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Project Title: Wind turbine generated sound: Targeted research to improve measurement, analysis, and annoyance thresholds based on measured human response

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Congressional District: (Corporate office) Minnesota 5th
Congressional District: (Project location) Minnesota 1st and 5th

MILESTONE REPORT 7

Executive Summary

Milestone 7 report includes the final research plan and protocols report for human response testing, summarized in the technical progress section and detailed in Appendix A, an update summary on the first test group for the human response testing, and an IRB-approved safety plan for human subjects to be tested as Appendix B.

Human response testing consists of a target of approximately 80-100 healthy people individually subjected to a combination of amplitude modulated audible and infrasound noise files for a short duration in a controlled laboratory environment. Testing consists of postural stability, self-reported detection and rating of intensity of amplitude modulated audible sound and infrasound from turbines, and self-reported symptoms such as nausea. Subjects are blind to the knowledge that the stimuli were recorded or derived from acoustic measurements near wind turbines.

To date, fifty-two healthy subjects have attended to audible and infrasound signals measured from wind turbines and recreated in the laboratory. A few subjects reliably indicated detection of infrasound signals. A few participants indicated mild symptoms, a rating of 1 on a scale from 0 to 4, following the test. So far, no evidence of change in postural sway in the presence of infrasound has been observed.

Technical Progress

Research Plan: Human Response Study

Human response testing consists of a target of 80 – 100 people individually subjected to a combination of amplitude modulated (AM) audible and infrasound noise files for a short duration in a controlled laboratory environment. Results consist of measured postural stability, self-reported detection and rating of intensity of the sound, and self-reported symptoms such as nausea. Subjects are blind to the knowledge that the stimuli were recorded or derived from acoustic measurements near wind turbines.

Facilities: Human Response Study

Each individual is tested at the Center for Applied and Translational Sensory Science (CATSS) and the Multi-Sensory Perception (MSP) laboratory at the University of Minnesota. The testing protocol was approved by the University of Minnesota Institutional Review Board (IRB), which is included as Appendix B. The testing room is a 6 by 15 by 8 foot room with reproduced audible and infrasound recordings obtained from the field measurements of wind turbine noise.

Postural stability and sway is measured by having individuals stand on an AMTI balance forceplate which measures left-right and front-back sway continuously.

Infrasound stimuli is generated using an Eminent Technologies rotary subwoofer with a frequency range of 0.01 to 30 Hz. Audible stimuli are played through a custom subwoofer with a frequency range of 50-800 Hz simulating the audible turbine noise.

Audible and infrasound signals were recorded from the field sites as described in milestone reports 5 and 6. The signals are recreated in the CATSS lab and noise levels are calibrated using the measurement equipment from the field campaign as well as a Brüel and Kjær 2250 sound level meter.

Stimuli: Human Response Study

Three types of infrasound stimuli are presented: a) no infrasound, b) unaltered recorded infrasound obtained from field data; and c) spectrally peaky infrasound artificially generated to enhance spectral peaks.

Three types of audible stimuli are presented: a) no audible sound, b) steady-state recorded audible turbine noise, and c) the audible turbine noise with sinusoidal amplitude modulation at the blade passing frequency superimposed on the signal with a modulation depth of 10 dB.

All exposure is randomized and presented with eyes open and eyes closed. Each stimuli is repeated. Each stimulus lasts 40 s, including a 5 s start-up, 30 s of the stimulus, and a 5 s ramp down.

Measurements: Human Response Study

Measurement of human response include measurements from the balance force plate and self-reporting from the individuals. During exposure, postural sway is measured for front-back and left-right motion and analyzed for the area of the center of pressure (CoP) which indicates the amount of movement during and after the stimulus. After each exposure condition, listeners are asked to indicate (Yes/No) whether they detected the acoustic noise of interest and asked to rate the pleasantness/unpleasantness of the sounds using a sliding visual scale from Very Unpleasant to Very Pleasant. Following the full procedure, participants fill out a survey of any symptoms they experienced during the session.

Analysis: Human Response Testing

The results of the postural sway (CoP) is analyzed using several factors:

- Pre- vs post-test baseline change in CoP indicating whether the postural stability of the individual significantly changed overall after exposure to the full range of stimuli.
- Comparison of CoP during amplitude modulated versus unmodulated audible sounds
- Comparison of CoP during infrasound present versus absent

The results of the self-reporting are used for descriptive statistics of detection and symptoms during testing.

Interim Summary of Findings

To date, fifty-two healthy adult subjects ages 21-73 years attended to audible and infrasound signals recorded from a wind turbine and re-created in the laboratory. Stimuli consisted of modulated and unmodulated audible sound at 50 dB SPL, as well as recorded and peak-enhanced infrasound at an overall level of approximately 85 dB SPL (peaks up to 95 dB SPL). Participants were tested for their postural stability, detection, and ratings of audible and infrasound emissions from turbines. They also completed pre- and post-testing surveys for symptoms of imbalance. All subjects were blind to the knowledge that the stimuli were recorded from wind turbines. No significant adverse effects from healthy adults have been noted to date. Some individuals reliably indicated detection of infrasound signals. A few participants indicated only mild symptoms (a rating of 1 on a scale from 0 to 4) following the test.

General Effects:

To date, We have no evidence of any change in postural sway in the presence of infrasound for the group tested. We have no evidence of change in postural sway depending on the type of infrasound presented (recorded vs peak-enhanced) for the group tested. Among the individuals who showed an increase in postural sway from the pre-test to the post-test, there does not appear to be a relationship to the subjective report of fatigue, dizziness, etc.

Symptom Reports:

To date, no participants have reported motion sickness. On a 0-3 scale (0 = not at all, 1 = mild, 2 = moderate, 3 = severe), most participants reported 0 post-testing. About half of participants reported 0 for all symptoms.

Of the non-zero responses, most are 1, or “mild” symptoms. A few scattered “moderate” reports (2) have been made. There have been no reports of any “severe” symptoms. The moderate symptoms and number of occurrences out of 52 are shown here:

General discomfort – 1
Fatigue – 3
Eyestrain – 1
Difficulty focusing – 1
Sweating – 1
Fullness of head/ears – 4
Stomach awareness – 1

For the subjective rating (negative to positive slider scale):

All combinations of the audible and infrasound were rated neutral on a positive to negative slider scale.

For the detection:

As a group, participants detected something other than the audible stimulus for about half of the trials that contained an infrasound stimulus. They detected something other than the audible stimulus for a fifth of the trials that did not contain an infrasound stimulus. Some individuals reliably detected the infrasound stimuli.

Appendix A

Stimuli Details

Original audio files used:

AudibleWAV = dw_300m_run13_40to70_audible_2016_06_09.wav

InfrasoundWAV = dw_300m_run13_40to70_infrasound_2016_06_09.wav

The 30-s files were extended to 40 s by duplicating the first and last 5 seconds and time reversing the duplicated "padding".

Audible Sound (Subwoofer)

"White"

(Gaussian) white noise.

Presentation Level: 40 dBA

"Flat"

AudibleWAV used.

Band-pass filtered at 50 and 4000 Hz (3rd order Butterworth).

Presentation Level: 50 dBA

"AM"

"Flat" stimuli with 0.8-Hz modulation imposed on it with a depth of 10 dB (peak-to-trough dB difference).

Presentation Level: 50 dBA (measured at the modulation's peak)

(See Figure 1 for "Flat" and "AM" waveforms and spectra.)

Infrasound (Rotary Woofer)

"IOff"

Rotary Woofer (fan) on, but no signal.

"IRec"

InfrasoundWAV used.

Low-pass filtered at 50 Hz (3rd order Butterworth).

"IEnh"

"IRec" stimuli's spectra smoothed with 100-(FFT)-point averaging window.

Random phases given to all spectral components.

Pure tones added to create a 0.8-Hz infrasound signal (with five harmonics).

Frequencies = [0.8, 1.6, 2.4, 3.2, 4.0, 4.8] Hz

Relative Levels to IRec peaks = [0, -7, -12, -18, -20, -22] dB

Low-pass filtered at 50 Hz (3rd order Butterworth).

(See Figures 2, 3 and 4 for infrasound stimuli waveforms, original spectra, and measured spectra/levels.)

9 Stimuli Conditions

(All stimuli are windowed with 1-s raised cosine on/off ramps.)

IOff - White	IRec - White	IEnh - White
IOff - Flat	IRec - Flat	IEnh - Flat
IOff - AM	IRec - AM	IEnh - AM

Test Outline

Pre-Test (no stimulus):

Two sets of: Eyes Open, Eyes Closed, and Reading Text conditions.
Random condition order within each set.

Main Experiment:

9 Eyes Closed conditions
9 Eyes Open conditions
9 Eyes Closed conditions
All stimuli conditions present in each set, order randomized.
Mid-session break before block 14 (of 27), half-way through Open condition set.

Post-Test (no stimulus):

One set of: Eyes Open, Eyes Closed, and Reading Text conditions.
Random order.

Miscellaneous Procedural Details

The subject/monitor/table are in the center of room, with the subject facing the subwoofer and the rotary woofer to their back.

The subject initiates each block (by clicking a button on the display) and can abort the experiment at this point before each block.

Subject is given auditory instructions (through subwoofer) for the type of condition:

"Please close your eyes."
"Keep your eyes open."
"Read the text on the wall."

Subject response after each block:

"Did you sense anything besides the sound?"
"Yes" or "No" buttons.
"How would you rate the condition?"
Slider: "Very Negatively" -to- "Neutral" -to- "Very Positively"

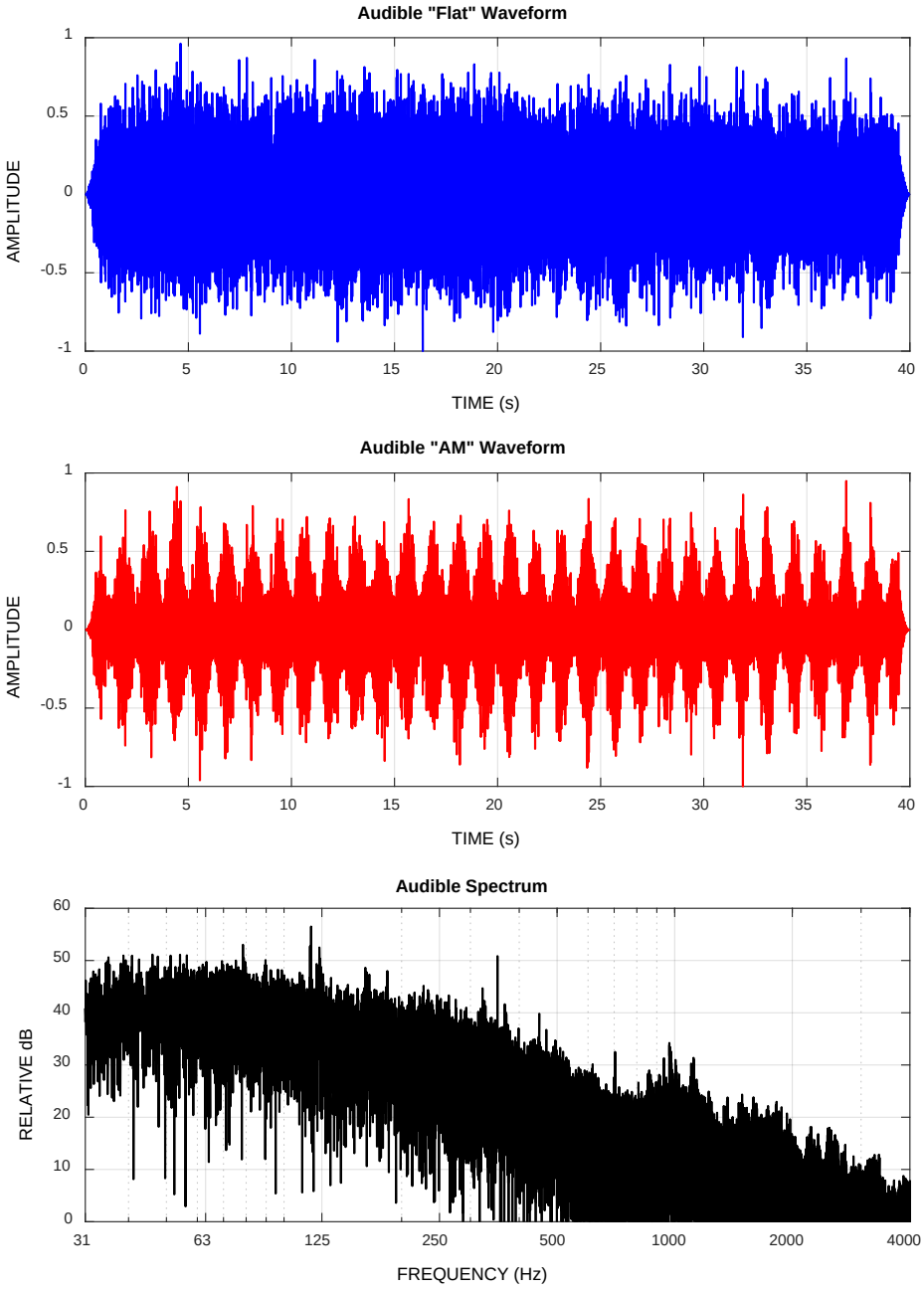

Figure 1: Audible noise stimulus with and without amplitude modulation

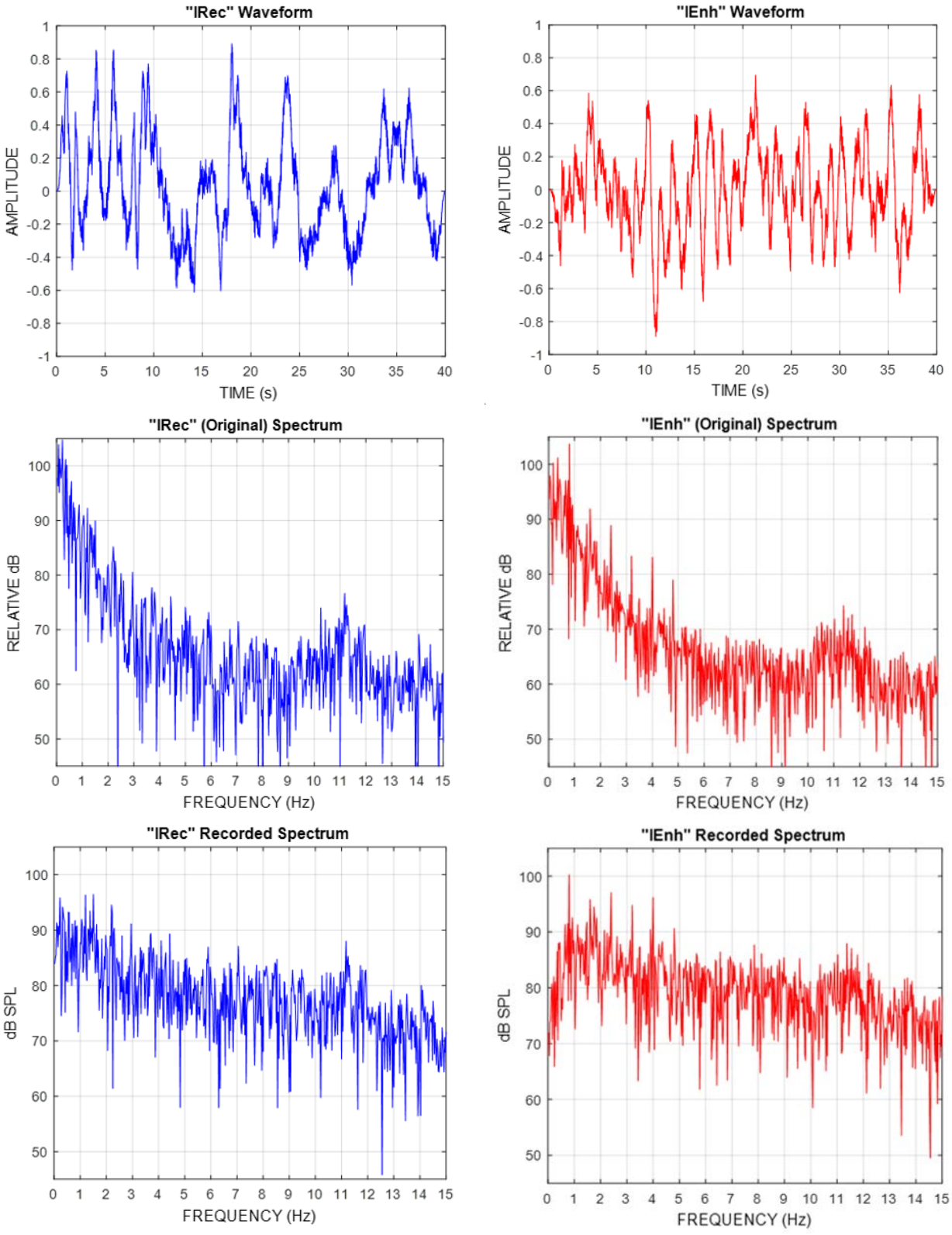

Figure 2: Waveforms and spectra for the original (IRec) and enhanced infrasound stimulus (IEnh)

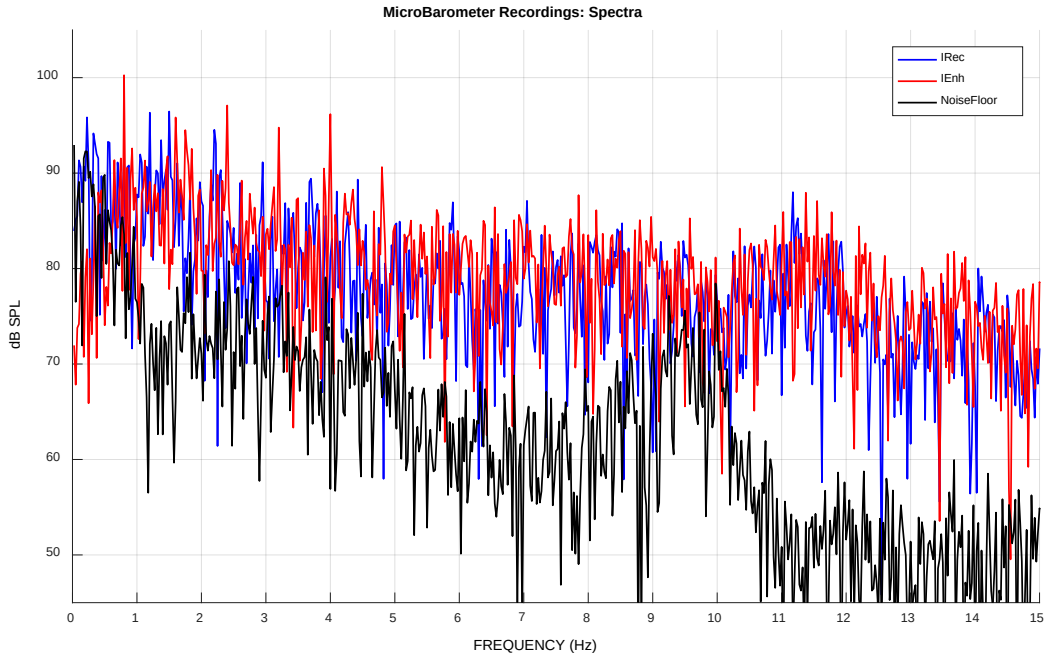

Figure 3: Spectral plots of the original infrasound, enhanced infrasound, the background noise in the CATSS lab.

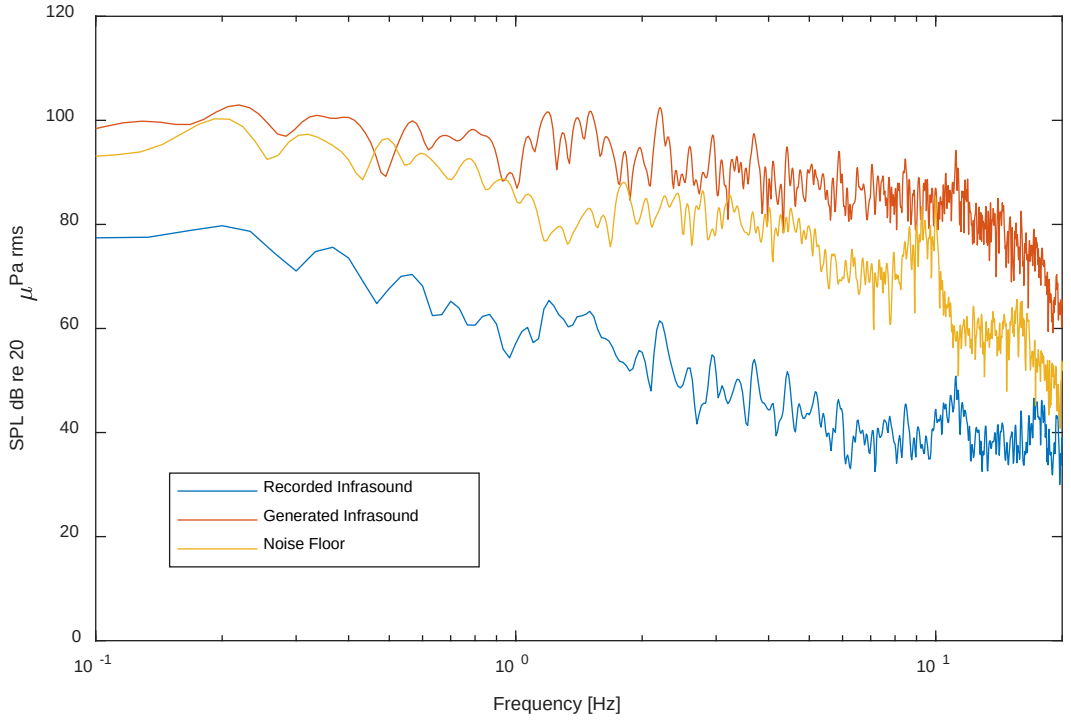

Figure 4: Spectral plots of infrasound for a 30 s segment of field measurement data (blue), the noise floor in the lab (yellow), and the reproduced infrasound (red)

Appendix B

PROTOCOL TITLE:

Wind turbine generated sound: Targeted research to improve measurement, analysis, and annoyance thresholds based on measured human response

PRINCIPAL INVESTIGATOR or FACULTY ADVISOR:

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STUDENT INVESTIGATOR:

VERSION NUMBER/DATE:

Ver 1, Dec 2017

1610M96881

REVISION HISTORY

Revision #	Version Date	Summary of Changes	Consent Change?

Table of Contents

ABBREVIATIONS/DEFINITIONS

- None

STUDY SUMMARY

Study Title	Wind turbine generated sound: Targeted research to improve measurement, analysis, and annoyance thresholds based on measured human response
Study Design	Observe human responses to turbine generated signals
Primary Objective	Determine response to wind turbine generated sound and infrasound
Secondary Objective(s)	Describe annoyance or subjective response to sound and infrasound from wind turbines
Research Intervention(s)/Investigational Agents	None
Scientific Assessment	Not required, Minimial Risk Study
IND/IDE # (if applicable)	N/A.
IND/IDE Holder	N/A.
Investigational Drug Services # (if applicable)	N/A.
Study Population	Healthy adults ages 21 to 75 years
Local Sample Size (number of participants recruited locally)	100

Objectives

1.1 Purpose:

We will identify the range of normal responses to acoustic and infrascound signals generated by wind turbines, and will describe those outliers who experience imbalance or annoyance to those sounds.

Background

Significance of Research Question/Purpose:

Little to no scientific data exists to confirm or refute the extent of the negative effects of wind turbine audible sound and infrasound. Claims are made that emissions from wind turbines are the cause of self-reported negative health effects such as imbalance, disequilibrium, and loss of sleep (e.g. Knopper 2011). Data from Salt and Huller (2010) suggest that there may be a likely cochlear mechanism for some people to experience disequilibrium or imbalance in the presence of turbine-generated infrasound (Salt and Huller, 2010). There does not appear to be enough energy in infrasound from wind turbines to allow detection by humans, and there is only limited data regarding human tolerance of infrasound from any source. We propose, therefore, to test 50 typical healthy adult human subjects for their detection, annoyance, and sway to modulated audible sound and infrasound typical of wind turbines.

This is a part of a larger study of wind turbine emissions, which are being measured in the field. Following field measurements, we will generate modulated audible acoustic noise based on the measured turbine noise that is deemed to be most annoying based on initial pilot testing. In preliminary testing we will collect pilot data to determine the more annoying components of the audible sounds. We will generate both modulated and unmodulated versions of these most annoying sounds so that we can determine the effect of the modulation patterns on the overall annoyance ratings. We will also generate infrasound signals similar to those emitted by the experimental turbine to determine thresholds for annoyance for infrasound.

Overall the results will help us to determine:

- The effect of the modulation patterns on ratings of annoyance of audible sounds
- Characteristics of those listeners who report greater annoyance
- Difference between clinical and typical participants for their ratings of imbalance
- Effects of PE tubes on imbalance

Results can help lead to greater understanding of human response to wind turbine noise, and to potential remediation of some of those factors.

1.2 Preliminary Data:

None exist

1.3 Existing Literature:

ONLY anecdotal data exist. This is the first study of its kind.

Study Endpoints/Events/Outcomes

1.4 Primary Endpoint/Event/Outcome:

Postural stability will be measured in the presence of turbine-generated sound.

1.5 Secondary Endpoint(s)/Event(s)/Outcome(s):
Subjective annoyance, or experience of any mild negative symptoms will be observed.

Study Intervention(s)/Investigational Agent(s)

Description:
Each person will come to the MSP lab and be tested for 60 minutes. We will measure stance and sway for each of those sounds (modulated audible sounds, unmodulated audible sound, and infrasound) in isolation and in pairs. Participants will stand on a forceplate and measures of left-right and front-back sway will be continuously obtained. For that we will follow procedures used at the University of Minnesota by consultant Dr. Tom Stoffregen from Kinesiology.

Following each stimulus presentation, we will ask listeners to rate the pleasantness/unpleasantness of the sounds. Following the full procedure, participants will fill out a general health survey as well as a survey of their history of motion sickness and any symptoms they experienced during the session.

We will analyze the results of the modulated versus unmodulated sounds to quantify the effect of the modulation patterns on ratings of annoyance. We will further divide the participants into three groups, post-hoc, based on their annoyance ratings (below average, average and above average annoyance). We will then analyze the characteristics of those who report greater annoyance (age, general stress, sleep habits, obtained from the GHI).

1.6 Drug/Device Handling: NA

1.7 Biosafety: NA

1.8 Stem Cells: N/A

Procedures Involved

1.9 Study Design: Describe and explain the study design.

1.10 Study Procedures:

Describe:

Each person will come to the MSP lab and be tested for 60 minutes. We will measure stance and sway for each of those sounds (modulated audible sounds, unmodulated audible sound, and infrasound) in isolation and in pairs. Participants will stand on a forceplate and measures of left-right and front-back sway will be continuously obtained. For that we will follow procedures used at the University of Minnesota by consultant Dr. Tom Stoffregen from Kinesiology.

Following each stimulus presentation, we will ask listeners to rate the pleasantness/unpleasantness of the sounds. Following the full procedure, participants will fill out a general health survey as well as a survey of their history of motion sickness and any symptoms they experienced during the session.

We will analyze the results of the modulated versus unmodulated sounds to quantify the effect of the modulation patterns on ratings of annoyance. We will further divide the participants into three groups, post-hoc, based on their annoyance ratings (below average, average and above average annoyance). We will then analyze the characteristics of those who report greater annoyance (age, general stress, sleep habits, obtained from the GHI).

1.11 Study Duration:

- Each participant will come for 1 hour
- The study will be complete within 1 year.
-

1.12 Individually Identifiable Health Information: NONE

1.13 Use of radiation*:* NONE

1.14 Use of Center for Magnetic Resonance Research*:* None

Data and Specimen Banking

1.15 N/A

Sharing of Results with Participants

N/A

Study Population

1.16 Inclusion Criteria: Any healthy volunteers aged 18 - 80 who can answer questions in English and who can stand on a board for about 10 minutes.

1.17 Exclusion Criteria: Inability to understand and explain in English. Inability to stand for stretches of 10 minutes
Screening: Questionnaire and interview

Vulnerable Populations

1.18 Vulnerable Populations:

☐ Children
☐ Pregnant women/Fetuses/Neonates
☐ Prisoners
☐ Adults lacking capacity to consent and/or adults with diminished capacity to consent, including, but not limited to, those with acute medical conditions, psychiatric disorders, neurologic disorders, developmental disorders, and behavioral disorders
☐ Approached for participation in research during a stressful situation such as emergency room setting, childbirth (labor), etc.
☐ Disadvantaged in the distribution of social goods and services such as income, housing, or healthcare
☐ Serious health condition for which there are no satisfactory standard treatments
☐ Fear of negative consequences for not participating in the research (e.g. institutionalization, deportation, disclosure of stigmatizing behavior)
☐ Any other circumstance/dynamic that could increase vulnerability to coercion or exploitation that might influence consent to research or decision to continue in research
☐ Undervalued or disenfranchised social group

☐ Members of the military
☐ Non-English speakers
☐ Those unable to read (illiterate)
☐ Employees of the researcher
☐ Students of the researcher
☒ None of the above

1.19 Additional Safeguards:

- N/A

Local Number of Participants

1.20 Local Number of Participants to be Consented: 100

Local Recruitment Methods

1.21 Recruitment Process: Flyers in Elliott and Shevlin Halls

1.22 Identification of Potential Participants: Posted flyers only.

1.23 Recruitment Materials: Flyer attached

1.24 Payment:
$12 per hour paid in cash at the time of the session

1.25 Withdrawal of Participants

1.26 Withdrawal Circumstances: N/A This is a single session

1.27 Withdrawal Procedures: N/A

1.28 Termination Procedures: N/A

Risks to Participants

1.29 Foreseeable Risks: There is minimal risk associated with participation. A very small proportion of the population may experience mild symptoms like those associated with mild motion sickness, including light-headedness or disequalibrium. We will be measuring these continuously during the test, and will stop the test at any sign of the onset of these symptoms.

1.30 Reproduction Risks: N/A

1.31 Risks to Others: N/A

Potential Benefits to Participants

1.32 Potential Benefits: None

Statistical Considerations

1.33 Data Analysis Plan: Mean and standard deviation of postural stability across sound conditions, ANOVA, correlation between age and postural stability.

1.34 Power Analysis: None

1.35 Statistical Analysis: Describe statistical analysis plans.

1.36 Data Integrity: Data will be de-identified and stored on protected hard drive. Data will be backed up monthly on secure external hard drive.

Confidentiality

1.37 Data Security: *Data will be de-identified and stored on password-protected hard drive. Data will be backed up monthly on secure external hard drive.*

Provisions to Monitor the Data to Ensure the Safety of Participants

1.38 Data Integrity Monitoring.

- The PI is monitoring the data monthly and ensuring its accuracy.

1.39 Data Safety Monitoring.N/A

Provisions to Protect the Privacy Interests of Participants

1.40 Protecting Privacy: Participant identity is protected using a transposed-initial format. Identified data are kept in a locked cabinet in S30 Elliott Hall.

1.41 Access to Participants*:* NA

Compensation for Research-Related Injury

1.42 Compensation for Research-Related Injury: N/A

1.43 Contract Language: N/A

Consent Process

1.44 Consent Process (when consent will be obtained):

- Consent will take place in Elliott Hall S30 at the time of the experiment. There is only one session so there is no waiting period or ongoing consent. Consent form is attached.

1.45 Waiver or Alteration of Consent Process (when consent will not be obtained): N/A

1.46 Non-English Speaking Participants: N/A

1.47 Participants Who Are Not Yet Adults (infants, children, teenagers under 18 years of age):

- N/A

1.48 Cognitively Impaired Adults, or adults with fluctuating or diminished capacity to consent:

- N/A

1.49 Adults Unable to Consent:

- N/A

Setting

1.50 Research Sites:Elliott Hall S30 for testing and recruitment

1.51 International Research: N/A

Multi-Site Research

"N/A"

Resources Available

1.52 Resources Available:

- I have 30% time devoted to research
- The Center for Applied and Translational Sensory Science has the necessary facilities for the postural sway and the infrasound generation.
- All staff are highly trained in research processes.

References