Microwave Scattering and Life Detection

By Giles Wright

A senior thesis submitted to the faculty of

Brigham Young University – Idaho

in partial fulfillment of the requirements for the degree of

Bachelor of Science

Department of Physics

Brigham Young University – Idaho

December 2015
Brigham Young University – Idaho

Department Approval

Of a senior thesis submitted by

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This thesis has been reviewed by the research committee, senior thesis coordinator, and department chair, and has been found to be satisfactory.

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ABSTRACT

Measurements and Analysis of Microwave Scattering to Detect Rat’s Breathing Rate

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Bachelor of Science

Microwaves are high frequency radio waves. They can penetrate ground, concrete, and many other materials much better than electromagnetic radiation of other frequencies. While they’re able to penetrate many kinds of rubble, they do not penetrate water very well, but often reflect off an interface between rubble and materials with high concentrations of water. Living organisms generally consist of high concentrations of water, so this property makes microwaves particular useful when trying to locate organisms, including people, trapped within many different kinds of rubble. This research attempts to determine the effectiveness of an alternative method for analyzing microwaves scattered by an animal while changing size due to breathing, in an attempt to isolate signatures of life from the backscattered microwaves.
Acknowledgments

I would like to thank my wife, Ashley Wright. She has demonstrated great patience and support as I have conducted my research, and worked on my thesis. My life permanently changed for the better when she became involved with it, and I am very thankful to her for her willingness to continuously improve my standard of living. I love you, Ashley.

I would also like to thank the faculty of the Brigham Young University – Idaho Physics department for their dedication to excellence. I’m thankful to have studied under their direction, and taken part in their masterfully prepared and delivered lectures, demonstrations, and discussions. Brother Hansen in particular has pushed me to be more mindful of avoiding easier alternatives to hard work and dedication, for which I am grateful. Brother Hatt has also played a significant role during my time studying physics at BYU – Idaho, and I’d like to recognize his mastery of combining physics lectures with humor, wit as well as his determination to challenge students, and improve instruction with modifications appropriately based on available knowledge and technology.

I would also like to thank my peers, namely Tucker Sprenkle, Josh Heiner, Forest Hubert, Michael Corrigan, Timothy Harbison, Matthew Brownell, Jimmy Favaron, Sarah Young, and James McCulloch for their support, encouragement, and friendship. I have fond memories with each of you, mostly during times of shared struggles, and I’m grateful for the good times we have had.
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Chapter One

Introduction

1.1 Overview

Very little technology is available to aid search and rescue efforts in the event of avalanche or building collapse. Many traditional imaging methods don’t work in these scenarios. Visible light such as that from a torch/flashlight doesn’t penetrate the rubble well enough to reach survivors. Instead it is mostly reflected off the surface of the rubble revealing little to no insight into what lies beneath. Other imaging techniques which use more penetrating electromagnetic radiation such as x-rays, penetrate the rubble, but often are either absorbed by materials within the rubble, including objects of interest, or continue through them with little to no backscattering. Neither the absorbed nor the penetrating radiation is useful, because there’s no reasonable means of detecting them. Electromagnetic radiation in the region from 300 MHz (1 m) to 300 GHz (1 mm), better known as microwave radiation, has unique properties, which allow it to pass through many materials, interacting with objects and structures within the material in a way which creates backscattering. The backscattered microwaves then return back through the material, and detectors can pick them up on the same side of the materials from which they were originally produced. This method of imaging known as Ground Penetrating Radar (GPR) reveals information on the objects or structures with which they interacted.
within the rubble. This property makes microwaves particularly useful during search and rescue efforts, because the data can be analyzed in a way that reveals vital signs of survivors trapped within rubble.

Microwaves are already being used as a non-destructive method of determining corrosion of rebar reinforced concrete and fractures within concrete slabs, as shown by Roqueta et al.\textsuperscript{1}. Lou et al.\textsuperscript{2} have shown the usefulness of microwave imaging as a non-intrusive method for producing high-resolution images, and methods are being researched showing that microwaves can safely be used on humans for medical purposes. Meaney\textsuperscript{3} explains how microwave imaging could have a significant impact, particularly for use in breast cancer detection, while it may also have other useful medical applications. In order to use microwaves to aid search and rescue efforts, we must better understand limitations on microwave imaging, and which methods are optimal when searching for potentially subtle signs of life through rubble. It is well established that microwaves can pick up on signs of life such as breathing rates, and heart rates. This was proven when JPL confirm successful field use of microwave imaging by locating four earthquake survivors buried in rubble as was reported in their press release\textsuperscript{4}. The methods they used are explained separately by Narayanan\textsuperscript{5}, Howard\textsuperscript{6}, and Aria\textsuperscript{7}. Investigation into using microwave imaging as a technique of detecting life signs has not been exhausted, however, and the methods explained herein may provide another useful and alternative method of microwave imaging. Most microwave imaging techniques are being used to image static objects, such as support rebar, and isolated areas within medical patients, however if it is determined that Fourier spectral analysis of the microwaves can reliable isolate vital
signals without harming subjects, their usefulness in locating survivors enclosed behind rubble would be unmatched.

An important part of isolating vital signs through microwave imaging is during the data analysis process. In theory, each breath or heartbeat alters the breather’s body in size sufficiently to cause a periodic increase and decrease in the amount of microwaves reflecting off the subject. After imaging this cycle of size changes, the detector should reveal a cyclic increase and decrease of backscattered microwaves. This cycle could easily and quickly be shown by generating a Fourier spectral analysis of the microwave data.

This research is designed to determine the reliability of using Fourier spectral analysis with microwave imaging to resolve signs of life such as breathing rates, and/or heart rates, and whether or not this method is a useful alternative method of microwave imaging analysis. Blaszczyk, a former BYU – I student studying physics has previously suggested that a rat can be imaged using microwaves from within a PVC pipe, which blocks any light in the visible spectrum of electromagnetic radiation. His research shows that the data likely picked up some of the rat’s vital signs, but it’s hard to say for sure, because the rat’s movements strongly affected the data. During this experiment a movement-restricted rat will be imaged using microwaves without any obstructions either between the rat and the microwave source, or between the rat and the microwave detector. The data will then be analyzed using Fourier Spectral analysis to determine the benefits to this method of analysis.

1.2 Experimental principles
Although microwaves were not used to penetrate ground during this experiment, the same principles and technology were used when gathering data as are commonly used for ground penetrating radar (GPR). For the safety of the rat involved in this experiment, and to increase the likeliness that the rat’s vitals remained consistent during each trial, rather than burying the rat, a rodent restraining cone was used to restrain the rat while on a table surrounded by air.

GPR works in much the same way as normal radar or even sonar. A pulse is emitted, which has properties allowing it to penetrate a media, interact with objects of interest, and return to the source which is either equipped with a detector, or has the functionality to operate as both transmitter and receiver. The median is often air in the case of radar, which used long wavelength electromagnetism in the radar spectrum. In the case of sonar, which uses sound rather that electromagnetism, the median is often water.

While GPR does have limitations, it can work very well within these limitations to provide valuable information otherwise unobtainable to those who have access to the proper equipment, and know how to use it.
As represented in the figure above, the many sources for reflections provide a background of confounding reflections. This is why data analysis revealing cyclic patterns would be crucial to distinguishing victim trapped within the rubble from other irregularities contained within the rubble.

A simplified explanation of how GPR works can be obtained by understanding a few basic equations explaining electromagnetic propagation. Griffiths\(^9\) explains the propagation of electromagnetic waves with the equations: 

\[
v = \frac{c}{n}, \quad n = \sqrt{\frac{\varepsilon \mu}{\varepsilon_0 \mu_0}} \approx \sqrt{\varepsilon_r}
\]

where \(v\) is the speed of the microwaves travelling through rubble, \(n\) is the index of refraction of the material, and \(\varepsilon_r\) is the dielectric of the material used to calculate \(n\). Air
has a low dielectric of 1, meaning it provides little resistance to microwaves allowing them to freely flow through it. Water has a high dielectric of 81, meaning it is very difficult for microwaves to flow through it. When microwaves travelling through a material with lower dielectric encounter an interface between the material with a low dielectric to material with a higher dielectric, they are likely to reflect off the material with a higher dielectric. These microwaves become the rebounding microwaves as illustrated in Figure 1.1, known as backscatter, which can then be detected by the receiver.

Although many of the microwaves pass through the rubble without much interaction other than travelling at a slower rate, some of the microwaves do interact with the medium resulting in a significantly diminished return of backscattered signal. Higher frequency waves as are the ones used in this experiment provide higher resolution than do lower frequency waves, but at the cost of depth penetration. Lower frequency waves provide more depth penetration, but less resolution. Microwave penetration decreases exponentially, placing limits on return when increasing initial power in order to increase penetrating depth.

For further detail, see the work of Fallahpour et al.\textsuperscript{10}. Hechts\textsuperscript{11} also provides a useful, although more general description of electromagnetic radiation, and several websites dedicated to GPR\textsuperscript{12,13} are also useful in gaining an understanding of how GPR works.
Chapter Two

Methods

2.1 Experimental Design

In preparation for running the experiment, approval from a committee for the use of a live rat was required. This process was very time consuming, as it required the coordination of various personnel. Once committee approval had been obtained, preparations for running the experiment began by assembling an artificial rat. An artificial rat was assembled. The motion of a rat’s body as it breaths is mocked by first closing off a balloon with a tube through it’s opening, allowing manipulation of the amount of air within this soon-to-be inner balloon through the tube. This inner balloon was then inserted into an outer balloon, which had another tube in it. The outer balloon was then sealed off, leaving the tubes as the only means of accessing the inside of either balloon. The outer balloon was then partially filled with water through the outer tube, which was then clamped off. The inner balloon was partially inflated with air through the inner tube, which then had a syringe connected to it, allowing regulated manipulation of air volume. An assembled version of the artificial rat is shown below in figure, “Artificial Rat Setup”. The syringe could be used to either increase or decrease the amount of air in the inner balloon, which then expanded or contracted the outer balloon simulating a rat’s breathing.
Figure 2.1 Artificial rat, showing a green inner balloon connected to a syringe, yellow outer balloon filled with water and sealed off.

This process could be controlled to simulate a rat’s breathing rate, breaths in rapid succession, or slow breaths. The figure, “Artificial breaths” shown below is a plot of the data gathered while simulating both artificial breaths, and long term manipulations of air volume.
Figure 2.2 Plot of data gathered while simulating breaths with the artificial rat. The syringe was used to inflate and deflate the rat, simulating breaths. The syringe is left alone for the first three seconds. Air is quickly removed from the artificial rat, leaving the artificial rat partially deflated for the following three seconds. The artificial rat is quickly inflated to its starting size, and left alone for another three seconds. Air is quickly removed and added, simulating nine rapid breaths. The artificial rat is inflated to its starting size again for three seconds. It’s deflated for another three seconds, and finally inflated again back to it’s starting size for the remainder of data collection.
Use of an artificial rat allowed us to optimally position equipment. If the detector was too close to the microwave source, or if it was angled in such a way that it received microwaves directly from the source, the detector would be saturated with reflected signal. Data collected while in a state of saturation would be useless. The figure, “Saturated detector” below is a plot of data gathered while the detector was moved out of, and back into a position of saturation.

Figure 2.3 Close up of the quick nine simulated breaths shown in the middle of figure 2.2
Figure 2.4 Plot of data points starting in a position where the receiver was saturated. Shows data as the receiver was moved away from the transmitter to a position without data saturation, held steady, and then returned back to a position of receiver saturation.

If the detector was too far away from the microwave source, or angled in such a way that it was not receiving microwaves which interacted with the artificial rat, the counts would be too low for the data to be useful in determining whether the amount of detected microwaves were changing. Placement of the source very close to the rat, with the detector off angle from the source about 20 degrees and 20-30 cm further back than the source, as shown below in figure, “Live Rat Setup”, resulted in optimal data collection.
Figure 2.5 Setup during live rat data collection session. The microwave transmitter is very close in proximity to the rat, and the receiver is further back, to ensure no direct microwaves from the transmitter are picked up. The rat is restrained within a rodent restraining cone. During this session, the cone was held shut around the rat’s tail with a rubber band. During later sessions the rubber band was removed, and the rat was held in the cone manually.

Data was read from the analog detector using a Data acquisition device (DAQ), which was also stored in a file with LabView, using generic data gathering and recording Software\textsuperscript{14}. The equipment is rated to produce and detect microwave light in the X region with wavelength of 2.8 cm. These microwaves are well below the 12 cm light used in microwave ovens, which generate heat by rotating water molecules. The Microwave Transmitter was set to continuous wave (CW) for data collection while working with the
rat. The Microwave Receiver was set to Gain 2 to increase the likeliness that any microwaves it picked up were reflections off the rat. Gain 2 was chosen of four gain settings which amplify to varying degrees the signal picked up by the receiver, so the receiver could be placed further from the rat, while still detecting a non null amount of microwaves. A power source was used to regulate the voltage supplied to the Transmitter, and the receiver was battery powered.

The rat was restrained with a disposable plastic rodent restraining cone. The cone was designed with a hole in the end, which provided the rat with sufficient access to air to prevent suffocation. As was described in the protocol approved by the animal experimentation committee, the rat was acclimated to the restraint during the week prior to experimentation. During the period when the rat was to be acclimated to the restraining cone, the rat was initially removed immediately upon entering the cone. Each day the rat was held in the cone for longer duration until by the end of the week it was being restrained within the cone for periods of 30 seconds as would be required during data collection sessions. After several attempts of holding the rat restrained within the cone by means of a rubber band, it became evident that discarding the rubber band, and handling the rat for the duration of the experiment resulted in less duress on the rat, a faster procedure altogether, and significantly increased ease of setup on part of the experimenters. The rat was lured into the cone with treats. Upon entering the cone far enough to obtain the treat, the cone would be closed behind the rat, which would be forced to proceed into the cone as far as was permissible, while the posterior of the cone was held closed behind it. The rat was released from restraint and rewarded another treat upon the completion of each data collection session.
2.2 Statistical analysis

Once data was gathered, initial inspection revealed useful points, which accurately show increases and decreases of microwaves, and a baseline representing a minimum of microwaves to no microwaves detected. An example of this baseline is shown in the data is shown below in the following figure.

![Live Rat Microwave Backscatter](image)

**Figure 3.1** Data gathered during live rat data collection session. The baseline referred to in the text is clearly visible across the bottom of the plot, while the varying data of interest is shown across the middle section of the plot. Other points represent miscellaneous noise, which accounts for a small
portion of the total data points. A large majority of the data points rest on either the base line or in sequence with the varying data points of interest accurately representing microwaves that have interacted with the rat.

The source of this base line was never discovered, and could have been a result of either the microwave detector, the DAQ, or the LabView software used to record the data. The data points on the baseline occurred at seemingly random intervals, and in cluster sizes ranging from 1-6 in an apparently random manner. After several attempts of either removing the baseline directly by deleting the base line data points, or indirectly by smoothing the data out, which resulted in significantly less reliable data analysis, and a method of repositioning the baseline data points back among the meaningful data points was used for the final analysis.

Once the obstacle of dealing with the base line within the data was removed, spectral analysis was used to determine which frequencies best represented the data. An analysis of the clearest sections taken of each data collections session reveals a consistent peak just outside of a range representing a rat’s normal breathing rate around 3.2-3.5 Hz. The peaks may still be representative of the rat’s breathing rate, while outside the normal range of a rat’s breathing rate due to the rat’s state of unrest, as they are all slightly faster than a normal breathing rate. Some of the data sets do still have distinct peaks within the range representing a rat’s breathing rate, although they are not always as strong, or consistent across all the data sets.

The range of interest when looking for the rat’s breathing rate in the data is determined by the following equations:
Rat's minimum breathing rate $\approx \frac{70 \text{ breaths}}{\text{minute}} \times \frac{1 \text{ minute}}{60 \text{ seconds}} \approx \frac{1.17 \text{ breaths}}{\text{second}}$

Rat's maximum breathing rate $\approx \frac{145 \text{ breaths}}{\text{minute}} \times \frac{1 \text{ minute}}{60 \text{ seconds}} \approx \frac{2.417 \text{ breaths}}{\text{second}}$

These equations give us a range of frequencies between 1.17 and 2.147 Hz. If the data shows peaks in the power spectrums within this range of interest, they are likely to be caused by the rat’s breathing rate.
Chapter Three

Results

3.1 Results

The figures below show the analysis of data representing data gathered in the absence of a rat, data generated to simulate a breathing rate of 111 breaths per minute (a frequency of about 1.8 breaths per second), and data gathered while the rat was present. The plot of data showing data gathered in the absence of a rat is useful, because the power spectrum analysis reveals seemingly random frequencies representing the data as should be expected. The plot of generated data clearly shows a significant spike of power in the frequency representing a breathing rate of 111 breathes per minute. The plot of the experimental data reveals two peaks within the range representing a rat’s breathing rate, which may be representative of two breathing rates, from when the rat was more and less restless during data acquisition.

Each of the graphs has grey sections indicating an area representative of frequencies reasonably expected to be within a range representing a rat’s breathing rate. The blue lines are connecting data points.

The process to generate these plots utilizes several MatLab programs, which perform various functions. First the data must be saved as into an x variable. Then the program: SmoothDataFinal must be run, to restore the data points lying on the baseline
back into the useful data. Lastly, the program: SpectralDensityFinal will prepare the necessary variables, and plot a spectral analysis of the data, and the program: FillSpectralDensityPlot can be run with alterations depending on which data set was used, in order to generate the grey range locator indicating the expected range of a rat’s breathing rate.

Figure 4.1 Power spectrum of data gathered in the absence of a rat. Region indicated by green represents frequencies representative of a rat’s breathing rate. Strong peaks on both sides of this region indicate that the data is best accounted for by random frequencies.
Figure 4.2 Power spectrum of data generated with a frequency of about 1.8 Hz. Noise was incorporated into the data generation, which accounts for the broadness of the peak. Relative to other peaks around it, it is very prominent, and clearly shows that the data is strongly correlated with a frequency of about 1.8 Hz.
Figure 4.3 Power spectrum of selected data based on clarity gathered during the fourth session of live rat data collection.

3.2 Discussion

This research was designed to determine the usefulness of analyzing microwave backscatter data using Fourier spectral analysis as a means of detecting the breathing rate of a stationary rat. Determining the usefulness of this analysis technique could improve the effectiveness of microwave imaging when used as an aid to search and rescue efforts. The experimental results seem to agree with theoretical results as is shown in the figures,
above where two peaks show up within the grey region. The signal is not as prominent in the experimental results as it is in the theoretical results where a much larger peak is shown in comparison to others around it, but such is expected when comparing experimental data to theoretical data, because there are many more factors affecting the real data which are difficult to simulate in the artificial data.

The analysis of the data would be improved if there were a way to gather relevant data without the inclusion of the unwanted baseline. If the preferred improvement of ridding the data of the baseline is unachievable, the analysis could still be improved if there were better more established methods for determining the power spectrum of the data with irregular time intervals resulting from the removal of the unwanted baseline data. Discrepancies in the data would likely be cleared up and better explained by repeating the experiment with better equipment, and comparing the changes, or by increasing the duration of the data collection. Further testing of this method of analysis could help in determining and improving microwave-imaging capacities. Results from such an experiment would further improve our ability to determine whether microwave imaging could be a useful tool in search and rescue efforts.

The method of analysis used results in an apparent quadratic increase in intensity as frequency decreases. Initially it was thought that this was due to the sampling rate of 2000Hz used during data collection, but smaller segments of data have been used with the same sampling rate, which don’t display the same quadratic increase in intensity associated with a decrease in frequency.
Chapter Four

Conclusion

4.1 Conclusion

The data indicates that the analysis technique of using Fourier spectral analysis along with microwave imaging can be used to pick up a rat’s breathing rate. In order to be useful both the equipment and the analysis process would need improvement, however the research is in agreement that microwave imaging has the potential to find disaster survivors buried within rubble. The equipment can, and has been made portable, and successfully used to aid search and rescue efforts, but there may still be ways in which the equipment or methods can be improved.

Continuing work

There is still much research, which could contribute to the effectiveness of microwave imaging. This method of analysis in particular could be improved by better accounting for the baseline. The method used does not reliable restore data points on the baseline back into the majority of useful data points, because there’s still noise within the data skewing averages. If these data points representing noise could be selected through a measurement of the variance of data points around them, and then reworked into the
closest data points with the smallest variance, the data would be significantly cleaner, and thus more useful before analysis even started. Another improvement on the analysis of the data would be to generate waves using the frequencies that best represent the data chosen after the Fourier spectral analysis, and match them to the data. Then apply a least square fit, to determine how well the frequencies really match the data.
## Section 1: General Information

1. **Project Title:**

2. **Principal Investigator:**
   - Department: 
   - Telephone: 208-496-7740
   - Email: linest@byui.edu

4. **Protocol Type:**
   - Instruction
   - Training
   - Research

5. **Protocol Category:**
   - New
   - Revision ~ Original Protocol #:

6. **Will this protocol require funding?**
   - Yes
   - No

7. **Please specify the source of funding for this protocol:**

8. **Project Period:**
   - 6 / 01 / 2015 to 6 / 05 / 2015

9. **Other Personnel (including students) Working with Animals on this Project:**

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<th>Department</th>
<th>Phone</th>
<th>Email</th>
<th>Role</th>
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<tr>
<td>Giles B. Wright</td>
<td></td>
<td>(541) 415-0650</td>
<td><a href="mailto:wri08004@byui.edu">wri08004@byui.edu</a></td>
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## Section 2: Study Overview and Assessment of Unnecessary Duplication

1. **Provide a brief abstract describing the nature and purpose of this study.**

   **Include an answer to the following question: Why is this study important?**

   The purpose of this study is to look at a unique model for life detection systems. The basis of this study is the idea that long-wavelength light will scatter from higher living organisms in a way that varies as the organism’s volume changes with breathing.
Previous studies have produced have likely captured the breathing rate of the rat. This study is designed to determine definitely if the microwave system is capable of detecting the breathing rate of the rat. The results will let us build better detectors. This study could lead to the development of systems for the detecting of people trapped in collapsed buildings or buried in avalanches.

2. **BRIEFLY EXPLAIN THE EXPERIMENTAL DESIGN AND SPECIFY ALL ANIMAL PROCEDURES.**
   
   **THIS DESCRIPTION SHOULD ALLOW THE IACUC TO UNDERSTAND THE EXPERIMENTAL COURSE OF AN ANIMAL FROM ITS ENTRY INTO THE EXPERIMENT TO THE ENDPOINT OF THE STUDY. SPECIFICALLY ADDRESS THE FOLLOWING:**

   The animal will be placed in a cone. The experimental setup includes a light emitter and receiver. The emitter and receiver will be placed on a uniform side of the rat. The emitter releases light with wavelength of 2.8 cm, and a frequency of 10.7 GHz. The rat will be exposed to 30-second burst of light. 10.7 GHz light is not detectable by rat eyes; the rat will be unaware of the light. The receiver will measure the light that bounces back off the rat. The major difference from previous conducted studies is the limited motion of the rat will result data with more certain data analysis. The previous experiments were done as a proof of concept. This experiment will be repeated four times to ensure good results.

   During the week prior to exposing the rat to any microwaves, the rat will be introduced to restraint by means of a cone with increasing increments of time. The first day, the rat will simply be inserted into the cone, and then immediately removed. The second day the rat will be held in the cone for 10 seconds. The third day it will be held in the cone for 20 seconds. The next day as well as during the experiment, the rat will be held in the cone for periods of 30 seconds. The rat will be removed from the cone and any restraints in between each experiment. The rat will experience a total exposure of 2 minutes to the microwaves. The entire procedure consisting of four trials will last 6 minutes, with downtime of about 4 minutes total in between periods of restraint. As shown in Adang's paper, results of similar waves, at much longer exposures than those this experiment is purposing, had minimal negative effects to the animal. Adang, who exposed the rats to similar wavelengths for two hours every day, seven days a week, at three and eight months, only noted that the only difference between exposed to unexposed rats was that the exposed group had a 20% difference of monocytes.

   The rat will be transported from Ricks 113A to 113B and back in its enclosure. The rat will be returned to its enclosure before looking at data. Total time in the cone will be less than five minutes. After data is collected, the animal will be released to the endpoint transfer to Protocol number #1302001: Investigating Principles of Learning Through Maze Running, bar pressing, and navigation through other obstacles, by rats and veterinarian technicians’ restraint techniques and minor procedures.

<table>
<thead>
<tr>
<th>• <strong>Experimental injections or inoculations</strong> (substances, e.g., infectious agents, adjuvants, etc.; dose, sites, volume, route, and schedules).</th>
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<td>• <strong>Blood withdrawals</strong> (volume, frequency, withdrawal sites, and methodology).</td>
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<td>• <strong>Surgical procedures</strong> (provide details of survival and non-survival surgical procedures on Appendix II).</td>
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<td>• <strong>Radiation</strong> (dosage and schedule).</td>
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<tr>
<td>• <strong>Methods of restraint</strong> (e.g., restraint chairs, collars, vests, harnesses, slings, etc.). Include how animals are restrained for routine procedures like blood.</td>
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withdrawals. Prolonged restraint must be justified with appropriate oversight to ensure it is minimally distressing. Describe any sedation, acclimation or training to be utilized. The rat will be placed in a cone identical to those commonly used for the administration of injections.

- **Animal identification methods** (e.g., ear tags, tattoos, collar, cage card, implant, etc.). cage card

- **Resultant effects**, if any, that the animals are expected to experience (e.g., pain or distress, ascites production, etc.). N/A

- **Other potential stressors** (e.g., food or water deprivation, noxious stimuli, environmental stress) and **procedures to monitor and minimize distress**. If a study is USDA Classification E, indicate any non-pharmaceutical methods to minimize pain and distress.

  During the week prior to exposing the rat to any microwaves, the rat will be introduced to restraint by means of a cone with increasing increments of time. The first day, the rat will simply be inserted into the cone, and then immediately removed. The second day the rat will be held in the cone for 10 seconds. The third day it will be held in the cone for 20 seconds. The next day as well as during the experiment, the rat will be held in the cone for periods of 30 seconds. During the experiment, the rat will be removed from restraint while the equipment is reset and prepped for the next trial. This will all be done in an effort to reduce distress on the rat.

- **Experimental endpoint criteria** (e.g., tumor size, percentage body weight gain or loss, inability to eat or drink, behavioral abnormalities, clinical symptomatology, or signs of toxicity) must be specified when the administration of tumor cells, biologics, infectious agents, radiation or toxic chemicals are expected to cause significant symptomatology or are potentially lethal. List the criteria to be used to determine when euthanasia is to be performed. Death as an endpoint must always be scientifically justified. N/A

- **Veterinary care** (indicate desired plan of action in case of animal illness, e.g., initiate treatment, call investigator prior to initiating treatment, euthanize). N/A

### Section 3: Assessment of Unnecessary Duplication

1. **USDA regulations require that the principal investigator assure that the proposed research does not unnecessarily duplicate previous work.** Provide a narrative describing the methods or sources used to determine that this project does not duplicate previous work, or, if it does, why duplication is necessary. If a computer-assisted literature search was conducted, provide the name(s) of the database(s) used, and the date(s) of the search(es). Please keep copies of the search results.

   The initial search started with looking for papers written by the members of the initial paper. We realized that they had continued to work under the same model, just using it under different circumstances.


   This was the original article that started our desire to try a different shape. This article is the basis for all future articles that I found on the subject.
Section 4: Justification of Species Selection and Number of Animals

1. **COMPLETE FOLLOWING TABLE:**

<table>
<thead>
<tr>
<th>SPECIES OR STRAIN</th>
<th>COMMON NAME</th>
<th>NUMBER TO BE USED IN YR. 1</th>
<th>NUMBER TO BE USED IN YR. 2</th>
<th>NUMBER TO BE USED IN YR. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>rattus rattus/ norvegicus</td>
<td>Lab rat</td>
<td>0</td>
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2. **JUSTIFY THE SELECTION OF SPECIES (CHECK ALL APPLICABLE BOXES).**

- **☐ THIS IS A NEW MODEL.**
- **☐ A LARGE DATABASE EXISTS FOR THIS SPECIES, WHICH WILL ALLOW COMPARISONS WITH PREVIOUS DATA.**
- **☐ THE ANATOMY, GENETICS, PHYSIOLOGY, OR BEHAVIOR OF THE SPECIES IS UNIQUELY SUITED TO THE STUDY.**
- **☐ THE SPECIES SELECTED IS THE LOWEST POSSIBLE ON THE PHYLOGENETIC SCALE.**
- **☐ THE RESULTS OF THIS STUDY WILL BE DIRECTLY APPLICABLE TO THE HEALTH AND CARE OF THIS SPECIES.**
- **☒ OTHER (PLEASE DESCRIBE):** The rat is similar enough to a human in biology that it makes a good human analog for data collection.

3. **JUSTIFY THE NUMBER OF ANIMALS TO BE USED. THE NUMBER OF ANIMALS SHOULD BE THE MINIMUM NUMBER REQUIRED TO FULFILL THE PURPOSE/OBJECTIVE OF THE STUDY AND/OR TO OBTAIN VALID AND MEANINGFUL RESULTS.**

One animal is necessary to test our model on a living organism. The scanning has been done with water balloons, and varying sizes has been successfully detected. A rat is similar in biology to a person, in the fact that it has regulated organs. The lab rat is the right size so it won’t be hurt by long wavelength light. We will use the rat to collect raw data to be analyzed under a new geometrical model.

Section 5: Pain or Distress Classification and Consideration of Alternatives

1. **PAIN OR DISTRESS CLASSIFICATION:** (see USDA Classifications and examples below)

   **B.** Animals being bred, conditioned or held for use in teaching, testing, experiments, research or surgery, but not yet used for such purposes.  
   **Examples:**
   - Breeding colonies of any animal species (USDA does not require listing of rats, mice, birds) that are held in legal sized
caging and handled in accordance with the Guide and other applicable regulations. Breeding colony includes parents and offspring.

- Newly acquired animals that are held in proper caging and handled in accordance with applicable regulations.
- Animals held under proper captive conditions or wild animals that are being observed.

C. Animals upon which testing, research, experiments, or tests will be conducted involving no pain, distress, or use of pain-relieving drugs.

**Examples:**

- Procedures performed correctly by trained personnel such as the administration of electrolytes/fluids, administration of oral medication, blood collection from a common peripheral vein per standard veterinary practice (dog cephalic, cat jugular) or catheterization of same, standard radiography, parenteral injections of non-irritating substances.
- Euthanasia performed in accordance with the recommendations of the most recent AVMA Panel on Euthanasia, utilizing procedures that produce rapid unconsciousness and subsequent humane death.
- Manual restraint that is no longer than would be required for a simple exam; short period of chair restraint for an adapted nonhuman primate.

D. Animals upon which experiments, teaching, research, surgery, or tests will be conducted involving accompanying pain or distress to the animals and for which appropriate anesthetic, analgesic, or tranquilizing drugs will be used.

**Examples:**

- Surgical procedures conducted by trained personnel in accordance with standard veterinary practice such as biopsies, gonadectomy, exposure of blood vessels, chronic catheter implantation, laparotomy or laparoscopy.
- Blood collection by more invasive routes such as intracardiac or periorbital collection from species without a true orbital sinus such as rats and guinea pigs.
- Administration of drugs, chemicals, toxins, or organisms that would be expected to produce pain or distress but which will be alleviated by analgesics.

E. Animals upon which teaching, experiments, research, surgery, or tests will be conducted involving accompanying pain or distress to the animals and for which the use of appropriate anesthetic, analgesic, or tranquilizing drugs will adversely affect the procedures, results, or interpretation of the teaching, research, experiments, surgery, or tests.

**Examples:**

- Procedures producing pain or distress unrelieved by analgesics
such as toxicity studies, microbial virulence testing, radiation sickness, and research on stress, shock, or pain.

- Surgical and post-surgical sequella from invasion of body cavities, orthopedic procedures, dentistry or other hard or soft tissue damage that produces unrelieved pain or distress.
- Negative conditioning via electric shocks that would cause pain in humans.
- Chairing of nonhuman primates not conditioned to the procedure for the time period used.

2. **CONSIDERATION OF ALTERNATIVES**: If any procedures fall into USDA’s Classification D or E, causing more than momentary or slight pain or distress to the animals, describe your consideration of alternatives and your determination that alternatives are not available. Delineate the methods and sources used in the search. Database references must include databases searched, the date of the search, period covered, and the keywords used. Alternatives include methods that (1) refine existing tests by minimizing animal distress, (2) reduce the number of animals necessary for an experiment, or (3) replace whole-animal use with in vitro or other tests. When ascites production is used to produce antibodies, justification needs to be given as to why in vitro systems cannot be used.

3. **ANESTHESIA, ANALGESIA, TRANQUILIZATION, OTHER AGENTS**: For ‘Classification D’ animals, specify the anesthetics, analgesics, sedatives, or tranquilizers that are to be used. Include the name of the agent(s), the dosage, route, and schedule of administration.

4. **‘CLASSIFICATION E’ ANIMALS**: An explanation of the procedures producing pain or distress in these animals and the justification for not using appropriate anesthetic, analgesic, or tranquilizing drugs must be provided on Appendix I. This information is required to be reported to the USDA, will be available under the Freedom of Information Act, and may be publicly available on the internet via USDA’s website.

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**Section 6: Animal Housing and Husbandry**

1. **FROM WHERE WILL YOU OBTAIN THE ANIMALS INVOLVED IN THIS STUDY (E.G., SPECIFIC COMMERCIAL VENDOR, TRANSFER FROM ANOTHER PROTOCOL)?**
   - Charles River Company

2. **INDICATE IF THE ANIMALS INVOLVED IN THIS STUDY HAVE BEEN OR WILL BE USED IN OTHER EXPERIMENTS OR INSTRUCTIONAL LABS.**
   - □ **THE ANIMALS INVOLVED IN THIS STUDY HAVE NOT BEEN AND WILL NOT BE USED IN OTHER STUDIES OR INSTRUCTION.** (Go to question 4.)
   - □ **THE ANIMALS INVOLVED IN THIS STUDY HAVE BEEN USED IN PRIOR STUDIES OR INSTRUCTION.** (Respond to question 3, and then go to question 4.)
   - ☑ **THE ANIMALS INVOLVED IN THIS STUDY WILL BE USED IN CONCURRENT STUDIES OR INSTRUCTION.** (Respond to question...
3, and then go to question 4.)

3. **Please describe prior or concurrent use of these animals, and what measures will be taken to prevent over-use.** #1302001: Investigating Principles of Learning Through Maze Running, bar pressing, and navigation through other obstacles, by rats and veterinarian technicians restraint techniques and minor procedures. The animal will be placed in marked cage and we will be the ones to remove the animal and put them back into the enclosure. The rat is only required for a short time with no activity expected from the rat in this study.

4. **Please indicate where the animals involved in this study will be housed (include facility name, building, and room number as applicable). The concurrent study will be in charge of the feeding, housing of the animal and all veterinary concerns.**
   
   *Lab 113*

5. **Provide the location(s) where experimental procedures with animals will be performed (include facility name, building, and room number, as applicable).**
   
   *Lab 113*

6. **Are special or unusual housing or husbandry conditions required for the animals involved in this study?**
   
   - [ ] **Special or unusual housing or husbandry conditions are required.**
     
     *(Respond to questions 7 and 8, and then go to section 7.)*
   
   - [X] **There are no special or unusual housing or husbandry requirements.** *(Go to section 7.)*

7. **Please indicate what type of special or unusual housing or husbandry conditions are required.**
   
   - [ ] **Food restriction.**
   
   - [ ] **Water restriction.**
   
   - [ ] **Single housing of social animals.**
   
   - [ ] **Brief restraint.**
   
   - [ ] **Environmental temperatures outside of established ranges.**
   
   - [ ] **Captive housing of wild-caught species.**
   
   - [ ] **Other. Describe:**

8. **Please describe the necessity for special or unusual housing or husbandry requirements, and how animal comfort will be assured under the conditions.**
   
   *N/A*

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**Section 7: Animal Well-Being**

1. **Will animals be physically restrained longer than one hour in a conscious state?**
   
   - [ ] **Yes** ~ **Complete table below**
   
   - [X] **No**

<table>
<thead>
<tr>
<th>SPECIES</th>
<th>PURPOSE</th>
<th>TYPE OF RESTRAINT</th>
<th>FREQUENCY</th>
<th>DURATION</th>
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**JUSTIFY THE DURATION OF RESTRAINT:**

**HOW WILL ANIMALS BE MONITORED?**

2. **HAVE ANY OF THESE ANIMALS BEEN PREVIOUSLY USED IN AN EXPERIMENTAL PROCEDURE OR ANOTHER PROTOCOL?**
   - **YES** ~ LIST SPECIES AND EXPLAIN IN FIELD BELOW
   - **NO**

   **EXPLANATION:** The rat will use be used concurrently with the protocol. #1302001: Investigating Principles of Learning Through Maze Running, bar pressing, and navigation through other obstacles, by rats and veterinarian technicians restraint techniques and minor procedures. So the rat might be trained and used before we get to scan the rats.

3. **IS IT LIKELY ANIMALS IN THIS PROTOCOL WILL EXPERIENCE PAIN/DISCOMFORT?**
   - **YES** ~ DESCRIBE IN FIELD BELOW
   - **NO**

   **DESCRIPTION:** The rat may experience slight discomfort due to minimal restraint.

4. **WILL BIOLOGICAL FLUID(S) BE COLLECTED?**
   (BLOOD, LYMPH, BILE, CEREBROSPINAL FLUID, URINE, ETC.)
   - **YES** ~ COMPLETE TABLE BELOW
   - **NO**

<table>
<thead>
<tr>
<th>SPECIES</th>
<th>FLUID</th>
<th>VOLUME</th>
<th>COLLECTION FREQUENCY</th>
<th>COLLECTION SITE</th>
<th>ANESTHETIC</th>
<th>DOSE</th>
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5. **EXPLAIN HOW YOU WILL MINIMIZE EXPECTED ANIMAL PAIN AND DISTRESS AND ENHANCE ANIMAL WELL-BEING (E.G., USE OF SEDATIVES, TRANQUILIZERS, OR ANESTHETICS; FAMILIARIZATION/CONDITIONING OF THE ANIMAL; ENRICHMENT OPPORTUNITIES).**

Rather than anestatizing the rat to ensure motion is limited, and due to the brevity of our experiment, we will follow standards for restraint commonly used when administering injections. No injections will be administered, as the immobilization due to the cone will be sufficient to ensure good data collection. The rat will also be introduced by increments to this method of restraint during the week prior to exposing the rat to any microwaves. The first day, the rat will simply be inserted into the cone, and then immediately removed. The second day the rat will be held in the cone for 10 seconds. The third day it will be held in the cone for 20 seconds. The next day as well as during the experiment, the rat will be held in the cone for periods of 30 seconds. During the experiment the rat will be removed from restraints while the equipment is reset and prepped for the next trial.

**Section 8: Euthanasia and Animal Disposal**
1. **Will animals be euthanized during or at the conclusion of this study?**
   - ☒ Animals will not be euthanized. *(Respond to question 2, and then go to section 9.)*
   - ☐ Animals will be euthanized. *(Go to question 3.)*

2. **Describe the intended state of the animal(s) at the conclusion of the study (e.g., transferred to another approved study, maintained in a research, teaching, or training herd, donated to an animal shelter, etc.).**
   Protocol number #1002003: Investigating Principles of Learning Through Maze Running, bar pressing, and navigation through other obstacles, by rats

3. **Indicate the proposed method of euthanasia. If a chemical agent is used, specify the dosage and route of administration. If the method(s) of euthanasia include those not recommended by the AVMA Panel Report on Euthanasia (e.g., decapitation or cervical dislocation without anesthesia), provide justification why such methods must be used.**

4. **How will you dispose of animal carcasses?**

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**Section 9: Principal Investigator Assurance**

- ☒ The information provided in this protocol form accurately reflects the intended use of animals for this research activity.
- ☒ I certify that I have completed the institution’s base training module (“The humane care and use of laboratory animals”) and the species module(s) relevant to this study.
- ☒ I certify that I have completed the institution’s safety module (“Occupational health and safety”).
- ☒ I certify that all personnel involved in this study have completed the institution’s base training module (“The humane care and use of laboratory animals”), the species module(s) relevant to this study, and the safety module (“Occupational health and safety”).
- ☒ I certify that I have discussed the design and implementation of this protocol with the attending veterinarian.
- ☒ I certify that this protocol is not unnecessarily duplicative of previous work.
- ☒ For USDA classification D and E protocols only. I certify that I have reviewed the pertinent scientific literature and the sources and/or databases as noted in Section 5.2, and have found no valid alternative to any procedures described herein which may cause more than momentary pain or distress.
- ☒ I certify that I will obtain formal approval from the IACUC prior to implementing any significant changes in this study.
- ☒ I certify that I will notify the IACUC regarding any unexpected study results that impact the animals, and that any unanticipated pain or
DISTRESS, MORBIDITY, OR MORTALITY WILL BE REPORTED TO THE ATTENDING VETERINARIAN AND THE IACUC.

- IF THE IACUC APPROVES MY APPLICATION, I AGREE TO EXECUTE THIS WORK AS DESCRIBED AND ASSUME RESPONSIBILITY FOR THE SUPERVISION AND WORK OF ALL ASSOCIATED PERSONNEL.

- I AGREE TO COMPLY WITH THE PROVISIONS OF THE ANIMAL WELFARE ACT, THE PUBLIC HEALTH SERVICE POLICY, AND THE GUIDELINES ESTABLISHED BY BYU-IDaho REGARDING THE CARE AND USE OF LABORATORY ANIMALS.

- TRAINING OF RESEARCHERS IN PROPER POSITIVE REINFORCEMENT TECHNIQUES OF RATS BY THE LAB RAT TECHNINANS

STATE THE REASON/S IF YOU CANNOT CERTIFY OR AGREE TO ANY OF THESE STATEMENTS:

<table>
<thead>
<tr>
<th>PRINCIPAL INVESTIGATOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIGNATURE:</td>
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<tr>
<td>DATE:</td>
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</table>

Section 10: Protocol Approval

<table>
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<tr>
<th>CERTIFICATION OF REVIEW AND APPROVAL BY THE INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE:</th>
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<tbody>
<tr>
<td>NAME:</td>
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<td>SIGNATURE:</td>
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OFFICE USE ONLY

<table>
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<th>DATE RECEIVED:</th>
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<th>PROTOCOL #:</th>
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Appendix B

The data, and MatLab codes can be found at this URL:

https://www.dropbox.com/sh/jw8y4xfu9esfo1g/AAD38lJOCz29_h1qZltq32Fta?dl=0
References


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