custom-generated seismic vibrations to wild elephants in the field in Kenya. It will monitor elephant responses to changing seismic vibration volume and type (e.g. mimicking elephant-generated vocalisation versus weight drop) over changing noise levels and terrains.

These questions are important for understanding how elephants interact with their environment and other animals in their ecosystem. For instance, if elephants are found to be highly sensitive to seismic vibrations, this opens up the possibility that they can communicate and gather information about the savannah ecosystem over long distances. This could include the possibility of finding a mate kilometres away, or detecting distant animal movements or rainfall.

Moreover, elephants may have preferred terrains to send or receive this information. [redacted]

These questions are also important for understanding how human noise pollution may affect elephants, reducing the range and scope of information transfer. This has implications for captive and wildlife management strategies, as well as captive elephant welfare.

| **Project start date:** | **Project end date:** |
|---|---|
| 01 July 2018 | 30 June 2019 |

**Project country:**

United Kingdom

**We have chosen a selection of keywords, which cover the breadth of the ecological research we fund. These keywords link the ecological content of an application to the most appropriate member of the BES Review College.**

**As your selections will determine which reviewers are asked to assess your application, please select carefully.**

**Please choose three words from the following:**

- ☑ Conservation ecology
- ☑ Environmental Physiology
- ☑ Pollution

**Please provide a project description**

**This should include:**

**a) background and rationale**
**b) the question or hypothesis to be tested**
**c) an outline of the methods to be use**
**d) expected outputs**
**e) expected timescales**

**Please capitalise all headings**

BACKGROUND & RATIONALE
African elephants have complex links to their savannah ecosystem. One fascinating interaction with their environment is

the use of ground-based vibrations for communication. Elephants generate these seismic vibrations through infrasonic vocalisations and locomotion. They respond to seismic playback, discriminating between elephant seismic signals (O'Connell-Rodwell et al. 2007,J.Acoust.Soc.Am.,122,823). Seismic noise pollution, the terrain and source amplitude is thought to impact this mode of information transfer, but no data exist probing the links between these physical factors and elephant seismic sensitivity. This proposed project therefore aims to study the behavioural responses of elephants to seismic vibrations over different ecological settings, including over varying source properties, noise levels and terrain types.

RESEARCH HYPOTHESES
Elephants are more likely to behaviourally respond to playback...
a) ...of elephant-generated seismic vibrations
b) ...when no seismic noise is superimposed
c) ...at higher amplitude levels
d) ...when on river sand
Hypotheses are in order of priority to make sure that playback experiments are scientifically rigorous, limiting habituation, excluding pseudoreplication but generating a sufficient number of repeats for statistical analysis. This will depend on the number and accessibility of elephants present over the field trip, which is maximised by conducting field work in the Samburu/Buffalo Springs National Reserves in the wet season, where many elephants are GPS collar-tracked.

METHODS OUTLINE
I will develop a seismic playback system that delivers seismic waveforms into the earth with desired waveform characteristics. I already have a library of biotic (elephant rumbles and walks) and abiotic (car, rain) source functions for experiments. White and car noise of two different amplitudes will be superimposed over the source functions as additional tracks.

Playback experiments involve filming the responses of wild elephants in their natural habitat to playback tracks using a video camera. Temperature, humidity, notes on geology and surface soil, size of elephant group, distance between them and the source, as well as elephant identity will be recorded at each playback location. The staff at Save the Elephants can help us identify elephants and track groups during the fieldwork.

Experiments will start with playback tracks with source functions of: (i) elephant alarm rumble, (ii) elephant run, (iii) giraffe walk and (iv) weight dropping. Next, any source functions eliciting a behavioural response will be used with the two types of noise superimposed at a high amplitude, with the option for other amplitudes. The third hypothesis can be tested according to the distance of the focal elephants from the source. Therefore at each playback location we will record the amplitude of a controlled seismic wave at each elephant location to quantify seismic attenuation. Finally, the effect of terrain can be tested depending on the locations of each playback experiment.

EXPECTED OUTPUTS
The project will provide fundamental insights into the seismic-mediated interactions between elephants and their savannah ecosystem. It will provide data to test the implications of anthropogenic seismic noise and whether certain terrains are of higher biological use than others. The outputs have implications for the conservation management of captive and wild elephants.

Manuscript for a top Biology journal on seismic sensory ecology of elephants and the implications for their conservation
Presentations at international conferences: British Ecological Society & Society of Experimental Biology
Article for 'The Conversation'
Schools outreach sessions, including primary level
NERC independent fellowship application on seismic-mediated ecosystem interactions, including elephants locating water sources

EXPECTED TIMESCALES
July-September 2018. Buy equipment, book fieldwork, develop playback procedure
October 2018. Research assistant starts, finalise fieldwork preparation
November-December 2018. Fieldwork in Kenya (31 days) then research assistant finishes
January-June 2019. Data analysis, preparation of expected outcomes

**What are the risks to the health and safety of those involved in the project and how are these risks to be minimised?**

Vaccinations and anti-malaria pills are needed for fieldwork. Heavy equipment will be shipped and designed to limit manual handling. We will hire taxis, booked through Save the Elephants, to take us around Nairobi and a driver, booked through the car hire company, to drive between Nairobi to Samburu. The Samburu research camp have rangers patrolling the camp overnight. We will hire a ranger (with a gun) to be present during all times in the field. He will advise on when it is safe to place playback equipment outside the 4x4. Roof hatch will enable safe monitoring.

**Please provide details of agreed collaborations and project partners that will facilitate the proposed project:**

[redacted]

[redacted]

[redacted] have agreed to host me in their [redacted]. They will facilitate hiring a park ranger and have granted me access to their elephant tracking app (using GPS collars). They can aid us identifying elephant individuals from our videos as required.

**Please provide details of the suitability of the institution where the work will be carried out and the availability of equipment and facilities required for the work:**

[redacted] will provide the necessary space (laboratory and outdoor space for experimental validation), facilities (including electrical and mechanical workshop) and administrative support (risk assessments, travel insurance) for the proposed project. I already have a lot of equipment necessary for the project within my independent lab space (geophones, data acquisition units etc.) and have requested funds to develop the novel seismic playback system.

As a project partner, [redacted] (accommodation, food, work space) in [redacted] and will facilitate meetings with the Kenya Wildlife Service and Reserve rangers.

**Please provide details of necessary permits/licences obtained, if applicable:**

I have a valid research permit for postdoctoral research in Samburu, Kenya on the topic of 'Elephant Vibration Landscapes', which is valid until August 2019.
I will also need to pay for park entry permits for both the Samburu and Buffalo Springs National Reserves for myself and the research assistant, which is paid upon entry.

**Please indicate how you will assess the scientific impact of the project and the benefits for non-academic audiences:**

I will publish the results of the project in a general biology journal, thus maximising impact for a biologist academic audience. Furthermore, I propose to present the findings at the British Ecological Society and Society for Experimental Biology conferences in 2019, thus increasing the reach and impact of the project for academic audiences. In addition, I will write a piece for 'The Conversation', written with a journalist for non-academic audiences and will organise an interactive outreach session for school visits to the [redacted], particularly aimed at primary level.

**How do you intend to make your research data publically available?**

I will include the research data as part of our manuscript submission as supplementary material, which will also be available through [redacted] open access repository.

**Please provide details of any published papers relevant to this project:**

[redacted]

**Have you previously applied for a grant from the BES?**

No

**Equipment/Consumables**

| Item | Quantity | Description | Total Cost |
|---|---|---|---|
| Playback equipment | 1 | Custom build for low frequency coupling with the ground | £860.00 |
| Data storage | 1 | Hard drvies, SD cards | £300.00 |
| *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* |
| | | **Overall Equipment Cost:** | **£** 1,160.00 |

**Personal Travel/Accommodation/Subsistence**

| Description | Total Cost |
|---|---|
| *No Response* | *No Response* |
| *No Response* | *No Response* |
| *No Response* | *No Response* |
| *No Response* | *No Response* |
| *No Response* | *No Response* |
| *No Response* | *No Response* |
| *No Response* | *No Response* |
| *No Response* | *No Response* |
| *No Response* | *No Response* |
| *No Response* | *No Response* |
| **Overall Personal Travel Cost:** | **£** 0.00 |

**Field Travel/Accommodation/Subsistence**

| Description | Total Cost |
|---|---|
| Accommodation for two in Kenya (31 nights) | £1,930.80 |

| | |
|---|---|
| Flights for two to Nairobi, airport transfers | £1,307.40 |
| Car hire in Kenya, petrol & tyre replacement | £2,171.80 |
| Ranger and driver hire in Kenya | £323.90 |
| Park permits, visas and medical expenses | £335.15 |
| Internet credit and snacks for the field camp | £161.95 |
| *No Response* | *No Response* |
| *No Response* | *No Response* |
| *No Response* | *No Response* |
| *No Response* | *No Response* |
| **Overall Field Travel Cost:** | **£** 6,231.00 |

**Employment**
**(note only casual, short term assistance will be considered)**

| Position | Description of role | Rate & Duration of employment | Total Cost |
|---|---|---|---|
| Casual worker | Field assistant, and help developing playback protocol and analysing field data | 12 weeks full time at Oxford's 4.1 salary scale | £6,438.80 |
| *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* | *No Response* |
| | | **Overall Employment Costs:** | **£** 6,438.80 |

**If the total cost of the event is greater than the amount sought from the BES, please state how the balance will be met:**

*No Response*

**Other**

| Item | Description | Total Cost |
| --- | --- | --- |
| *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* |
| *No Response* | *No Response* | *No Response* |
| | **Overall Other Costs:** | **£** 0.00 |

**Total project cost:**
**£**
13,829.80

**Amount Requested from BES**
£13,829.80

## Section 2 - Contact Details

### PRIMARY APPLICANT DETAILS

| | |
| --- | --- |
| **Title** | [redacted] |
| **Name** | [redacted] |
| **Surname** | [redacted] |
| **Organisation** | [redacted] |
| **Tel (Work)** | [redacted] |
| **Email (Work)** | [redacted] |
| **Address** | [redacted] |

### CONTACT DETAILS

**Name** [redacted]
**Surname** [redacted]
**Email (Work)** [redacted]

## CONTACT DETAILS

**Name** [redacted]
**Surname** [redacted]
**Email (Work)** [redacted]

## GMS ORGANISATION

| **Type** | **Organisation** |
|---|---|
| **Name** | [redacted] |
| **Phone (Mobile)** | [redacted] |
| **Email (Work)** | [redacted] |
| **Address** | [redacted] |

**If you do not have a current organisation (i.e. you are an independent researcher/retired), please provide your preferred contact address above and select the checkbox to the right** Unchecked

# Section 3 - Grant Specific Questions

**Please provide any responses to the reviewer comments received for Part A of your application form. If these comments have resulted in any changes to your project proposal, please ensure you outline these changes here:**

Reviewers' comments:
High profile and charismatic system (African elephant) and an interesting topic make this proposal appealing to fund. The ideas hang together and the likelihood is high that interesting, useful and publishable research will be produced, likely for a reasonably prestigious outlet.

This is a fascinating project, but as written I have a number of questions about the hypotheses and methodology. The hypotheses all look to test behavioural response, but there is very little information about what this is, what expectations we might have, how it will be measured and the replicate number of responding elephants.

The candidate has a good track record and would clearly be able to complete the research proposed in a timely fashion.

My response:
I thank the reviewer for their time reading and commenting on the proposal. I am pleased that they think the project is fascinating, that the likelihood is high of interesting, useful and publishable results and that I have a good track record to enable me to complete the research proposed in a timely fashion.

The reviewer asks for more information on the hypotheses and methodology. I will briefly provide more information below, but more information is present in the Research Plan, and I will outline the changes I have made in response to these comments.

“The hypotheses look to test the behavioural response, but there is very little information about what this is, what expectations we might have...”

Based on the findings of the two seismic playback studies [1, 2], and numerous acoustic playback experiments [3-6], I predict the elephants will respond to elephant-generated alarm rumbles with increased vigilant behaviours (freezing, ears spread out, head scanning side to side, leaning on front legs or lifting front legs one at a time), with increased bunching compared to controls. The response to increased seismic white noise is harder to predict, but acoustic playback of white noise has been shown to elicit a significantly different behavioural response to alarm rumbles [6], with increased incidence of dispersive behaviours and/or vocalisations relative to controls. I predict that superimposed white noise onto elephant alarm rumbles will lead to behavioural responses more similar to the seismic white noise than to the elephant alarm rumbles alone, as elephant alarm rumbles will not be detected and discriminated as easily.

My other predictions are that behavioural differences relative to controls will be greater on sandy terrains and with the louder alarm rumble tracks. Differences may be greater in this context due to a greater incidence of specifically defined behaviours, changes in the latencies of behavioural responses, changes in the spatial distribution of elephants in response to the stimuli, or due to more elephants responding within a group.

"...how it will be measured..."
Details on all measurements during the playback experiments are given in detail in the Research Plan. In short, vigilance behaviours are measured over time via behavioural coding of video recordings of elephants and spacing between elephant pairs are coded every 20 seconds according to distance between them in body length (0 for <1 body length, 1=1 body length, 2 for >1 body length, after O'Connell-Rodwell et al. 2006). Vocalisations will be recorded using an infrasonic microphone. Behaviours of multiple elephants will be recorded using these methods, but data will only be included from an elephant if their behaviour is clearly visible on the video recordings for the entire focal period.

"...and the replicate number of responding elephants."
I will aim for at least 15 independent family groups (Objectives 1 & 3) and similar number of lone elephants (Objective 2). The number of independent family groups depends on the number present in the field. Our chosen field location and season helps to maximise our potential sample size, and similar studies in the region have achieved these sample sizes [6]. In line with previous studies [1,2,3,6], I am also aiming to apply repeated stimuli to the independent groups, thus tracking their responses to multiple stimuli. To avoid habituation, at least 5 days will be left in between repeat experiments. Elephant groups may leave the study area over the field period, and in this case number of independent groups may vary between treatments.

As a result of providing the additional detail on the methodology and hypotheses, I have made some modifications and clarifications to both. The hypotheses have been rewritten and given a new order of priority: testing firstly effect of noise, then seismic amplitude, then terrain. The previous hypothesis on whether elephant generated seismic vibrations are more worth responding to did not make the cut as this has been well explored through previous acoustic playback experiments [1,2,3,6], and was not directly related to physical factors on information transfer. As a result, the methodology has been expanded to explain how I will test these hypotheses. The overarching question is the same – how seismic information transfer is influenced by physical factors. However, I have had to remove some of the stimuli I was planning on testing, as it was not achievable for the number of elephants present in the region and the period of the field work.

**Amount sought from the BES:**

**If this has been altered in response to reviewer comments, please update.**

£16,325.50

**If relevant, please briefly summarise any amendments made to the budget:**

Amount requested is now £16325.50: with the extra detail on methodology, it has become clear that I need a second car for fieldwork. I have therefore requested funds so I can hire a second car (£2171.80) and ranger/driver (£323.90; to drive and assess safety when placing equipment outside of car). Car A (myself) will be in charge of geophone, microphone and video recordings, and will be blind to the stimulus type. Car B (research assistant) will be in charge of the seismic playback, monitoring spacing between elephant pairs, and randomly selecting tracks.

**Please describe the objectives of the project:**

The measurable objectives, in order of priority, are:
1. Perform seismic playback experiments on elephant family groups on a sandy terrain, utilising three seismic treatments: white noise, alarm rumble loud, and superimposed white noise on alarm rumble loud.
2. Perform seismic playback experiments on lone elephants on a sandy terrain, utilising three seismic treatments: white

noise, alarm rumble loud, alarm rumble quiet.
3. Perform seismic playback experiments on elephant family groups on a gneiss or basalt terrain, utilising a single seismic treatment: alarm rumble loud.

**Please provide details of the Research Plan:**

**This should include the background to the project, preliminary data, research questions, experimental approach and timetable for delivery.**

**Please capitalize all headings.**

1. BACKGROUND
Elephants communicate and gather information through a variety of modes, utilising chemical, tactile, visual and vibrational information. Information transfer through ground-based, or seismic vibrations is least well understood [7]. Elephants generate seismic cues as they move around, and their size means that these vibrations can propagate over the kilometre scale [8]. Whereas locomotion generated cues are incidental, elephants also purposefully generate seismic signals when they vocalise: their infrasonic 'rumbles' generate both an acoustic and seismic component in the frequency range under 20 Hz [4, 9]. The relative roles of the acoustic and seismic components are unknown, but each component is modelled to propagate to a maximum of 6 km under differing favourable conditions [8, 10].

Elephants generate over 27 distinct forms of rumbles, which are used for social communication, from greetings, to alarms, to courtship broadcast signals [11]. Upon detecting the rumbles of other elephants, which naturally contain both seismic and acoustic components, responses vary widely thus showing elephants can discriminate between rumbles. Responses include: retreat, smelling, urinating, freezing, bunching, lifting and spreading ears, leaning on and lifting front legs, secreting from temporal gland, scanning head from side to side and vocalising (defined in e.g. Poole et al. 1988). Responses are appropriate to the social context in which the signal has evolved in order to convey information.

Detection of seismic signals involves separating potential information from background noise. Elephant seismic sensors are thought to be the Pacinian corpuscles on the feet and/or the inner ear, which detects ground vibrations via bone conduction [12]. Discrimination relies on detection but goes further to classify the potential information according to the source identity and status, which often leads to a behavioural outcome. (Information above background noise may be classified as irrelevant and not elicit a behavioural response, meaning neither detection nor discrimination can be inferred from behaviour.) For example, discrimination of source identity affects behavioural responses of elephants (e.g. human versus bee acoustic cues [13]), as well as discrimination of source status (e.g. alarm rumble versus greeting rumble [5]). The mechanism for discrimination is complex, but relies on frequency content and amplitude changes over time, which can be recorded through the ground using geophones [8]. For seismic signals, propagation through the ground modifies the frequency content and amplitude compared to what was generated at the source, and furthermore seismic noise is superimposed during propagation [8]. This means that propagation distance, level of seismic noise in the environment and terrain influence the ability to both detect and discriminate between seismic vibrations [8].

Playback experiments allow researchers to modify and control stimuli and measure resulting behavioural outcomes relative to baseline behaviour. A series of acoustic playback experiments with elephants have been performed, but do not include a seismic component [3-6]. Only two studies to-date have used seismic playback experiments to explicitly test responses to ground-based vibrations [1, 2]. In both, the seismic component of elephant alarm rumbles were used for playback. In the 2006 study [2], they showed that the seismic component of an elephant alarm rumble is sufficient to elicit a behavioural response – increased vigilance behaviours, decreased spacing between individuals and less time spent in that location compared to controls. These are appropriate responses to an elephant-generated alarm signal. In the 2007 study [1], the seismic component of alarm rumbles was recorded from two different elephant groups, and then played back to one of the elephant groups. The elephants responded significantly to seismic playback of alarm rumbles from familiar elephants by increasing vigilant behaviours and bunching (decreasing spacing). It is currently unknown what the detection thresholds are for elephants for detection and discrimination of seismic stimuli.

What remains to be investigated are the influences of different physical factors on the elephants' ability to detect and discriminate seismic stimuli. Communication through substrate-bound vibrations are particularly sensitive to physical constraints, due to heterogeneity of the propagating medium [14]. This is exacerbated for elephant seismic communication as the communication range is so large and over variable terrain. [redacted]. The predictions from the computer models remain to be tested in the field, and here I propose to investigate how noise, seismic amplitude and terrain influence the ability of elephants to detect and discriminate seismic stimuli.

Through my previous work, I have experience observing elephant behaviour and recording their seismic vibrations in the same field location as proposed for this study. In particular, we have mapped the terrain of the region and have quantified the relative damping, background noise levels and seismic wavespeeds over different terrain categories (see attached Supplementary Material from Mortimer et al. 2018). I therefore aim to build on this experience to perform seismic playback experiments to elephants, in order to monitor their responses to seismic stimuli.

2. RESEARCH QUESTION & HYPOTHESES
How do the physical factors of noise, seismic amplitude and terrain affect the ability of elephants to detect and discriminate seismic vibrations?
A. Superimposed seismic noise influences the ability of elephants to a) detect and b) discriminate seismic vibrations
B. Seismic amplitude influences the ability of elephants to a) detect and b) discriminate seismic vibrations
C. The terrain influences the ability of elephants to a) detect and b) discriminate seismic signals
Both detection and discrimination are measured via behavioural responses of wild elephants in their natural environment. Detection will be inferred via a significant change in behaviour when stimulus is applied relative to baseline behaviour. Discrimination will be inferred via a significant change in behaviour between stimuli of different types.

3. EXPERIMENTAL APPROACH
3A EXPERIMENTAL DESIGN (see also Table 1 attached to application)
Three different categories of experiments will be used to test the proposed hypotheses in a robust manner with sufficient controls and number of independent replicates within each group (Table 1). From our experience, the elephants spend the vast majority of their time on the sandy terrain. Category 1 will have highest priority, which is playback to elephant families on a sandy terrain. Category 2 is playback to lone elephants (usually males) on sandy terrain. Category 3 is playback to elephants on a gneiss or basalt terrain. Each playback experiment will use an ABA experimental design, collecting baseline behavioural data for 3 minutes before and after the stimulus, with the stimulus applied for 3 minutes in the middle.

In line with previous studies, each independent elephant/group will be exposed to repeated stimuli, separated by at least 5 days to avoid habituation [1, 3, 6]. Number of seismic stimuli will vary by experimental category. Category 1 will have white noise (wn), alarm rumble from familiar elephant (arhigh) and superimposed white noise and alarm rumble (wn+arhigh). This allows me to measure how superimposed seismic noise influences detection and discrimination ability on a sandy terrain. Category 2 will have white noise (wn) and alarm rumble played at two amplitudes (arlow and arhigh). This allows me to measure how seismic amplitude influences detection and discrimination ability (given sand geology and known distance to the source), where social cues from other elephants present have been removed. Category 3 will have only arhigh stimulus – this is because each family can only realistically be tested four times over the field period. This therefore allows me to measure how terrain influences detection and discrimination ability, when compared to experiments in Category 1.

I will gather data from as many independent elephant groups as possible within the field period, where at least 15 family groups will be present in the area [6], and more lone males. To avoid pseudoreplication and ensure independence of behavioural responses, we will identify elephants in each trial and track the composition of groups. This can be done in real-time using GPS collars and also through development of an identification guide in collaboration with staff from Save the Elephants (using specific ear shape and features of tusks for individual elephant identification).

Within each family group, the number of elephants varies from c. 3-30+, with a mean of 14 [8]. Data will be collected from multiple elephants within each group, which leaves the scope for generating statistical models with elephant group as the random factor, or testing differences between mean responses of all focal elephants in different families, or different individuals within a family (collecting information on their size, as maturity affects behavioural response [15]).

Data will be collected at a similar time each day (10am-2pm), when elephants are typically resting under trees. As many different families as possible will be recorded each day, allowing for a 5 day break since last experiment (if applicable).

3B DATA COLLECTION
Measurements will be gathered in the field, with myself in car A (video, geophone and microphone recordings), and a research assistant (RA) in car B (playback equipment and spacing monitoring). Elephants in Samburu and Buffalo Springs National Reserves are habituated to the presence of cars. We will take our experiments to the elephants, so will need to

firstly identify the elephants, then park the two cars at a set distance and deploy the geophone and playback equipment outside the cars and out of the elephants' view. Real-time GPS data from elephant collars (delay up to 1 hour) can be used to target specific elephant families (most families have at least one collared elephant). All recordings will be synched with the playback tracks (via audio cue giving starting time of video, geophone and playback), which will include the periods of silence.

Vigilance behaviours (amongst others) will be recorded using a video camera via a roof hatch in car A, keeping the closest elephant to the playback equipment in the centre of the screen. Acoustic and seismic recordings will be collected from car A at a known distance from the playback equipment in car B, which can be used to assess terrain-specific effects on seismic propagation, as well as evidence of low acoustic stimuli presence. Car A will also record distance from playback to the elephant group, using laser range finders and measurements to landscape features after trials have completed. In addition, car A will gather information at each location on other terrain features such as geology, top soil and vegetation type, as well as temperature, humidity, notes on weather and GPS location, and other sources of seismic noise, which may be biotic (other animals within 50m) or anthropogenic (cars within 100m).

Spacing behaviours will be recorded in the field by car B every 20 seconds, following the methodology of O'Connell -Rodwell et al. (2006). This involves scoring spacing between elephant pairs as 0, 1 or 2 for less than one body length, 1 body length or more than 1 body length apart respectively. RA will note elephant group composition and size, including presence of GPS collars and photos of individuals in case confirmation of identity is needed.

3C ANALYSIS
Data will be collated, synced and backed up every day in the field. Data from car A will link elephants in the video to the distances measured, for all elephants that are clearly in shot for the whole 9 minute period. Audio and geophone recordings will be linked to any noted sources of noise or elephant vocalisations (i.e. time on recording for elephant rumble/giraffe walking by).

Data from car B on elephant spacing will be summed for each 3 minute period and divided by the number of recorded spacings for that period. RA will generate the table linking treatment, arbitrary experimental code, elephant group information, and the environmental information collected by car A.

RA will work with staff at Save the Elephants to identify elephant families based on GPS data from elephant collars, photos and videos from the field, building up a guide for identification that can be used to identify families when in the bush. The RA will therefore be responsible for random allocation of playback tracks suitable for each elephant family, aiming to get three different treatments played to each family on sand in random order, where experiments are separated by at least five days. (I will not do this to make sure video analysis is not biased in any way.)

Behavioural coding from the videos will take place after fieldwork is complete. Treatment identity will be blinded during video analysis and videos will be cropped into three 3 minute segments and randomly ordered for analysis, limiting any bias of behavioural analysis. Vigilance behaviours include smelling, visual orientation towards source, freezing, rumbling, foot lifting and head scanning, which are well defined in the literature (e.g. O'Connell-Rodwell et al. 2006). Only elephants with distances relative to car A that are clearly on the video for the entire 9 minute period will be analysed.

Geophone recordings will be analysed to assess seismic level of playback tracks, using a custom-written matlab code analysing frequency content and magnitude over time. Geophone tracks will also be useful for future analysis linking elephant behaviour to seismic signature – contributing to a data set aiming to develop detection and discrimination algorithms (details in Mortimer et al. 2018). Audio recordings will be analysed to assess audio level of playback tracks (if detectable), and identify any elephant rumbles present, also quantified using a custom matlab code analysing frequency content and amplitude over time.

Decisions on exact statistical approach will be made after final data collation. Statistics will be needed first to show that group size, composition and distance to source do not affect behaviour. The data will then need to be tested to see if it meets the assumptions of parametric statistics, if not appropriate non-parametric alternatives will be used.

TIMETABLE FOR DELIVERY
July18-Sept.18. Buy equipment, book field travel & accommodation. Develop playback protocol, including playback tracks at different volumes, calibrated with microphones and geophones in the UK.
Oct.18. RA starts, finalise fieldwork preparation.

Nov.18 – Dec.18. 28 days fieldwork. Data collection, collation and back-up in the field (see Data Analysis section).
Dec.18. Make sure all data tables, elephant identification and collation from the field is complete. RA to write up detailed methods in a final report. RA finishes.
Jan.19 – March19. Analysis of video, geophones and microphone recordings.
Apr.19. Collating all data, performing statistical tests.
May19– June19. Manuscript and conference abstract preparation. Interactive outreach session preparation and delivery. Upon manuscript publication. Write article for 'The Conservation' based on the manuscript, as well as participate in any media interviews following press release.


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