Phantom signals: Erroneous perception observed during the audification of radio astronomy data

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This paper describes the work in progress of an investigation into utilizing audification techniques upon radio astronomy data, generated by the Search for Extraterrestrial Intelligence (SETI). The proposed system involves subjects listening to the data presented as background noise. The initial tests established that subjects are able to detect the presence of simulated signals when presented with white noise; however it was observed that there were significant reports of signals that were not present in the test files. Subjects regularly reported perceiving these "phantom signals". Further experimentation confirmed that phantoms were reported when listeners were presented with pure white noise and were asked to identify signals with this data. Exposing subjects to examples of potential signals prior to the test has a heavy influence on the prevalence and sonic characteristics of the illusory signals reported.

O INTRODUCTION

This team is investigating methods of utilizing sonification for data mining of large scale data sets, with a particular focus upon the exploration of radio astronomy data produced by the Search for Extraterrestial Intelligence or SETI [1]. Modern SETI techniques involve undertaking radio astronomy observations of a candidate star, storing this data as a file and then exploring the data for anomalies. A SETI definition of intelligence is the presence of a technology capable of being detected over interstellar distances. Our own technological society has been broadcasting radio waves throughout the universe since the development of radio. As radio waves propagate throughout the universe, early SETI researchers such as Drake [2] and Morrison & Cocconi [3] proposed that they could be used for interstellar communications. Another advantage is that our atmosphere is opaque to the radio spectrum – thus allowing earth bound observations.

The data used as a basis for this work was obtained via setiQuest [4]. Each observation produces approximately 8GB of data, which is saved in 8 bit format. Radio astronomy observations mainly consist of random fluctuations which have a Brownian noise characteristic. The search involves scanning through the noise-based data to detect signals that could be of extraterrestrial origin. Although it is impossible to anticipate the spectral composition of a signal transmitted from an alien civilization, it has been speculated that these signals would be narrowband and could be sinusoidal or pulse type signals [5]. Due to the Doppler Effect, caused by relative motion of celestial objects from the earth, signals could be shifted in frequency producing a chirp like effect.

Exploring large amounts of data through visualization can be time intensive, and so this team is investigating whether sonification methods are more effective than visualization alone.

It is proposed that this data could be audified and then explored by a listener, who could identify any sonic events that are different to the white noise background. However it would not be feasible for a listener to actively listen to a large amount of data, as a direct audification of one observation would take 54 hours to listen to. An alternative would be to present this data to the listener as background noise, so that they can listen to it passively. It is relatively common, when working in a noisy environment to use either white or pink noise at a low level to mask distracting noises e.g., construction noise or conversation. This team is investigating if this background white noise can be used for passive data exploration. If there are signals within this data, will a distracted listener perceive the signal?

It is anticipated that a series of experiments is required to establish the validity of this approach. The hypothesis of the first experiment is to establish if listeners are able to detect additional pseudo signals whilst actively listening to short periods of white noise. The next experiment would ascertain if listeners were able to detect signals presented with white noise, whilst passively listening with a distraction activity.

This paper outlines the experimental procedure and results of the first experiment into active listening to white noise.

0.1 Generation of sound sources

The white noise source for these experiments was taken from setiQuest radio observations of the Moon, the data was audified by creating a C++ program that extracts the sample data and converts it to an audio wav file, which was 30 seconds in duration @ 44.1Khz, 16 bit resolution. The white noise characteristics were confirmed by visually inspecting a spectrogram of the data – see Figure 1.

The pseudo signals were selected based upon criteria describe by SETI, when giving examples of potential alien signals. A C++ program was developed to synthesise tones, and the pulse and squiggle waveforms were generated by The vOICe, a Java application that converts images to sound [6]. The following signals were generated:

1) Sine wave at 200 Hz
2) Sine wave at 1 KHz
3) Sine wave at 10 KHz
4) Chirp from 200 to 10 KHz
5) Pulses
6) Squiggle – tone that deviates randomly in frequency.

Spectrograms illustrating the sonic characteristics of the white noise source, pulse and squiggle signals are shown in Figures 1 to 3.

A C++ application was created that mixed together the white noise at -30dB and the pseudo signals at -40dB, -46dB, and -52dB. The application randomized when the pseudo signal would start. As a control, two files were created that contained white noise only. This created a set of 18 files which were segued randomly using Steinberg's Cubase. Two files containing purely white noise, with no signal, were included as a control.

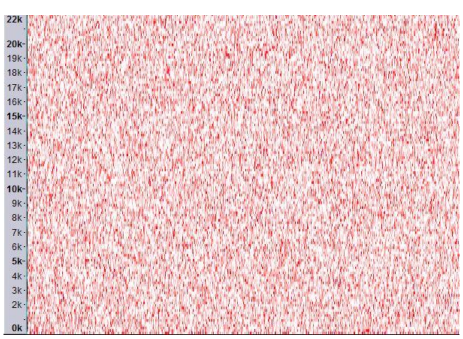

Fig.1 White noise source file spectrogram

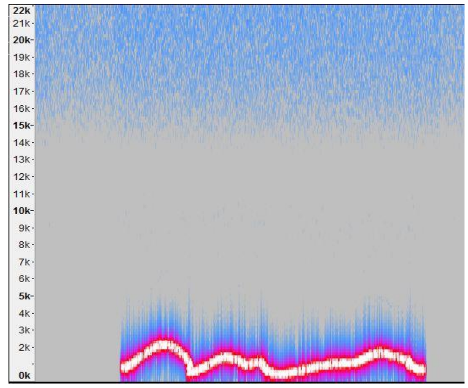

Fig.2 Squiggle signal spectrogram

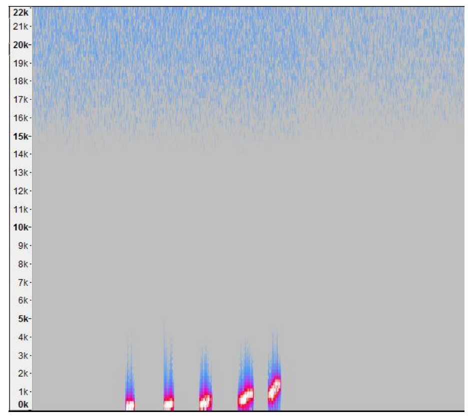

Fig.3 Pulsed signal spectrogram

1 EXPERIMENT 1 – DETECTION OF SIGNALS PRESENTED WITHIN WHITE NOISE

This test was designed to establish whether subjects are able to perceive signals presented within a background of white noise, actively listening over 30 seconds.

1.1 Experimental procedure

The tests took place in the radio production studio at the University of Huddersfield, which is an acoustically neutral room with modest sound isolation properties. The sequence of test files was randomized and played via the Audacity application on an Apple Mac Book Pro to the subject through a pair of Beyerdynamic DT100 headphones. After each file was played the subject was asked to score between 1 and 10 their confidence that they perceived a signal, with 10 indicating a high confidence that a signal was perceived. In addition they were asked to record whether they could identify the type of signal present; tone, pulse, chirp, squiggle, or no signal present. Prior to the test commencing each subject was played examples of each signal type without white noise for reference.

1.2 Test subjects

9 subjects performed this test, 1 female and 8 males aged between 20 and 47. All were Music Technology undergraduate students or lecturers at the University of Huddersfield, and all originated from the UK.

1.3 Experiment 1 results

Tables 1 and 2 provide a summary of the subjects' responses. For Table 1, the confidence scores from each subject are averaged for each signal type. The final column provides a summary of how accurate all subjects were at detecting the correct signal. Table 2 collated confidence and detection rates based upon the amplitude of the signal.

Table 1. Averaged confidence scores of detection of various signals

Signal Type	Average Confidence Score	Correctly Detected %
200Hz Tone	9.814	100
1KHz Tone	9.740	96
Chirp	9.703	100
10Khz Tone	8.888	93
Pulse	8.259	89
Squiggle	7.185	81
No signal	2.611	67

These results show that those surveyed can detect the presence of signals mixed with white noise. Confidence of detection is greatest with sinusoidal signal types, and increases with the amplitude of the signal.

1.4 Experiment 1 discussion

The two files containing only white noise had a relatively low level of accurate detection – 33% of subjects *incorrectly* identified a signal when none was present. Anecdotally several of the test subjects reported that they found the task quite difficult as they were unsure if they were actually hearing signals and that only after they had heard a "real" signal it reassured them that the signals they had earlier perceived were illusory. This reporting of "phantom signals", i.e., signals that were not present in the original files, was the most reported comment from this test. It was decided to further investigate this phenomenon by repeating the test, this time with the majority of audio files containing white noise only, with no additional signals. Now test subjects would be played just white noise, to establish the level of reporting of illusory signals. The team also wished to examine the influence of listening to example signals prior to the start of the test, as it appeared that subjects reported phantom signals with characteristics resembling the reference files.

Table 2. Averaged confidence scores of detection of various signals collated on signal amplitude

Signal Amplitude	Average Confidence Score	Correctly Detected %
-40 dB	9.666	98
-46 dB	9.488	98
-52 dB	7.977	83

2 EXPERIMENT 2 – DETECTION OF SIGNALS WITH PREVIEW

The object of this experiment was to establish whether listeners would report illusory signals with characteristics similar to reference audio files played prior to the test.

2.1 Experimental procedure

A series of 10 wav files, each 30 seconds in duration, was created, all containing white noise at -30dB. A control file, featuring both white noise and a 200 Hz tone at -40dB, was created. This control audio file (file number 6), with an actual signal mixed in, was used to establish if phantom signals are experienced after a real stimulus. This experiment was delivered under the same conditions as Experiment 1. Each subject was asked to actively listen to a series of excerpts of white noise and score their confidence that they perceived a tone from 1 to 10 (low to high). A score of 10 would indicate that the subject was highly confident that they perceived a signal, a score of 1 would indicate that they were confident that there was no signal, and the file contains pure white noise. They were also asked to record whether the signal was a tone, chirp, pulse, squiggle or no signal; examples of each signal were played to each subject prior to the experiment.

2.2 Test subjects

13 subjects performed this test, 12 males and 1 female, aged between 20 and 23. All were Music Technology undergraduate students at the University of Huddersfield. One subject originated from Greece, the remainder from the UK.

2.3 Test results

For each of the 10 files an average was calculated based upon the subjects' scoring of how confident they were that they had or had not perceived a signal – this data is collated into Table 3. The data was also collated by the incidences of incorrect reporting by signal type. This is displayed in Table 4, and ranked in order of the most reported signal types.

Table 3. Averaged confidence scores, and correct detection levels of Experiment 2

File Number	Average Confidence Score	Correctly Detected %
1	2.231	69
2	3.385	38
3	4.385	31
4	3.538	38
5	4.538	31
6	8.462	100
7	2.923	62
8	2.846	38
9	4.538	23
10	3.769	31

Table 4. Incidence of incorrect reporting of signal types

Signal Descriptor	% Incorrectly Reported
Squiggle	18.46
Pulse	16.92
Tone	7.69
Chirp	6.15
Other	4.62

130 separate tests were conducted (13 test subjects, each listening to 10 files). Only 60 returned with the correct response (no signal in files 1, 2, 3, 4, 5, 7, 8, 9 and 10 and a tone in file 6). 53.8% of tests returned with an erroneous response from the subjects. The best performing subjects in this test correctly identified 8 out of 10 files; the worst performance only correctly identified 2 files. ***All*** subjects correctly identified the control file with a tone. On average this subject group correctly classified 46% of the test files. A breakdown of the correct classification rates per file is detailed in Figure 4, with subject confidence in Figure 5.

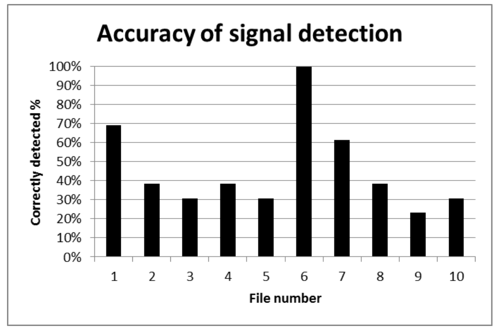

Fig.4 Accuracy of signal detection

Fig.5 Averaged listener confidence

2.4 Discussion of Experiment 2's results

100% of subjects correctly identified the test file with the tone added. Not one subject successfully identified every recording correctly – in other words all subjects reported phantom signals.

Files 1, 6, and 7 have greatest level of correct classification. It appears that subjects tend to accurately classify the first file played to them and then this accuracy tails off. File 7 has an increased accuracy, which could be due to its proximity to the only recording with a definite signal mixed in. Accuracy then tails off again when they are played subsequent examples of white noise.

Table 4 provides a summary of the prevalence of which phantom signals were reported. Most subjects reported phantom signals with similar characteristics to those played prior to the listening test, with only 4.6% of reports being of phantom signals with novel characteristics.

An interesting effect happens with the reporting of phantom tones, which is illustrated in Figure 6. The reporting of tones (as opposed to other signal types) diminishes after file 6, which contains a real tone. This would indicate that when a tone is heard within the context of white noise the listener then becomes less likely to false report tones in subsequent files. However, the presence of a real tone does not appear to influence the level of reporting of other phantom signal types.

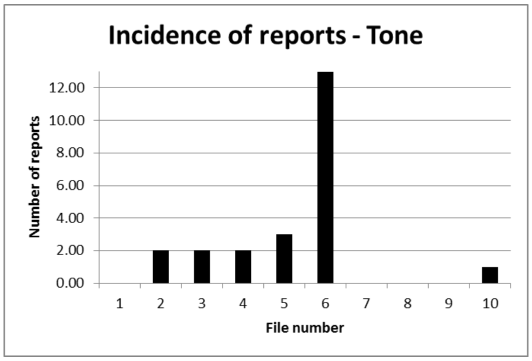

Fig.6 Number of reports of phantom tone

3 EXPERIMENT 3 – DETECTION OF SIGNALS WITHOUT PREVIEW

The objective of this experiment was to establish the prevalence of illusory signal reporting on white noise listening with no preview of potential signals.

3.1 Experimental procedure

This test was conducted in similar conditions to Experiment 2, utilizing the same set of test files. No discussion of potential signal types was entered into with the subjects, and no examples were previewed. Each subject was told that there may be a signal mixed in with the white noise.

3.2 Test subjects

10 subjects performed this test, 7 males and 3 females, aged between 20 and 31. Most were Music Technology undergraduate students at Birmingham City University, one was an administrator. All subjects originated from the UK. None of these subjects had participated in the previous 2 studies.

3.3 Test Results

The results of this experiment have been collated into Tables 6 and 7. Table 6 has a column for averaged confidence, and a column for how many subjects correctly detected whether the audio file had a signal mixed in with the white noise or not. Table 7 is a collation of the characteristics described by the listeners, when falsely reporting signals. Responses have been categorized into 5 broad descriptors. Terms like water or wind are Natural sounds. Mechanical sounds describe motorway, railway or machine type sounds. Any speech type reports are included into Voice, and Tones describes any sinusoidal or test tone reports. The Filter category is included because several listeners reported hearing filter sweep type events. The second column in Table 7 describes the incidence of false reports of signals in each category.

Table 6. Averaged confidence scores and detection levels of Experiment 3

File Number	Average Confidence Score	Correctly Detected %
1	3.9	30
2	4.3	50
3	5.1	20
4	5.0	20
5	4.2	30
6	9.9	100
7	5.3	40
8	5.4	40
9	7.5	10
10	5.8	20

Table 7. Incidence of incorrect reporting of signal types

Signal Descriptor	% Incorrectly Reported
Natural	15.38
Mechanical	25.00
Tones	36.54
Voice	13.46
Filter	9.62

3.4 Discussion of Experiment 3's results

Similar to the results of Experiment 2, 100% of listeners correctly identified file 6, a 200Hz tone mixed with white noise. Besides file 6, the second file played to listeners had the highest level of correct detection – 50%. However, in contrast to the results from Experiment 2, listeners reported higher levels of phantom signals after listening to the one file which did have a signal present.

Several different descriptors were used to describe the phantom signals perceived by listeners, from natural sounds (such as the sea and wind noises), mechanical sounds (such as railway or motorway type sounds), and sounds with speech-type characteristics (such as talking or voices). Sinusoidal signals were the most commonly reported in this experiment. This may be due to listeners anticipating that a listening test may feature signals of this type. 8 out of 10 participants reported experiencing the same signal in multiple files.

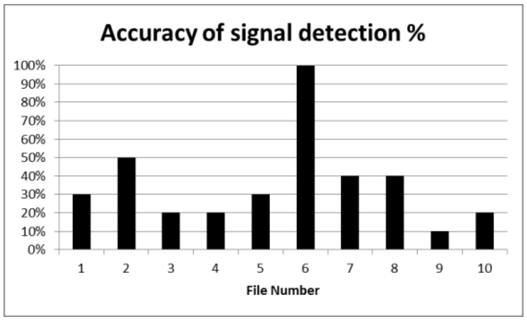

Fig.7 Accuracy of signal detection for experiment 3

4 PHANTOM SIGNALS

Taking into consideration the results of these experiments, it is clear that participants are reporting the presence of illusory or phantom signals when asked to actively listen to short bursts of white noise. When tests are pre-empted with example signals, as in Experiment 2, the majority of phantoms reported are identified as having similar characteristics to the examples. Although each listener was given the option to identify the signal as “other” i.e., not sharing characteristics of tone, pulse, or squiggle, the majority chose to categorize the phantom within the scope presented by the researcher. It would appear that the listener’s perception is influenced by the examples played before the test. It is possible to steer a listener to report a particular type of phantom signal, just by playing an example earlier.

The incidence of phantom signal reporting increases when no examples are played to the test subject. It seems that by providing no context to the listener this enhances their perception of phantoms. The phantom signal effect disappears completely with knowledge; if a subject is informed of the true purpose of these experiments they are no longer reported. A musician sat the test with prior knowledge and achieved a 100% detection rate; this was used to externally confirm that the test files are purely random in nature, with no artifacts that could be perceived as a signal. Listeners were allowed only one listen to the test files, so they could not go back and confirm if the phantom signal was present. If an interactive sonification [1] approach was adopted where the listener could replay the audio, this may improve the accuracy of signal detection.

There are several possible explanations for the phantom signal effect. Most readers will be aware of the human need to find order when presented with chaotic stimuli, seeing shapes of animals in the clouds or seeing faces in woodchip wallpaper. This effect is called pareidolia [2], and phantom signals are a form of auditory pareidolia. The role of the researcher who engages the listener in these tests may be significant. Most subjects were students and the researcher was a senior lecturer. The participants may want to perform well in these tests, to save face in front of an authority figure. This is similar to the authority figure effect first observed by Milgram [3]. These phantom signals are similar to the auditory illusions discovered by Diana Deutsch [4]. A similar effect has been observed when white noise has been added to gaps in speech [11] and [12], where the addition of noise in gaps provides spectral restoration. Termed the picket fence effect, this describes how, if a tone or speech is interspersed with gaps containing just noise, there is an illusion of continuality of the tone during the noise bursts. The phantom signals reported by listeners in this test, differ from the picket fence effect as they occur with no tonal stimulus present.

5 CONCLUSIONS AND FURTHER WORK

The results of Experiment 1 demonstrate that test subjects are able to distinguish the presence of pseudo signals when actively listening to white noise, although under the experimental conditions described most listeners reported the existence of illusory tones that were not added to the white noise by this team.

Experiments 2 and 3 confirm that when presented with pure white noise and asked to detect signals, listeners will report phantom signals. The pre-test phase, where listeners are played examples of possible signals appears to heavily influence perception during the test – subjects are more likely to report phantom signals with similar characteristics. These results highlight an interesting phenomenon when actively listening to white noise. Further testing is required to establish if the effect persists when listeners are exposed to white noise passively.

This will have implications when audifying white noise type data. It is recommended that interactive sonification techniques are utilized to reduce the impact of phantom signal detection. Consideration should also be given to the influence on the participant of pre-listening prior to a listening test, as these results indicate that this can have an effect upon perception during the test.

This team intends to continue this study by investigating listener’s abilities to detect signals mixed into white noise passively. These tests will be longer in duration, and each subject will be involved in a distraction task to prevent them from actively listening to the subject material.

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