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Empirical evaluation of in-field, binaural record and playback reproduction

William Neale, Toby Terpstra and Gray Beauchamp

*Kineticorp, LLC, 6070 Greenwood Plaza Blvd., Suite 200, Greenwood Village, Colorado 80111;
wneale@kineticorp.com; tterpstra@kineticorp.com; gbeauchamp@kineticorp.com*

This research evaluates a methodology for calibrating in field, sounds for playback in a separate, interior environment. The ability to record sounds in the field and playback them accurately in a different environment is useful when the end user, or listener cannot be present at the location where the sound is being produced live. In forensics, for example, an expert or juror may need to evaluate an acoustic or auditory issue but not have access to the site where the sound is produced. The methodology presented here utilizes a binaural microphone where participants in the field, listen to a physical sound, and calibrate the binaural microphone by adjusting recording levels until the sound heard in their headphones matches the sound being produced live in the field. A second group of participants are presented with the same live physical sound but in an interior environment. Using the same setup, these participants compare the live sound with the recorded and reproduced sound calibrated by the in-field participants. Participants in this second group empirically evaluate the similarity of the reproduced sound to the live physical sound in the interior environment.

1 INTRODUCTION

This research evaluates a methodology for calibrating in-field sounds for playback in a different environment. The ability to record sounds in the field, and play them back accurately in a different environment, is useful when the end listener cannot be present at the location where the sound is being produced live. In forensics, for example, an expert or juror may need to evaluate an acoustic or auditory issue, but not have access to the site where the sound was produced. Legal matters involving sound can require the trier of fact to evaluate the role of audio in specific circumstances, such as whether someone could hear an approaching vehicle or if warning sounds were audible over background noise. The evaluation of audibility creates a need for faithfully reproducing audio recorded at the incident site such that the trier of fact can experience audio within the courtroom that is accurate to field recordings. The methodology presented here utilizes binaural microphone equipment, and a method for calibrating the recorded sound such that the playback of the recorded sound is substantially similar to the sound heard live in the field. Testing of this methodology was performed where participants in the field listen to a physical sound and calibrate the binaural microphone by adjusting recording levels until the sound heard in their headphones matches the sound being produced live in the field. This sound can then be replayed using the same headphones and output settings at any location. The methodology involves several steps which are summarized in *Table 1*.

Methodology	
1	Analysis of area where sound is to be recorded
2	Preparation and setup of the equipment
3	Calibration of the live feed levels
4	Recording of the live sound
5	Documentation of setup and settings
6	Playback of recorded sound in a different location

Table 1 – Summary of Steps of the Methodology

A second group of participants repeated the experiment with live sounds in an interior environment. The purpose of this second experiment was identical to the first, but in a different interior environment. The results overall were the same, with the exception that, as expected, the sounds were slightly louder in the interior environment due to reverberation.

2 METHODOLOGY

The methodology for creating an accurate and faithful reproduction of a sound event requires an assessment of the area where the sound is being produced, preparation of equipment, calibration of the recording, and documentation of the process. The last step in the methodology describes the playback process. The methodology developed and presented here, utilizes specific equipment that is listed. In the event different equipment is used, as long as that equipment has similar specifications and features of the equipment described herein, the results would likely be comparable. Binaural headphones for audio capture, and equipment specifically designed for in-field recording should be used for best results. Each step of the methodology is detailed in sections that follow.

2.1 ANALYSIS OF THE AREA WHERE SOUND IS TO BE RECORDED

There are practical issues and physical constraints that may need to be considered when recording sound in the field. Prior to accessing the site, it is advisable to evaluate the recording area for accessibility and safety. Forensic testing might include moving vehicles like tractor trailers, emergency vehicles, trains and other large equipment that may pose a risk during recording. The movement, travel path and time schedule for the vehicles may need to be coordinated or considered to balance safety concerns with the quality of the recording. Other considerations include whether the environment is indoors or outdoors. Indoor conditions can introduce reverberation of the sound that can cause the sound to be heard slightly louder than if the sound did not contain reverberation. Due to reverberation effects, the sound should be recorded in a similar environment as the location the sound occurred. Outdoor sounds can contain ambient and environment noise levels. It is important to know whether those ambient noise levels should be included in the recording, or if they are irregular to the area. Measuring the ambient sound pressure level, and the source of the ambient noise, would be appropriate during this step. Also, noting unique conditions of the site that might play a role in the interpretation of the sound when played back in a different location would be important in this step. It is also worth being attentive to distinct, unique, or sudden sounds, such as horn blows, sirens or other sounds that are not meant to be recorded, so that these additional sound sources can be accounted for.

2.2 PREPARTION AND SETUP OF THE EQUIPMENT

Several instruments and equipment were used in this methodology. *Table 2* provides a list of the equipment utilized in this research. Other equipment exists that is comparable to the list below.

Equipment
3Dio Free Space Pro II binaural microphone
Zoom 4HN field recorder
Quiet Comfort 35 Bose wireless headphones II
FiiO E17 USB DAC Headphone Amplifier
Tripod with adjustable rotating 3/8" head mount

Table 2 – List of Equipment

The 3Dios Free Space Pro II binaural microphone is first mounted to the tripod. The Free Space Pro II uses matched DPA 4060 hi-sensitivity microphone capsules with a frequency range of 20 Hz to 20 kHz, which is roughly the range of human hearing¹. Shaped like a human head, and with molded ears, the sound enters the microphones in a physically realistic manner, since the ear canals of the mold collect and transmit the sound waves the same as in a live subject. The microphone and tripod setup are shown in *Figure 1*. In this research, the microphone was mounted on a tripod and the height adjusted to match the height of each participant.



Figure 1-Photograph of 3Dios microphone setup on the tripod

The Zoom 4HN field recorder is connected to the microphone and mounted on the built-in bracket of the 3Dios. This allows the live audio feed from the microphone to pass to the recording device. The Zoom field recorder has a recording capability of 24-bit/96kHz sampling frequency in stereo mode and was setup with the 3Dio binaural microphones as an input. A 24-bit recording allows for a more accurate digital representation of the physical sound since a 24bit recording has a wider range of values than lower bit ranges. The field recorder was set to record sound files in the “.wav” digital audio format. The Quiet Comfort 35 Bose wireless headphones II were connected to the Zoom recorders output jack to have the live feed audible in the headphones. To make sure that the sound coming in to the headphones was sufficient to match the sound pressure level of the live sound being recorded, an inline FiiO E17 USB DAC Headphone Amplifier was added between the Bose headphones and Zoom recorder. *Figure 2* depicts the equipment in this methodology and *Figure 3* depicts the setup.



Figure 2-Photograph of sound recording equipment



Figure 3-Equipment assembled, setup, and ready for calibration

After connecting the equipment as depicted in *Figures 2 and 3*, the amplifier was set to level 50 (out of 60) with a gain level of 12. The amplifier has three gain settings, 0, 6, and 12. Without the amplifier, the setup was unable to achieve a sound level that was louder than the physical sound, making adjustments limited. With the amplifier at these settings, participants were able to exceed the sound pressure level experienced by the physical sound to better adjust to the correct setting. Additionally, the in-field recorder input sound level was tested and set such that the clicker sound being produced for testing is neither too low or too high for the recording equipment. The in-field recorder graphically displays the dB(a) levels for both the left and right channels as monitor level meters. Monitoring these levels during this step while the sound is being produced will show whether the recording level is too high (where the graphical bars exceed the available range) or too low (where the graphical bars do not appear on the

available range). The microphone input recording level on the in-field recorder should be adjusted while the sound from the clicker is being produced such that the monitor level meter displays a recording neither too high or too low. Clipping can occur when the sound being recorded is greater in Sound Pressure Level (SPL) than the capabilities of the recording device or the settings. Since the full range of the sound being recorded is typically wanted, setting the input level so none of the sound is clipped is performed at this setup stage. If the sound being recorded is not available at the time of this setup, a different physical sound source, such as a clicker, can be used to estimate the SPL that is expected from the source sound to check for clipping. After the input level is set such that clipping does not occur, no further adjustment is needed. Ambient SPL is measured prior to the start of the course recording. In this case, the outdoor recording did not contain any significant and distracting ambient or environment noises.

2.3 CALIBRATION OF THE LIVE FEED SOUND LEVELS

In order to calibrate the sound recording, a basic method is performed to adjust the output levels of the field recorder until the sound produced in the headphones matches the same sound quality and SPL as observed in the field with the headphones removed. To begin, with the headphones plugged in to the zoom field recorder, adjust the recorder output volume to be maximum, and check that the volume level in the headphones exceeds the sound level of the physical sound when the headphones are removed. In other words, make sure the headphones can reproduce the physical sound louder than it exists in the real world. If the sound in the headphones cannot exceed the volume of the physical sound in the real world, then the input recording level of the zoom field recorder may need to be increased and approach the clipping max. Likewise, increasing amplifier gain and output levels may be necessary. After checking that the headphones can play back a higher volume than the live sound, the Zoom in-field output level is set to zero. With the source sound present, the output level is slowly increased until it is heard in the headphones. The headphones are then removed to obtain a live sound experience of the source sound. The headphones are then placed over the ears again, and the output level of the in-field recorder increased or decreased to match the same quality and SPL. This process is repeated until the sound through the headphones and the live sound are indistinguishable. At this point, the output level is recorded. The output level is set to zero again, and the process repeated, where the output level is increased until the sound heard in the headphones matches the source sound observed in-field with the headphones removed. This process is performed three times with each sound source to obtain three separate output level adjustments. With three volume levels noted, the average of the three is recorded for future play back purposes. At this point, the recording device is calibrated and the source sound can be fairly and accurately recorded to the Zoom device. If new or unfamiliar with the process, performing the step of increasing the output level to gain familiarity with the methodology may help improve results. *Figure 4a-4b* visually demonstrates the process of calibrating the equipment.



Figure 4a-Photographic series of the calibration process



Figure 4b-Photograph of the calibration process

2.4 RECORDING THE SOURCE SOUND

After the iterative process of listening to the source sound with the headphones on and off and adjusting the Zoom in-field recorder's output level to match the sound heard in the headphones to the source sound heard live, the system is calibrated. The source sound can be recorded to the in-field recorder, saving the sound in a digital format, for use in both playback and editing. After recording, the digital sound can be played back and heard in the earphones, reaffirming a good match between the live source sound and the recorded sound to be used in playback.

2.5 DOCUMENT SETUP AND SETTINGS

Documenting the setup includes photographing the equipment, specification sheets of the equipment utilized and recording of the input and output level settings, and calculated averages. For the research here, *Table 3 and Figure 5* show an example of the documentation of the setup used in this research.

Field Recording Documentation	
1	Location & environment/ surroundings
2	Ambient SPL
3	Make & model of equipment
4	Microphone setup
5	In-line amplifier levels
6	Field recorder levels

Table 3 – Documentation List



Figure 5-Example images of the documentation of the calibration process

Documentation of the instruments with a camera is recommended but may be difficult due to device screen refresh rates. Reviewing photographs to make sure the necessary information is documented is recommended, as is taking field notes.

2.6 PLAYBACK OF RECORDED SOUND IN A DIFFERENT LOCATION

The digital audio recording of the source sound can be played back in a different location, while maintaining the same sound level and quality as observed during the recording process. This is based on matching the playback settings to the same volume settings used during the recording process. The sound level adjustments made during calibration created a preview for the listener of what the digital audio file will sound like. The digital audio file is simply a permanent record of the preview. When played back, without the settings changing, the digital sound will appear the same as the preview did during the calibration process. While it is possible to measure the SPL of the sound source while at the scene, this measurement is not particularly useful in a calibration process. This is due to the fact that the SPL is measuring only in decibels and does not account for audibility or the sound frequency ranges that make the sound heard. Measuring the SPL of the source sound alone does not provide a useful indication of the audibility of that sound. SPL does not incorporate frequency masking, amplitude masking, or temporal masking, and does not incorporate a signal to mask ratio (SMR) which influences the audibility of a particular soundⁱⁱ. Specific sounds may have frequency distributions that make them masked by the background noise, or stand out, even though the difference in SPL with the addition or removal of this sound is not measurable. As an example, the sound of a siren may be heard through the background noise of other traffic, even though the SPL when measured is the same level with or without the siren present. For this reason, calibrating the sound through an iterative process of listening to the sound live and then listening to the sound through earphones after the sound has been digitized is more reliable. Further, even though both live sounds and digital sounds can be measured, the scales for measurement are not readily comparable, and clipping ranges can differ based on the specific equipmentⁱⁱⁱ.

Some additional issues to consider when performing playback of the recorded sound is whether it is in an indoor or outdoor environment. If playback occurs in an outdoor environment, the presence of additional sound sources or background noises that were

not present at the time of the recording may need to be considered, particularly if these sounds are extremely loud or audible. If playback occurs in an indoor environment, control of the ambient sound may be easier, and when replaying the sound in earphones using the same setup, the sound heard is essentially unchanged. When playback occurs indoors, and through speakers, the speakers can be calibrated the same way as the headphones were calibrated during the recording of the source sound. Set up the equipment the same as during the calibration process and increase the volume of the speakers until they match the sound heard in the headphone.

3 TESTING THE METHODOLOGY

The methodology described here was tested using participants in both outdoor and indoor settings. Participants in the field listened to a source sound and calibrated the binaural microphone by adjusting recording levels until the sound heard in their headphones matched the sound being produced live in the field. A second group of participants were presented with the same physical source sound, played live, but in an interior environment. Using the same microphone and headset setup, these participants repeated the experiment indoors with the same sound sources.

3.1 OUTDOOR SOUND SETUP

A total of 12 participants were involved in the testing of the methodology, including 6 participants used for the outdoor sound calibration, and then 6 other participants used for the indoor evaluation. Table 3 shows the list of participants and related details. Half of the participants were male and the other half female and ranged in age between 26 years to 42 years. *Table 3* lists the outdoor participants first, followed by the participants that evaluated the reproduced sound indoors.

Participant Title	Age	Outdoor	Indoor	Gender
Participant 1-O	33	X		F
Participant 2-O	38	X		M
Participant 3-O	31	X		F
Participant 4-O	42	X		F
Participant 5-O	35	X		M
Participant 6-O	29	X		M
Participant 1-I	34		X	M
Participant 2-I	26		X	F
Participant 3-I	37		X	M
Participant 4-I	29		X	M
Participant 5-I	23		X	F
Participant 6-I	40		X	F

Table 4 – List of Participants

3.2 OUTDOOR SOUND CALIBRATION

Three physical sound sources were used in this testing. Physical sound sources were utilized, as opposed to a digital sound played on a speaker, since this methodology is designed to record live source sounds. The physical sound sources that were selected could produce a consistent sound during testing. Since various participants were used over an extended period and in different environments, a repeatable sound device was important. For the testing, a clicker, a bell, and a power drill were utilized, and depicted in *Figure 4*. There was a distance of 10 feet between sound source and recorder/subject in all cases.



Figure 4 – Three physical source sounds used in testing

Outdoor participants were positioned in an open environment, with the equipment setup as described in the methodology. With the zoom in field recorder adjusted to avoid clipping, and the physical sound source in position and ready to produce sound, each participant was positioned at the location of the headphones (which is also at the location of the binaural microphone). Participants were informed that the headphones have a volume level of “zero” and no sound will be heard, even though a sound signal is being transmitted through the binaural microphones and being played through the in-field recorder. The physical sound is played repeatedly and the participants are instructed to listen to the live sound, then to put on the headphones and increase the volume of the headphones until they believe the volume coming through the headphone speakers is equal to that in volume and quality as the sound being generated by the physical sound source. The subjects controlled the volume but could not see the volume level. For later testing, subjects were instructed to first increase the sound until it was obviously louder than the live sound, then decrease back to an audible match. These instructions reduced variability in the results. The iterative process of having headphones on and off is continued whereby the participant removed the headphones, listened to the sound again being played by the physical sound source, put the headphones back on and adjusted the headphone volume to get the volume the same between the physical sound source and the headphone sound source. The adjustment to the volume ranges from 0-100, 0 being no sound, and 100 being the loudest transmission of the physical sound. *Figure 7* shows an example of the setup of the outdoor testing.



Figure 7 – Outdoor testing setup using the bell

When the participant felt the volume of the headphones was at the correct level, this level was recorded for analysis. This process was then repeated for the other physical sound sources. After each sound source had been calibrated by a participant, the participant

repeated the entire process, beginning again with the first sound source until the participant had calibrated each sound source 3 times. This is done in order to measure any internal variation a participant has when calibrating a sound. After all the volume levels were documented, the next participant repeated the same process.

3.3 INDOOR SOUND EVALUATION

For the indoor sound evaluation, each participant was placed in the jury box of a courtroom. *Figure 8* shows an example of the setup of the indoor testing. The live physical sound (same as the outdoor sounds) was placed at the same distance from this participant as it was in the outdoor testing setup. Ambient sound pressure was measured prior to the start of the testing. Each participant put on the headphones and listened to the sound recorded by the binaural microphone. The participant then removed the headphones and listened to the sound made by the physical source. Through the same iterative process, the participant found the volume setting which most accurately replicated the physical sound without the headphones on. When the participant felt the sound heard in the headphones matched the sound made by the physical sound, the volume level was again recorded for analysis. Each participant listened to each sound with and without headphones and calibrated the volume setting in the same way as was described previously. For each test run, the output volume level which produced the best match to the live sound was recorded.



Figure 8 – Indoor testing setup using the bell

4 ANALYSIS OF TESTING RESULTS

There were six participants for both the outdoor and indoor testing. Each of the six participants listened to each sound three times. A statistical t-test was used to determine if there was a significant difference in the sound sources. As will be discussed later, there was no significant difference in the sound sources. The average volume levels selected by each participant for all tests were computed and compared.

4.1 RESULTS

For each outdoor test, the output level which produced the best match to the live sound was recorded. Table 5 depicts the data collected for the outdoor testing. Resulting volume levels for all three sound sources were compared with a t-test. It was found that there was no significant difference in volume selected for the different sounds. Table 5 also depicts the average for each subject (all sounds), 53 to 62, and the average for all tests, 57. In the first round of testing (Click-01), Participants 3 and 5 selected volume settings that were outliers to their other selections. These outlier values were not included in the calculated averages and in subsequent testing the participants were given a chance to familiarize themselves with the equipment.

	P1	P2	P3	P4	P5	P6
Click-01	54	58	47	53	39	59
Click-02	56	53	60	64	56	52
Click-03	57	50	57	63	52	53
Bell-01	58	53	65	65	56	50
Bell-02	59	57	61	57	58	54
Bell-03	59	57	54	65	53	56
Drill-01	58	56	52	62	61	48
Drill-02	58	55	60	62	65	47
Drill-03	57	55	57	63	59	54
Average For Each Subject	57	55	58	62	58	53
Average For All Tests	56.5					

Table 5 - Outdoor testing results

Table 6 depicts the data collected for the indoor testing. The different sounds were compared with a t-test. Similar to the outdoor setting, it was found that there was no significant difference in volume selected for the different sounds. Table 6 also depicts the average for each subject (all sounds), 69 to 77, and the average for all tests, 73.

	P1	P2	P3	P4	P5	P6
Click-01	67	67	80	89	83	70
Click-02	71	67	80	79	74	71
Click-03	68	69	80	83	76	65
Bell-01	74	70	76	80	86	67
Bell-02	71	67	74	72	78	67
Bell-03	72	71	74	72	77	66
Drill-01	76	72	76	61	74	75
Drill-02	69	72	75	65	72	74
Drill-03	70	70	76	70	72	72
Average For Each Subject	71	69	77	75	77	70
Average For All Tests	73					

Table 6 - Indoor Testing Results

4.2 ANALYZING THE SENSITIVITY OF THE RANGE

The results from the testing in each environment showed a variance in average adjustments in the calibration between -4 and +5 of the average volume level of the Zoom recorder. In order to give this range context, additional testing was conducted using the same equipment. The purpose of the additional testing was to measure the level of adjustment needed before a sound difference was perceivable. Participants were asked to place the headphones on their ears and were played the sound of the drill twice. They were then instructed that the sound would be played once as a baseline sound, and then a second time at a different sound level. The second time they heard the sound, they were asked to determine if it was louder, softer or if they could not tell. Participants were only to comment that it was louder or softer if they were confident in the change. Otherwise, the default is that they are unsure. Testing of participants showed close agreement in the volume change that is required before it is even perceived. For increases in volume, increasing by +3 was required for participants to have confidence that they heard an increase. For decreases in volume, a minimum level of -4 was required before there was agreement that the sound they heard was softer. This sensitivity testing showed that the volume change needs a range greater than -4 to +3 before the change is even perceived. Therefore, the variances in the average outdoor and indoor testing results, between -4 and +5 of the average volume, are substantially similar in volume.

4.3 SOUND ATTENUATION IN ENCLOSURE

When performing our testing indoors, the difference in the perception by the participants of the three live sound sources showed a consistent pattern. The indoor participants consistently adjusted the digital recording playback to be on average 17 units louder in the headphones than those participants in the outdoor environment. In other words, all the sound sources were louder when heard indoors. The explanation for this lies in the difference between the environments in which the source sounds were played. The indoor environment differed in the amount a reverberation that propagated the sound sources. Outdoors, sound ceases when the source stops, provided that there are no objects off of which it can reflect. In an enclosed or covered area, however, sound energy lingers, and this decay is called reverberation^{iv}. The courtroom consisted of walls and ceilings made of painted drywall, and thin padded floor tiles that cause reverberation in the courtroom environment. Additional sound energy reverberating back to the participant in the indoor testing would account for the increase that participants consistently adjusted their headphone volume levels to match what they heard in the real world to the digital reproduction. The reverberation time (*RT*) is defined as the length of time, in seconds, it takes for sound to decay by 60 dB. Reverberation time is directly proportional to the volume of a space and inversely proportional to the units of absorption, or sabins, as expressed in the equation^v:

$$RT = \frac{KV}{a} \quad (4)$$

In which RT is equal to reverberation time in seconds. K is a constant, equal to 0.161 (for volumes in m^3). V is equal to volume in m^3 and a is equal to total absorption in sabins, calculated with equation 5^[11]:

$$a = S\alpha \quad (5)$$

Where S is the surface area in square feet and α is the average coefficient of absorption. Sound absorption is measured in sabins and different materials absorb sound energy more at some frequencies than others. This makes it important to determine the sound absorption for materials and varying frequencies. *Table 8* is a partial list of various absorption coefficients, α , at varying frequencies^{vi}.

Surface	Frequency (Hz)					
	125	250	500	1000	2000	4000
Acoustic tile, suspended	0.5	0.7	0.6	0.7	0.7	0.5
Drywall, gypsum, 1/2 inch on studs	0.3	0.1	0.05	0.04	0.07	0.1
Plywood, 1/4 inch, on studs	0.6	0.3	0.1	0.1	0.1	0.1
Vinyl on concrete	0.02	0.03	0.03	0.03	0.03	0.02
Heavy carpet on concrete	0.02	0.06	0.15	0.4	0.6	0.6
Padded carpet	0.1	0.3	0.4	0.5	0.6	0.7
Window glass	0.3	0.2	0.2	0.1	0.07	0.04
Upholstered seats, unoccupied	0.2	0.4	0.6	0.7	0.6	0.6
Upholstered seats, occupied	0.4	0.6	0.8	0.9	0.9	0.9

Table 7 - Common Absorption Coefficients, α , for Indoor materials

Since the average coefficient of absorption is affected by the frequency range of the sound, an analysis was performed to determine the range for the three live sound sources that were being tested. *Figure 9* shows the sound sources for the bell, the clicker and the drill respectively.

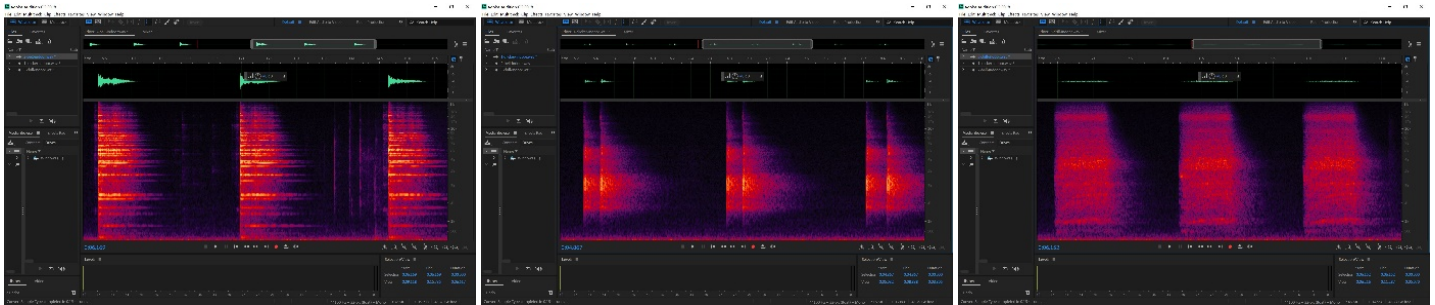


Figure 9 – Spectral frequency analysis (left to right) of the bell, clicker, and drill

From analysis of these waveform, an average range of predominant frequencies for the three sounds was approximately 2,000-5,000Hz. After obtaining the surface area and material properties of the courtroom, a summary of the variables used to calculate reverberation was created and is shown in *Table 8*.

Surface	Material	Freq Range (hz)	Surface Area (m^2)	avg. coeff (α)
Floor	hard carpet	2000-5000	153.6	0.45
Walls	drywall, gypsum	2000-5000	207.6	0.085
Ceiling	drywall, gypsum	2000-5000	198.2	0.085

Table 8 – Summary of variables for reverberation

The total volume for the courtroom was $615.9m^3$. Based on the predominate average range of frequencies, absorption coefficients for the floor wall and ceiling materials were determined to vary from .085 to .45. When calculated, the surface area and absorption coefficients yielded a value of $103.6m^2$ -sabins. The resulting reverberation time was approximately 1 second. This level of reverberation is characteristic of reverberation time of a movie theatre^{vii}, and would account for the increase in the sound energy that required the participants to amplify the sound in their headphones to match the perception of the live courtroom sound.

5.0 DISCUSSION

The ability to record sounds in the field and play them back accurately in a different environment is useful when the end listener cannot be present at the location where the sound is being produced live. This paper has described a method for recording calibrated

sound in one location and playing it back through headphones in another location at the correct volume. It is recommended that the same or similar audio recording equipment that was used in this study be used to achieve the same level of accuracy.

There was no statistical difference in the volume selections of the three sound sources.

Given the sensitivity of the participants to the different volume level increments on the device, it was found that all the participants chose volume levels that sounded substantially similar. In some cases, participants selected volumes on their first test that were outliers to the rest of their volume selections. The authors advise that whoever is to record the sound be familiar with the equipment and practiced in the process. These early outliers would likely have been eliminated with some practice.

Although the average selected volume levels were similar among all participants, variance in the results could likely be decreased further if multiple people were to each listen and select the best agreed upon volume level. In the field, having more than one person agree on the volume levels would be preferable.

A comparison of the average volume level of each participant showed good agreement in each test environment, even though there was a greater variance in individual tests. In the field, three volume levels should be gathered, and the average volume level should be used for playback of the sound to the end listener.

There was a difference in the sound in the outdoor and indoor environments due to reverberation effects. Care should be taken to ensure that sound is recorded in the same or similar environment to where the original sound of interest occurred.

The methodology in this paper can be used to record sound in one location and play it back to a listener at a different location at the correct volume level.

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