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Simulating vibrational soundscapes to investigate the effect of vibrational road noise on animals

ABSTRACT

It is widely agreed that Earth is experiencing a sixth mass extinction, and there is a pressing need to identify causes of species declines. Roads are likely contributors, through noise: traffic creates vibrations which propagate into roadside habitats, where many animals use vibrations to communicate about activities vital to their survival. Thus, there is great potential for vibrational road noise to affect animals, but this topic is not well studied. I will study the effects of vibrational road noise on *Entylia carinata*, a plant-living insect that uses vibrational communication. I will assess the effects of continuous road noise on development and reproductive success and test adult behavioral responses to road noise. To execute this study, I will develop software to play calibrated vibrations continuously through plants. The findings will be novel contributions to the field of animal behavior, and the software will be freely available for future vibrational communication research.

PERSONAL STATEMENT

I am dedicated to pursuing the kind of questions you go to bed and wake up thinking about. At a young age, I learned that these questions often lay at the intersection of multiple disciplines, so I began connecting a subject I loved, biology, with other subjects. When I worked at the intersection between biology and chemistry for a high school project, I was surprised by how it reshaped the way I thought about biology. I chose to compare solar panels to chloroplasts, structures that help plants photosynthesize. I was dying to know: how can a manufactured tool achieve the same process as a structure inside a plant? If scientists mimicked nature and created a renewable energy source, how else we might benefit from using nature's designs?

By asking these questions, my idea of biology began to expand. I always loved biology because it was fun to think about, but with this project I realized that copying nature can be incredibly useful! A TED talk about this topic introduced me to Janine Benyus, a scientist who would soon become a role model of mine. Her words stuck with me: "life creates conditions conducive to life." Benyus' discussions of solution-driven science revealed that we can create a sustainable future for our planet by mimicking nature. However, if we want to copy nature's designs with intention, we must develop a deep understanding of the processes that create and govern these designs. I decided to contribute to this understanding through research.

I sought out opportunities to develop skills to become a great researcher and became a Leader in Conservation Biology Fellow at the Discovery Place in Charlotte. I learned how to think critically about research papers, a skill that I used to deepen my understanding of biology outside the classroom, and I discovered the value of collaboration through mini-experiments with my peers. Most importantly, I discussed conservation research with a professor at UNC Charlotte, Dr. Ringwood whose work was on coral reefs. From her I learned about how humans affect marine ecosystems, which ignited my passion to investigate how humans impact terrestrial ecosystems at Elon.

My research occupies the intersection between computer science and biology. If awarded the Lumen Prize, I can be creative and bold at this intersection by pushing methodological boundaries and addressing compelling gaps in knowledge. To prepare for this work, I will develop research skills and interact with like-minded researchers at the Cornell Sound Analysis Workshop, an experience that will enhance my development as a scientist.

The Lumen Prize will also help me to expand science accessibility. Science is a powerful tool: it helps us understand the world around us and within us. I believe that everyone should have the opportunity to uncover the world's wonderful secrets. I hope to connect students with real science, just as Dr. Ringwood did with me, so I will share my research with middle school students from the Alamance-Burlington School System at a summer camp (*Elon Explorers*) where I have interned. I will also develop an open source computer program with the intention of reducing economic barriers to research. Lumen funding would help me share this product with scientists at international venues, like the Biotremology and Animal Behavior Society Conferences. Overall, the Lumen Prize will accelerate my first steps towards an exciting career in computational biology research and science education.

PROJECT DESCRIPTION

Focus

We are currently experiencing the sixth mass extinction. Species are disappearing at rates much higher than typical extinction rates, globally and across most animal groups (Dirzo and Raven 2003; Barnosky et al. 2011; Ceballos et al. 2015; Pimm et al. 1995). Amplified extinction rates demand our concern: the diversity of species makes Earth habitable for us. Earth has recovered from mass extinction events before, but such recovery occurs over millions of years. This means that species replacement will not occur during our lifetimes (*reviewed in* Barnosky et al. 2011), and if we hope to maintain biodiversity, slowing extinctions is the only option. To slow extinction rates, we must first uncover factors that contribute to species declines. This aim has received significant effort in ecological research, and several agents of species loss have been identified (*reviewed in* Brook et al. 2008). One recognized driver is habitat loss and fragmentation by roads (Fahrig 2003). However, roads may also contribute to species declines in other ways.

Roads are an extensive source of anthropogenic noise. In fact, road traffic has been identified as a primary source of acoustic noise pollution in the US (National Academy of Engineering et al. 2010). Road noise certainly has the opportunity to affect many terrestrial animal populations in the U.S., with 83% of land within ~ 1 km of a road, and 20% of land within 127 m of a road (Riitters and Wickham 2003). Most research on how road noise affects animals has focused on airborne road noise, and its impacts are often adverse, ranging from declines in species diversity to reproductive costs (*reviewed in* McGregor et al. 2013). However, traffic on roads creates more than just airborne noise. As cars make contact with the road's surface, vibrational noise propagates through the ground into roadside habitats and is detectable by many animals (Caorsi et al. 2019). Animal species ranging from invertebrates to elephants communicate using vibrational signals (Hill 2008), including an estimated 200,000 insect species (Cocroft and Rodríguez 2005).

Communication is essential: it allows animals to exchange information about activities central to their survival and reproduction, like foraging and mating. Airborne road noise hinders communication by masking airborne animal signals (Costello and Symes 2014), and it is likely that substrate-borne road noise masks vibrational communication, too. Animals demonstrate two main behavioral responses to airborne signal masking: changing signaling frequency (i.e. pitch) and reducing the amount that they signal. Some animals change frequency to avoid getting drowned out by noise (Shieh et al. 2012; Lampe et al. 2012), though others appear unable to do so (Costello and Symes 2014; Nelson et al. 2017). In contrast, signaling *less* may be a generalized response to noise (Costello and Symes 2014; Caorsi et al. 2019; Gallego-Abenza et al. 2020). Altered signaling behavior in response to road noise can result in reduced survival and reproduction (Wartzok and Tyack 2008), which could eventually threaten species abundance and biodiversity.

Insects provide a model to assess how an environmental factor like road noise might affect other kinds of animals: they are small, they can be studied in large numbers, and their short life cycles make it possible to observe their development (Morley et al. 2014). Insects are important because they comprise most of all animal species (Zhang 2013; Stork 2018), and they perform key roles in ecosystems including pollination, dung recycling, and being food for other wildlife

(Losey & Vaughan 2006). If road noise threatens insect populations, it also threatens these ecosystem services, which are conservatively valued at an estimated 57 billion dollars per year in the U.S. (Losey & Vaughan 2006). Unfortunately, insect populations appear to be declining, perhaps globally (Hallmann 2017; Sánchez-Bayo & Wyckhuys 2019; van Klink et al. 2020). Factors that affect overall biodiversity also affect insects, and one of these factors may be anthropogenic noise pollution (Caorsi et al. 2019; Phillips et al. 2020).

Most work on the effects of anthropogenic noise measures immediate, behavioral responses by animals (McGregor et al. 2013; Morley et al. 2014). However, many animal species experience road noise continuously during their development, and chronic exposure may impact them. Surprisingly, few studies to date have examined the effects of vibrational road noise on vibrationally communicating animals (Wu and Elias 2014). I will address these gaps by investigating the effects of vibrational road noise on the behavior, development and reproductive success of the keeled treehopper (*Entylia carinata*), a vibrationally communicating, plant-dwelling insect that is distributed throughout the Americas. My research will provide some of the first findings on how animal development and reproductive success are influenced by long-term, continuous exposure to vibrational road noise, and how adult animals respond to short-term vibrational road noise. This work will reveal whether road noise can threaten biodiversity and will be of interest for conservation planning (Gregory et al. 2021).

Scholarly process

I began this project with a review of the peer-reviewed literature on the effects of anthropogenic noise on various animal taxa. I compared methods across experimental papers and identified compelling gaps in knowledge. I then outlined an experimental study, which makes a methodological contribution to the field of animal behavior and addresses these gaps.

My methodological contribution will be a program for studying vibrational communication and a continuous vibration playback setup that can be used to study effects of vibration on animals over longer time periods than is currently feasible. With Dr. Hamel and colleagues at the University of Missouri, I have begun developing a program that plays and records substrate-borne vibrations and also calibrates transducers (hardware used to play vibrations). To enable long-term vibration playbacks, I will automate the programs to play vibration tracks on a continuous loop and recalibrate transducers at programmed intervals. I will build a prototype for a large vibrational playback experiment: a plant that is isolated from ambient vibrations (e.g. electrical hum, the footfalls of people walking nearby) will sit inside a mesh cage; an accelerometer (which detects vibrations) and a linear resonant actuator (LRA; which plays vibrations) will be attached to the plant and connected to a Raspberry Pi (microcomputer running the program); and the Raspberry Pi will be powered by a power bank (see *Figure 1*). I will test the prototype in the McMichael greenhouse and begin drafting a methods paper about the program and continuous vibrational playback method (Fall 2021).

I will test the effects of vibrational road noise on insect development and reproductive success in a large playback experiment, by raising juvenile *Entylia* under three conditions: silence, wind vibrational noise (which reduces signalling; McNett et al. 2010; Hamel and Cocroft 2019), and road vibrational noise. I will also test the behavioral responses of adult *Entylia* to vibrational stimuli.

To begin my empirical study, I will record and document the parameters of road vibrations as they propagate through the plants that *Entylia* live on. During Summer 2022, we will collect two groups of juvenile *Entylia* from the field. The first group of *Entylia* will be raised on potted plants with a continuous vibrational setup. One of three different vibration conditions will continuously be played to each plant of juvenile insects. I will measure the length of their juvenile development, and once they reach adulthood, I will characterize their signals (i.e. signaling frequency) and document how many signals they make (i.e. signaling rate). I will also measure female reproductive success by counting how many eggs they lay and how many offspring hatch. The second group of *Entylia* will be raised until adulthood on potted plants without a continuous vibrational setup, and I will play short-term noise to them to determine effects on their signaling behavior, as described above.

During Fall 2022, I will analyze data collected during the summer using the programming language R, develop conference presentations of our findings, and write a research paper about the effects of vibrational road noise on animal development, reproductive success, and behavior.

Through my research experience, I will establish skills that prepare me for a career in computational biology. Creating the software and prototype for this experiment will contribute to my development as a programmer and problem solver. Through my empirical study, I will learn how to ask and answer research questions. I will also learn how to communicate science to a variety of audiences, as I discuss my research with middle school students through *Elon Explorers* and established researchers at conferences.

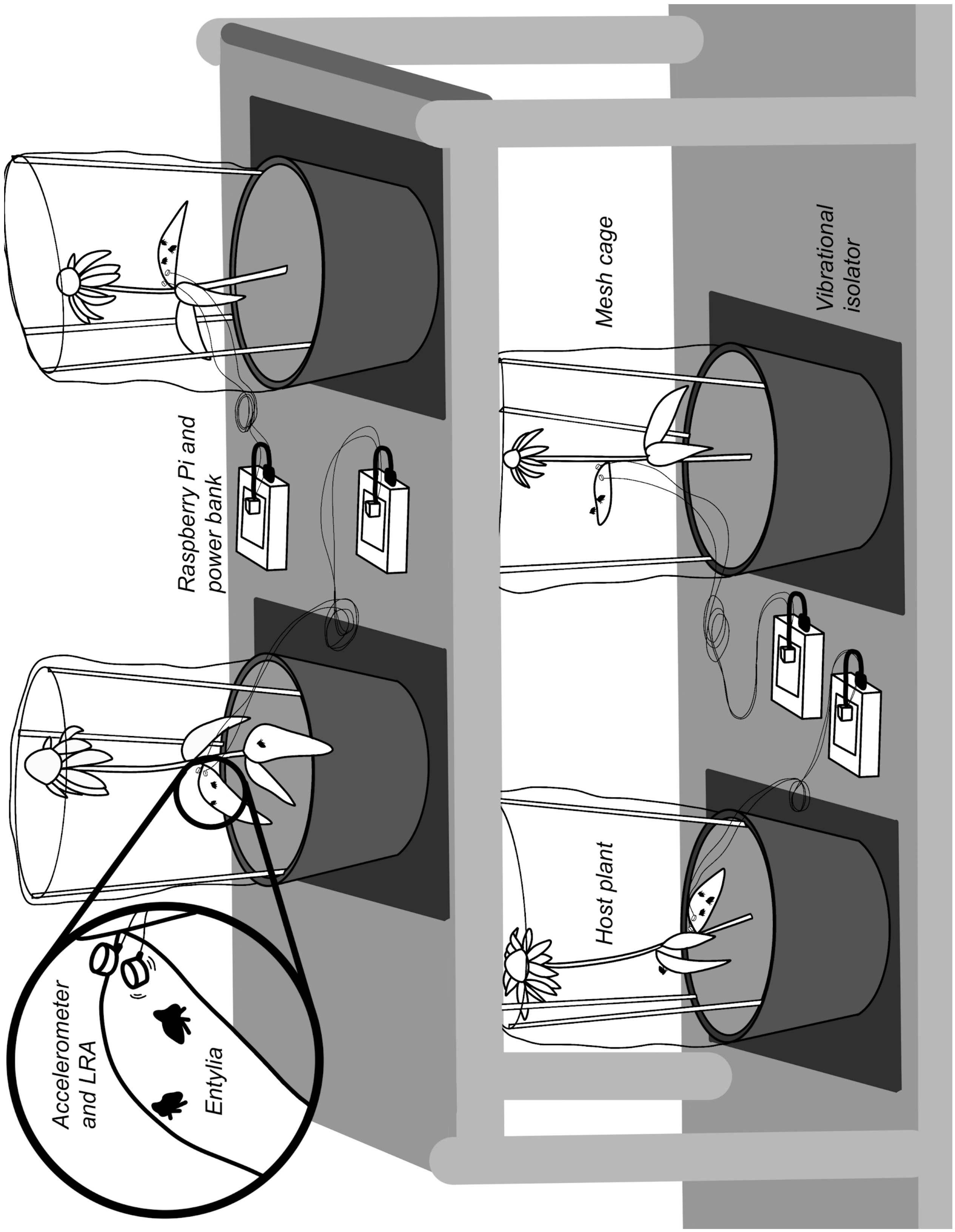

Figure 1. Continuous vibration playback set up.

Proposed Products

1. Methods manuscript about our software and vibration playback method, with Dr. Rex Cocroft (Univ. Missouri), Sabrina Michael, and Dr. Alfred Simkin, to be submitted to a peer-reviewed disciplinary journal. A publication will allow other researchers to use our methods in vibrational communication studies.
2. Research manuscript about the effect of vibrational road noise on *Entylia carinata*, to be submitted to peer-reviewed disciplinary journal. A publication will make our work available to other animal communication researchers as well as to organizations involved in conservation planning.
3. Present at research conferences such as: The North Carolina Academy of Science (regional), The Biotremology Society (international), and Animal Behavior Society (international)

FEASIBILITY

We are basing our program, written in Python, on another vibration playback program, written in Matlab by our co-developer Dr. Rex Cocroft (Cocroft et al. 2014). Dr. Hamel has used and augmented the Matlab program in her research on vibrational communication. We are able to use the Matlab program as a point of comparison to develop our program and test the code I have written, which records and plays vibrations well in the laboratory. Remaining work includes writing code to compensate for substrate filtering and program automation. By beginning the software development process over WT 2021, I have established a strong understanding of signal processing (i.e. analyzing and modifying signals). To further develop our signal processing skills, Dr. Hamel and I will both attend the Sound Analysis Workshop at the Cornell Lab of Ornithology, and Dr. Hamel will complete a class on writing code in Python. I will also have a programming expert, Dr. Alfred Simkin, who is native in Python review my work and provide feedback (see *Letter of Support*).

After program development, I will create a hardware prototype. I will hire a technician through SE Systems in Greensboro to custom build transducers and circuitry (i.e. micro-accelerometers, LRAs, pre-amplifiers, etc.) according to schematics already used by the Hamel lab. Dr. Hamel has experience developing hardware solutions for vibration experiments and in disseminating the information: a description of her playback methods is included in an academic book aimed at researchers in the field. Dr. Hamel and I will take a course in programming Raspberry Pi micro-computers, and Dr. Simkin has also expressed interest in contributing to prototype development for the playback system.

Our empirical study of the effects of road noise on *Entylia* is rooted in vibration communication work with which Dr. Hamel has extensive experience. Findings from her research in this area are published in high impact journals, as well as two academic books. She has mentored several research students on vibrational communication projects, including research on our focal insect species. Finding and collecting *Entylia* will be easy because they are ubiquitous in the N.C. Piedmont. The Hamel lab has documented them on local organic farms, along Elon roadsides, and at the UNC Mason Farm Biological Preserve. Raising *Entylia* should also be straight-forward because Dr. Hamel has previously raised them in laboratory settings.

The Hamel lab has knowledge and much of the necessary equipment for data collection and analysis. The lab has calibrated micro-accelerometers for detecting and recording vibrational signals to assess effects on signalling behavior. The lab also has a high quality Olympus microscope for counting small insects and eggs to measure development and reproductive success. We will need to purchase additional accelerometers, LRAs, and several Raspberry Pi's to simultaneously play vibrations to many individual potted plants. Dr. Hamel has successfully trained multiple students how to detect, record, and analyze vibrational signals; how to score and count eggs and small insects; and how to perform statistical analyses using R.

I have considered that challenges may be encountered during the study. For example, during the prototype phase, I may find that hardware falls off the plants. If so, I can write code that notifies me to reattach them. Power banks may prove an inefficient power source, because recharging them interrupts power to the Raspberry Pi's. If this is the case, I can consider an alternative source of energy, like a solar powered battery. In short, there are many technological pieces in this study, and some of them are new methods with some uncertainty involved. I have therefore planned a long "runway" before the main experimental work, so that I have ample time in Summer and Fall 2021 to develop and test software, hardware prototypes, and methods.

I recognize that future travel is uncertain due to the current world situation. Although in person travel to the workshop and conferences outlined here would be ideal, my project is not reliant on any travel outside of North Carolina. All travel outlined here can be postponed or occur virtually. In the case that travel is feasible, I expect to be fully vaccinated before departure.

TRAVEL OUTSIDE THE US

PROPOSED TRAVEL: Slovenia

I hope to attend the 3rd International Conference on Biotremology, at the Marine Biological Station in Piran, Solvenia, from 20–24 September 2021. Although I will not be ready to present work in Fall 2021, this conference is a small gathering of all the experts in this field, and it only happens every two years.

Therefore, it will be very helpful for me to attend this year, meet the community, and hear the state of the field from the experts. Information on the conference and host facility are available at http://projects.nib.si/biotremology2020/. I plan to travel to Slovenia on Sep 19, and return on Sep 26 (adding one day after the conference to explore Piran). Dr. Hamel would also be attending this conference. We would stay at a local hotel within walking distance of the conference venue (Hotel Vile Park, https://www.hoteli-bernardin.si/en/accommodations/st-bernardin-resort/hotel-vile-park).

GEC PREASSESSMENT:
Assessed by:

BUDGET

Large vibrational playback equipment: Materials and labor to build 50 setups:
Raspberry Pi 4 Model B, 8GB ($75 x 22) = $1,650
Eggtronic Power Bank ($60 x 40) = $2,400
Power outlet surge protector ($36 x 4) = $144
Samsung T5 Portable SSD 1TB ($120 x 4) = $480
Knowles micro-accelerometers ($42 x 50) = $2,100
¼" tips for micro-accelerometers ($2 x 50) = $100
LRAs ($7 x 50) = $350
¼" tips for LRAs ($2 x 50) = $100
Mogami W2687 Spool of shielded cable ($25 x 2) = $50
Transistors ($2 x 50) = $100
Resistors ($6) = $6
9 volt batteries ($15 x 9) = $135
9 volt battery connectors = $20
Metal enclosures ($10 x 50) = $500
¼" jacks 2 per enclosure ($2.50 x 100) = $250
Bench fee for circuit electronics assembly ($35/h x 50h) = $1,750
Inner tubes ($12 x 25)= $300
Foam padding ($17.99 x 5 pads) = $90
Concrete pavers ($2 x 50) = $100
Total for large vibrational playback experiment: $10,625

Materials for collecting, raising, and maintaining insects:
Plants and soil = $700
BioQuip white polyester insect mesh (7250A) (50 yards x $4.50) = $225
Blue Hawk 100-ft Multi-Purpose Clothesline Wire ($11 x 2) = $22
Velcro Brand Roll Tape, 1 yard ($4 x 34) = $140
Bamboo stakes 48" 25-pack (6) = $50

Field notebooks and hand lens = $50
Studio Quality Headphones (Audio-Technica) = $150
Total for collecting, raising, and maintaining insects: $1,337

Travel to Field Sites:
UNC Mason farm = $200
Field site A and B = $178
Total for travel to field sites: $378

Conferences, Training, and Applying to Graduate School:
North Carolina Academy of Science, East Carolina University (2023):
Registration & Membership Fee = $75
Food = $55

Biotremology Conference, Slovenia (September 2021):
Registration Fee = $300
Air travel = $3,500
Accomodations (150 pn) = $750
Food = $200
Local transportation = $100

Animal Behavior Society, location TBA (August 2023):
Registration & Membership Fee = $145
Air travel (based on mentor's travel from past years) = $600
Accommodations (based on campus dormitory housing from past years) = $200
Food (conference meal plan) = $100

Sound Analysis Workshop, Cornell Lab of Ornithology (Summer 2021, virtual):
Registration fee = $1,430
GRE Registration Fee = $205
Total for workshops and conferences: $7,660

Total: $20,000

PROPOSED EXPERIENCES and PRODUCTS

	Experiences	Products

Summer 2021	Draft Honors Thesis Proposal Programming Raspberry Pi course Complete computer program for short-term playbacks & develop automated computer program	Draft Honors Thesis Proposal Short-term playback computer program
Fall 2021	Register for LUM 498 credit hours Submit Honors Proposal Biotremology Conference: hear presentations from experts in field Drafting methods paper Pilot vibrational playback methods for Summer 2022 experiment	Completed Honors Proposal Draft of methods paper Protocol and hardware prototype for playback experiment
Spring 2022	Register for LUM 498 credit hours Sound Analysis Workshop, Cornell University Prepare greenhouse for large vibration experiment	
Summer 2022	SURE at Elon Elon Explorers camp visit (1-2 days) Vibration experiments & data collection	Data from experiments

Fall 2022	Register for LUM 498 credit hours Honors Thesis Presentation of Progress Register for HNR 498 credit hours Analyze data from Summer 2022	Completed Honors Thesis
Winter 2023	Begin preparing for conferences	Oral presentation draft
Spring 2023	Register for LUM 498 credit hours Prepare presentation for regional and international conferences (North Carolina Academy of Science and Animal Behavior Society) Write findings for a research manuscript	Oral and poster conference presentations

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