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Listener Evaluation of Common Drum Recording and Mixing Techniques

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Listener Evaluation of Common Drum Recording and Mixing Techniques

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ABSTRACT

This thesis explored whether listeners could perceive the differences between samples recorded and mixed according to methods reported by the so-called popular audio press and samples that did not utilize those methods. The three recording methods were: aligning multiple tracks to achieve a coherent phase relationship, microphone selection, and the style of recording. The three mixing methods were: inverting the bottom snare drum microphone to match the top snare drum microphone, having a pre-delay time on a reverb that matched the tempo of the sample, and routing the room microphones to the drummer's perspective. ABX listening tests, preference surveys, and subjective ratings were used to determine the efficacy of the methods. Testing revolved around a null hypothesis that assumed listeners could not perceive differences between, would not have a preference for, and would not grant higher ratings to samples mixed according to popularized methods. Results provided mixed evidence on all these accounts. The ability to perceive changes like pre-delay timing, polarity and time alignment of multiple tracks are harder than the more obvious spatial and timbral changes of routing the room microphones and using microphones commonly used for drum recording.

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DEFINITIONS OF TERMS

Ambient Drum Space: A stereophonic room recording where the left and right microphones in a stereophonic pair are facing the drum kit and are consistent with the drums' positions in the room. The microphone capturing the left side of the drum kit is routed to the left channel and the microphone capturing the right side of the drum kit is routed to the right channel.

Clarity: A subjective measure for ranking the impression of a recording where the listener can distinguish transients, timbre, and other details along with each of the elements of the drum set (i.e., different drums, cymbals, etc.) without distortion. [1]

Comb Filtering: Destructive combining of acoustic and electrical signals due to phase differences. [2]

Condenser Microphone: A microphone based on an electrically charged diaphragm/backplate assembly, which forms a sound-sensitive capacitor [3]

Drummer's Perspective: The area around the drum kit from the drummer's perspective (e.g., if the high tom is on the left side of the drummer, it is placed leftward in the mix, if the low tom is on the right side of the drummer, it is placed rightward in the mix).

Fidelity: A subjective measure for ranking the accuracy of an audio recording. [1]

Mixing: The process of combining and blending the individual elements of a drum recording, such as the individual drums, cymbals, natural and electronically generated reverberation, etc., into a finished composite waveform.

Moving Coil Microphone: A microphone that employs a diaphragm/voice coil/magnet assembly, which forms a miniature sound driven electrical generator [3]

Phase: Denotes a particular point in the cycle of a waveform, measured as an angle in degrees where a complete cycle comprises 360 degrees. [4]

Polarity Flip: A reversal of the positive and negative voltage of a signal. Commonly used when combing the top and bottom snare drum microphones.

Pre-delay: The amount of time between the original dry sound and the onset of early reflections in a reverberation signal.

Spaciousness: A subjective percept or impression of positioning as related to foreground, midground, background and width in a recording.

1. INTRODUCTION

The purpose of this thesis was to determine whether a selection of common methods of recording and mixing drums, as promoted by audio engineers in the popular press, influenced the perceptual "quality" of a drum mix. The following three elements of recording drums were assessed: aligning the tracks to be in phase with one another, specific microphones used, and recording styles characterized by varying quantities and placements of microphones.

The three elements of mixing that were evaluated: polarity, pre-delay, and the stereophonic image. The first common practice of inverting the electronic polarity on the bottom snare drum microphone to match the microphone on the top of the snare drum was tested. The second practice was adding a snare reverb with pre-delay that matched the tempo to contrast a pre-delay that was out of sync with the beat. The last mixing element, stereophonic image, was tested by summing the left- and right-overhead microphones and left and right ambient room microphones together and in competing configurations.

This thesis presents a series of listening tests designed to compare the six common recording and mixing techniques in several applications. Section 3.5 outlines the listening tests in further detail. The research questions for this thesis are:

- "Will the so-called popular methods of drum recording and mixing contribute to the listener experience?"
- "Are listeners able to distinguish between drum mixes that employ the common recording and mixing techniques from those that have not?"
- "Is there a preferred style of recording drums?"

If the results show that subjects have no preference between mixes using common methods reported by the popular press and those that did not, these methods could be omitted with little loss to the perceived quality of drum recordings.

2. PRIOR ART

The following chapter defines and outlines the recording and mixing techniques examined in this thesis.

2.1 Phase

When two or more signals occur simultaneously (i.e. multiple microphones on a drum kit), 'phase' describes the timing relationship between them [5]. Phase differences may occur provided that the microphones are different distances from the instrument and the fundamental frequency of the waveforms are related. When recording drums, engineers regularly capture 12 or more signals of individual instruments.

In a recording session, individual drum tracks are not necessarily going to be completely in time with one another. There are multiple arrival times for each drum in each of the different microphones. Engineers often minimize the destructive phase relationships so that each microphone adds to the tone and does not take anything away [6]. The snare drum microphones and overheads are aligned to have one relationship. The two kick drum microphones are time aligned with each other. If there are multiple microphones on an individual high or low tom drum, they are aligned to each other. When multiple tracks are in alignment, the sound has more clarity, greater focus and tighter bass. The added clarity results in the drums sounding like they are coming towards the listener instead of being in the background of the mix [7].

Figure 1 represents nine drum channels that were recorded without adjusting any timing between the two-kick drum, snare drum, and overhead microphones. There was a natural period of time between the signal reaching the close microphones and the overhead microphones. There was also a slight delay between the kick in and kick out microphones because of the physical locations of the two microphones. The snare top and bottom microphones also had a slight delay between the two channels due to the bottom microphone being placed further from the drumhead. In Figure 2, the kick out track was repositioned by shifting the track to match the kick in. The alignment of the two tracks provides a better phase relationship than when there is a timing gap. The snare bottom and the two overhead microphones were aligned with the snare top microphone to create one arrival time for the snare drum. This alignment provides a better phase coherence than when they are in their original position.

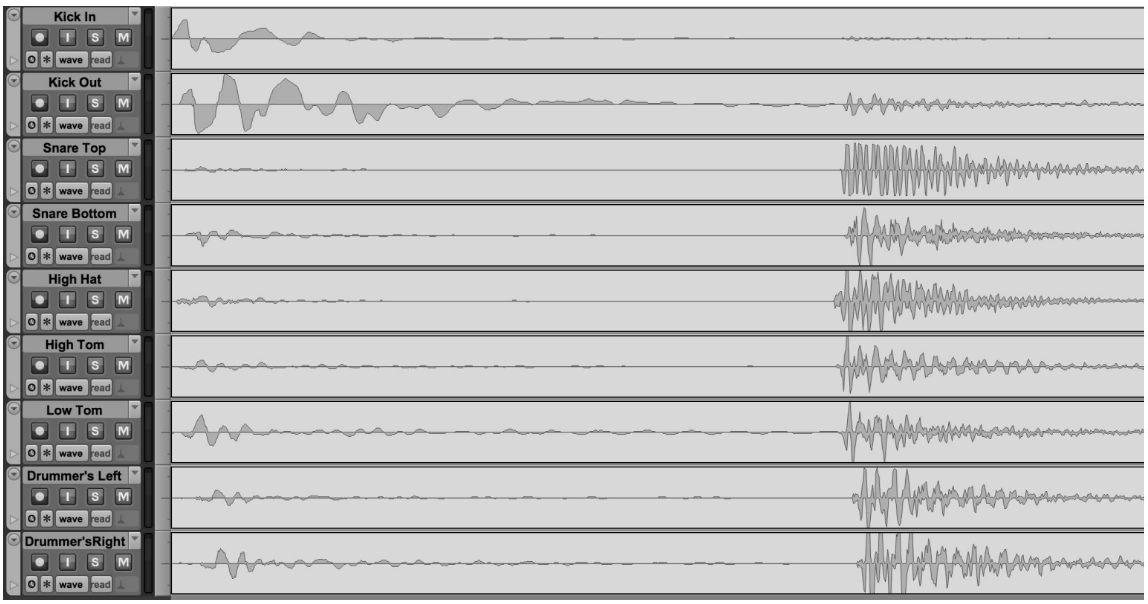

Figure 1. Drum tracks not time aligned.

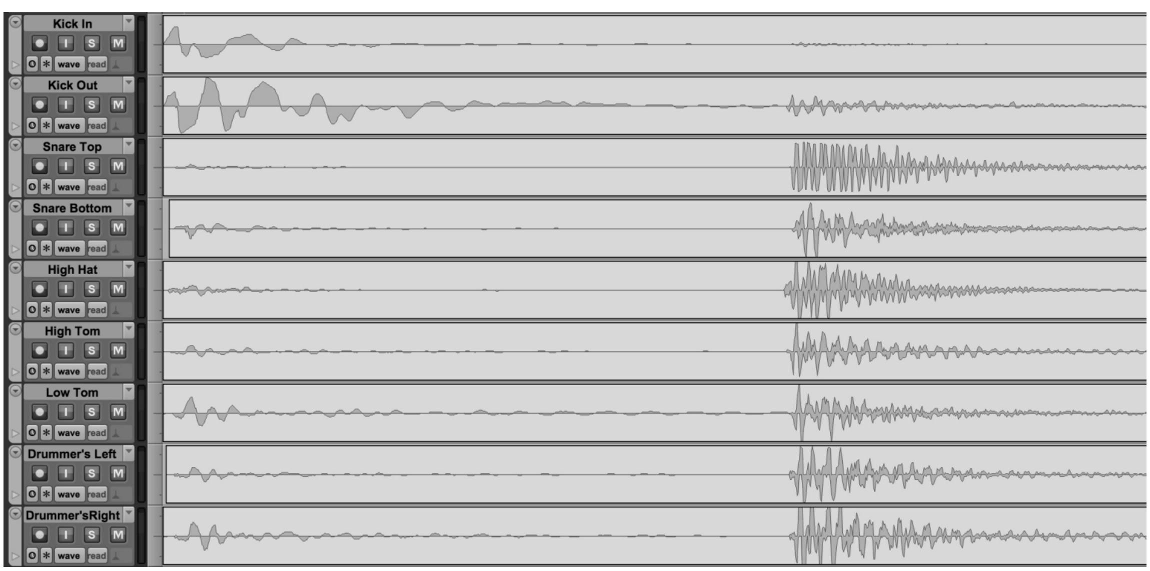

Figure 2. Drum tracks time aligned.

2.2 Microphones

2.2.1 Characteristics of Microphones

Microphones are chosen for specific recordings based on their headroom, size, type, directional pattern, and desired tone [8] [9]. There are three main types of microphones used in recording music: moving coil, condenser, and ribbon - each type has a unique sonic signature and use [10].

Moving coil microphones have a few advantages for being used for recording drums. The first is their construction and durability. Moving coil microphones are made of three main parts: diaphragm, voice coil, and a magnet. This design makes for a simple but robust microphone that can handle being used in a daily manner [11]. An engineer can place them close in high collision areas without having to worry about breaking if a drummer hits the body of the microphone with their drumstick. Common applications for moving coil microphones are kick, snare, and tom (high and low) drums. The second advantage is the ability to handle high sound pressure levels (SPL) without distorting.

Ribbon microphones are a variation on the moving coil microphone. A thin piece of metal is suspended between two magnetic pole pieces. As the metal vibrates in response to a sound wave, the magnetic line is broken, generating an electrical voltage [11]. The output of the microphone is usually low and extra amplification may be necessary. Due to the location of the thin piece of metal, this microphone is not as durable as a moving coil. High SPL can deform the metal causing inaccurate signals to be sent to the audio console. Ribbon microphones' advantage lies in the low mass of the ribbon, which enables better response to rapid transients. Ribbon microphones have a more linear frequency response than moving-coil microphones [11]. Ribbon microphones are commonly used for overheads and cymbals because of response to transients.

Condenser microphone elements use a conductive diaphragm and an electrically charged backplate to form a sound-sensitive capacitor. As the diaphragm vibrates in response to sound waves, the distance between the microphone and backplate fluctuates within the electrical field to create the signal [11]. Condenser microphone designs allow for smaller microphone elements, higher sensitivity and a smooth response across a wide frequency range. They can record in areas with extreme transients and high sound pressure levels, such as those generated by drums, with minimal distortion of the waveform and no damage to the microphone diaphragm. Common applications for condensers are high hats and overheads because of the bandwidth of these instruments and the speed at which is needed to capture the transients of the waveform onset [10].

A polar pattern is simply the sensitivity of the microphone from various directions. Three common patterns are: Omni-directional, Cardioid and Bi-Directional [12]. There are subsets of Cardioid: Super-Cardioid and Hyper-Cardioid [10]. An Omni-directional microphone captures the acoustic environment well because of the near perfect coverage (Figure 3) [13]. A Cardioid microphone is chosen when the engineer wants to capture direct sound but have control over the rejection from other sources of sound (Figure 4) [13]. A Bi-directional microphone captures sound from the front and back when rejecting the sides. It is used to capture sound sources as long as there is nothing directly behind the microphone. It can also be used to capture two things that are next to each other (Figure 5) [13] [14].

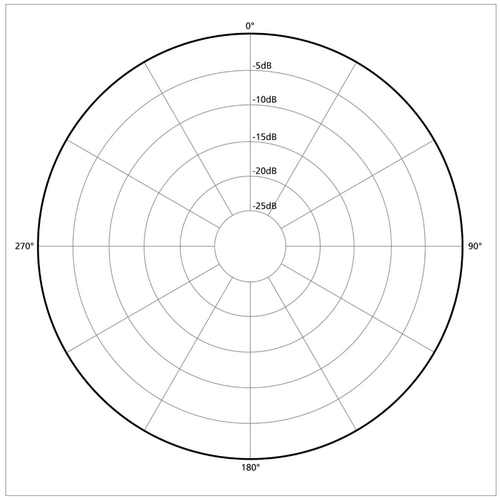

Figure 3. Omni - Directional polar pattern.

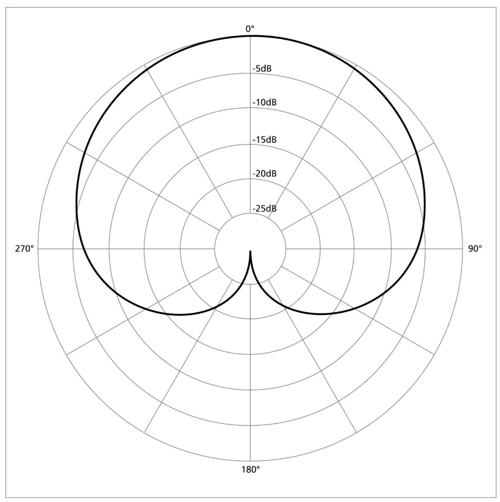

Figure 4. Cardioid polar pattern.

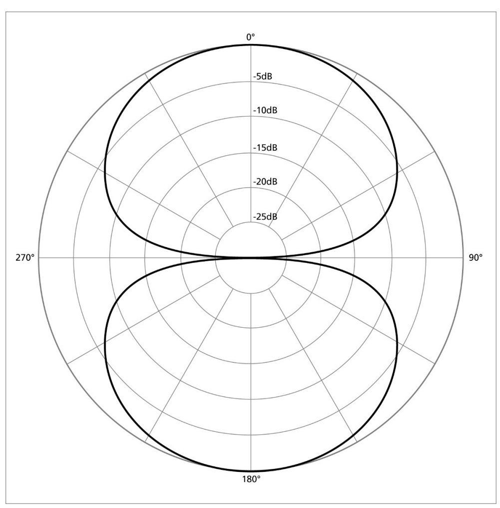

Figure 5. Bi-directional polar pattern.

2.2.2 Popular Microphones

There are a variety of microphone options for engineers to consider when deciding what microphones to use. The AKG D112 and Shure Beta 52 are regularly used to record the bass drum. Both microphones offer great low frequency response that can record the high amount of energy produced by the bass drum, 160 dB for the D112 and 174 dB for the Beta 52 [12] [15]. A popular choice for many engineers when recording snare drums is the Shure SM57. The SM57 can accurately record the high sound pressure levels produced by the snare drum transients. The SM57 has a relativity flat response form 150 Hz to 1200 Hz and a small boost starting around 2500 Hz. The fundamental frequency of snare drum is between 150-250 Hz. The flat response from the SM57 in this range may allow an engineer to capture these key frequencies as they are without adding to or losing the natural sound. The small boost in the high frequencies is great for capturing the "crack" of the snare drum [15] [16] [17]. For capturing high hats, engineers typically use a small diaphragm condenser with a cardioid pattern, often a Neumann KM84i. Small diaphragm condensers like the KM84i have an excellent high frequency response and the rejection off-axis may reduce leakage from the other instruments [8] [18]. The Neumann U47 F.E.T. is popular for use on the high and low toms. It is believed that the "near flat" low and midrange frequency response helps record the drums precisely [12] [15]. A popular choice for overhead microphones is a pair of condenser microphones because they have the potential to capture the drum kit without being overloaded by the acoustic energy. The AKG C414 is often chosen for this purpose. The C414 has nine polar patterns and can be fully customized for any type of stereo pair configuration [19]. Room microphones are chosen based on the recording environment. Since the engineer is trying to capture the tone of the room, an omni-directional microphone is frequently employed. The Neumann U67s are popular for this application because of their potential ability to capture the body of the kick and snare drum and also the low end in the tone of the room [8] [20].

2.3 Recording Styles

2.3.1 Early History

Recording engineers have used a range of styles to record drums beginning in the early 20th century. The recording technology limited how drums were recorded for decades. In the 1920's, the bass drum instrument was not used in some jazz recording. In its place, other instruments such as wood blocks were used. The acoustic process of recording used during this era could typically only record 250 Hz up to about 2,500 Hz and the recording device could not handle a high amount of energy that drums and other loud instruments produce [21]. When the electrical era of recording began, drums were introduced into the recording process. The beginning of this era of recording had new limitations for engineers. Most recordings were made with the use of a single microphone. The players in a band would have to position themselves carefully and not play too loudly. This practice lasted through the 1950's [22]. When multi-track tape recording was developed, multiple microphones were used to capture the entire band. However, the drums were usually recorded with a single microphone. In the early 1960's, overhead microphones were added to the process for recording drums [23].

2.3.2 Glyn Johns

During the 1960s, Glyn Johns developed a technique to set up a stereo pair of microphones, along with a microphone on the bass drum to record drums. Johns accidently discovered this two-microphone technique when he left a fader routed to the left channel of the mix from overdubbing. Johns adjusted the two microphones so that the one located near the center of the drum kit and the one located above the floor tom were equidistant from the snare drum. They were then routed half left and half right in the mix, creating a stereo image of the drum kit [24].

Photograph 1 shows the technique set up by Johns for recording Jeremy Stacey. This technique gained acceptance for rock recordings because of the natural stereo image and is still used today to record drums [22].

Photograph 1. Glyn Johns technique.

2.3.3 "Standard"

After the 1960's when multitrack recording became a standard practice, a new technique for recording drums was developed. The kick drum was recorded with a kick-in and kick-out microphone. This allowed the engineer to capture both the midrange and high frequencies from the beater on the head and the low frequencies from the drumhead. Microphones were placed above the top drumhead and below the bottom drumhead of the snare drum to record a more accurate snare drum sound. A microphone was placed near the high hat to capture the two-cymbal individually from the rest of the drum set. High and low tom microphones were used to record the direct sound of those drums. A stereo pair of microphones was used over the entire drum set for capturing overheads and the entire drum kit as a group [25]. This technique has become a common way to record drums in a studio. Figure 6 illustrates a standard way of placing microphones on a drum set [26].

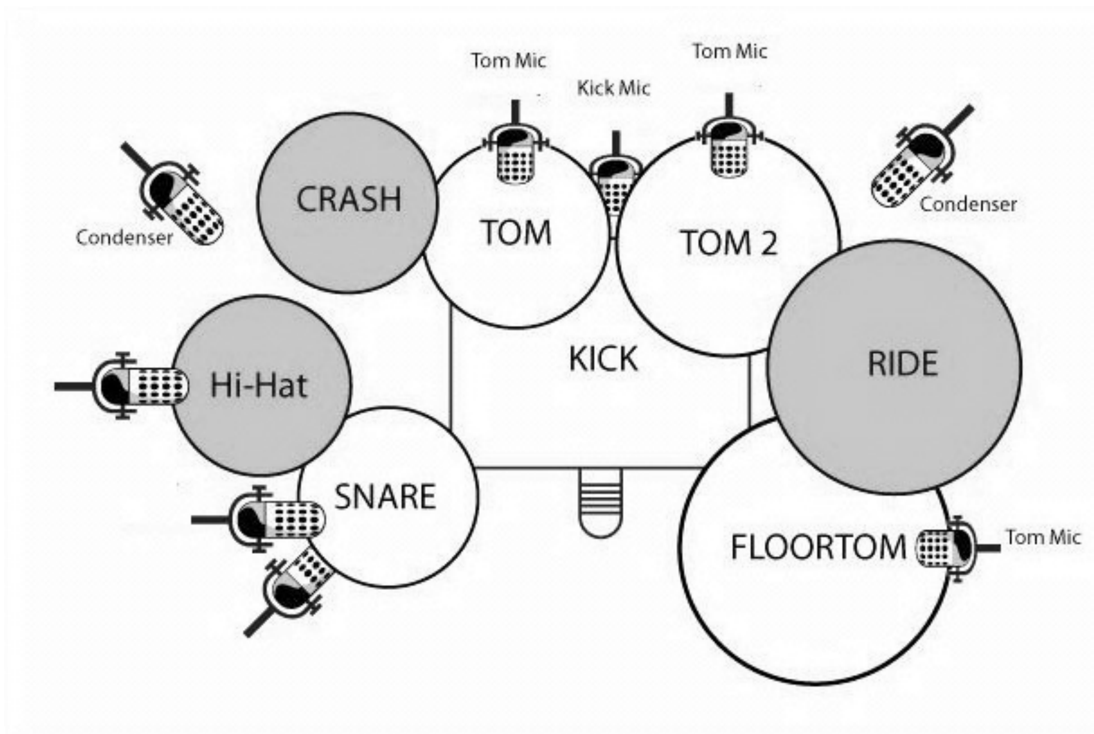

Figure 6. Standard placement of microphones

2.4 Polarity

The physical motion of a vibrating drumhead is an important consideration when recording it with two microphones. The sound of a drum is the result of complex modes of vibrations of a circular membrane [27]. In the simplest of forms, when struck and set into motion, the top drumhead of a snare drum moves inward and in response, the bottom drumhead moves outward. The assumption is that the vibrations coming from the two heads of a snare drum cause one of the microphones to receive a compression signal, while the other one receives a rarefaction signal [27].

Figure 7 shows an example of what top and bottom snare drum microphones capture when the drum is struck. From the initial impact between the drumstick and snare drum head, the microphone positioned above the drum initially captures a rarefaction signal, while the microphone positioned beneath the drum receives a compression signal. To avoid destructive cancellation when summing the two signals, a polarity switch on an audio console or Digital Audio Workstation (DAW) can swap the positive and negative voltage of one of the signals so that the two signals have the same compression and rarefactions patterns [28] [29]. Figure 8 displays the same scenario as Figure 7, but the bottom microphone has a polarity flip applied.

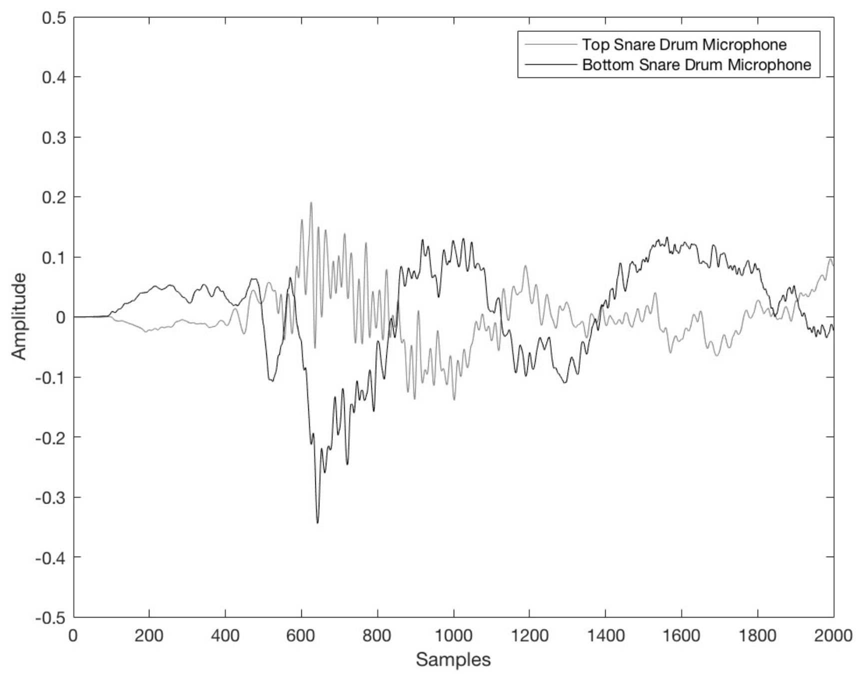

Figure 7. Snare Drum Microphones Polarity Inversion

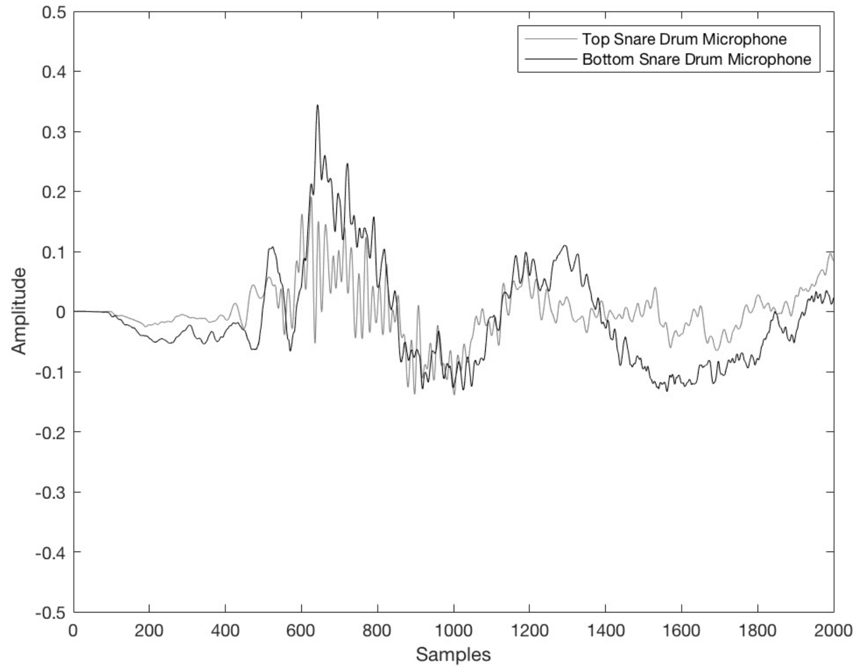

Figure 8. Snare Drum Microphones Polarity Matched

Figure 9 displays the summed signals from when the top and bottom microphones have opposite polarity and when the two microphones have the same polarity state. When summing two complex waveforms together, whenever the two signals share the same frequency elements, those elements may sound louder or softer depending on their relative phase relationship [27]. The summed signal with a shared relationship has less comb filtering and, possibly, a better tone. In Figure 9, the amplitude of the signal, when the two microphones share a polarity relationship, is greater than when they were opposite.

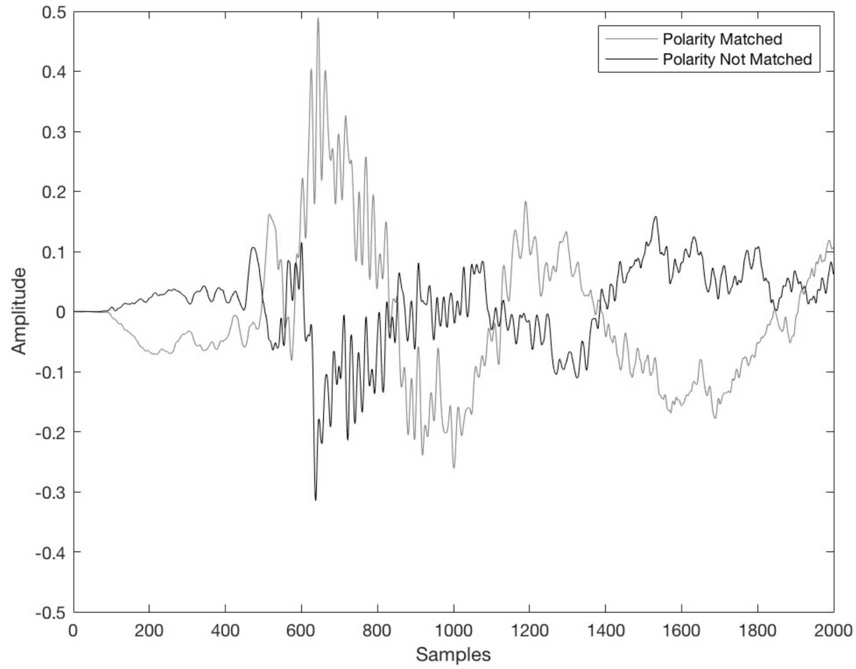

Figure 9. Snare Drum Microphones Summed

2.5 Pre-Delay

Pre-delay is an adjustable parameter offered on most reverberation hardware devices and software plugins. It sets the amount of time between the direct sound and the start of the early reflections [30]. Using pre-delay creates a larger and more natural reverberation. However, adding too much can lead to a decrease in clarity and cause the snare drum to overlap other drums in a non-musical way [31]. Pre-delay is based on other parameters on the reverberation device and factors such as tempo and reverb time. For example, with tempo and reverb time being held as constants and the pre-delay set to 0 milliseconds (ms), there is no time between the direct and early reflections. When an engineer increases the pre-delay from 0 ms, a slight and noticeable gap between the direct and reflected sounds is produced, but when the pre-delay is increased by an exceptional amount, it can cause a delay between direct and early reflections that may be non-musical [32].

2.6 Stereophonic Image

The following is a description of a conventional approach to mixing drums in stereo. When placing drums in a stereophonic field, it is ideal to route the microphones recording the drums in the natural direction where they occur. The ambient drum space should match the drummer's perspective in routing of the microphones. The left channel of the room microphones should be placed in the left channel of the mix, while the right microphone is placed in the right mix [33]. The ambient microphones should not be placed in the opposite channels of the mix. If the room microphones are placed incorrectly, it will create a competing image in the mix [34] [8]. A mix can have less clarity and impact due to the competing images in the left and right channels [35].

3. METHODS

This chapter outlines both the recording and mixing methods used to create the stimuli and describes the listening tests used to compare the common recording and mixing techniques.

3.1 Stimuli

3.1.1 Recording Stimuli

Experimental stimuli for investigating drum-recording techniques comprised time alignments of the individual drum tracks, popularized microphone choices, and the three styles of recording presented in section 2.3.3. Three samples and seven versions of each were generated - a control and six experimental versions. Control stimuli were recorded using the standard style and employed common microphones used for recording drums with all tracks in correct time alignment (COR - REC).

Experimental version #1 (INC - REC) also employed the standard recording style but used microphones that are not common for recording drums and individual tracks were not time aligned. This first version served as an example of an overall "incorrect" standard recording. Experimental versions #2 and #3 respectively altered the independent variables of microphone choice (MIC) and time alignment (PHASE) while keeping the other variables constant in what is generally considered the "correct" configuration. The remaining versions replicated the Glyn Johns technique (GLYN), the correct standard version (STANDARD), and a modified standard technique with additional microphones on the bottom of the high and low tom drums (EXCESSIVE). Table 1 is an overview of the different versions of the three samples.

Table 1. Common methods of recording overview

	MIC	PHASE	GLYN	STANDARD	EXCESSIVE
		Recording Stimuli			
Control: COR - REC				X	
Version 1: INC - REC	X	X		X	
Version 2: MIC	X			X	
Version 3: PHASE		X		X	
Version 4: GLYN			X		
Version 5: STANDARD				X	
Version 6: EXCESSIVE					X

3.1.2 Mixing Stimuli

Experimental stimuli for examining drum-mixing techniques involved switching the electrical polarity of the bottom snare drum microphone to match that of the top snare drum microphone, utilizing a pre-delay on a reverb in accordance to the tempo of the sample, and routing the ambient room microphones to the drummer's perspective. Three samples and five versions of each were generated - a control and four experimental versions.

Control stimuli employed an inverted polarity on the bottom snare drum microphone; pre-delay that matched the tempo of the sample (Table 3); and matching the ambient room microphones to the drummer's perspective in the left and right channels of the mix (COR - MIX).

Version #1 (INC - MIX) did not have the polarity on the bottom snare drum microphone inverted; used a pre-delay that did not match the tempo of the sample (Table 3); and routed the ambient room microphones to contradict with the drummer's perspective in the left and right channels of the mix. This first version served as an example of an overall "incorrect" mix. Experimental versions # 2, #3, and #4 individually altered the independent variables of polarity (PLRTY), pre-delay (TIMING), and routing of the ambient room microphones (PAN) while keeping the other variables constant in what is commonly considered the "correct" configuration. Table 2 is an overview of the different versions of the three mixing samples.

Table 2. Common methods of mixing overview

Mixing Stimuli	PAN	TIMING	PLRTY
Control: COR - MIX			
Version 1: INC - MIX	X	X	X
Version 2: PAN	X		
Version 3: TIMING		X	
Version 4: PLRTY			X

Table 3. Pre-Delay times used for TIMING versions

	Musical Pre-Delay	Non-Musical Pre-Delay
	TIMING	
Sample 4	18 ms	75 ms
Sample 5	24 ms	100 ms
Sample 6	18 ms	70 ms

3.2 Recording Procedure

To record the stimuli used to test the two popular methods of recording (samples one through three), the recording session was designed so that the control and six experimental versions could be simultaneously recorded. This was done to eliminate any potential changes in positioning of the microphones, changes in pre-amplifier settings, fader levels, and to get rid of any inconsistency in the playing of the drums. Microphones were chosen based on claims in the popular press and reported use in studios. Appendix A contains the input lists for the microphones used in the control and INC - REC versions (Tables 11 and 12).

To record the stimuli used for examining drum-mixing techniques the standard recording style and common microphones used for recording drums were employed. The microphones were recorded through an API 2098 console and an Apogee Symphony interface into Protools at a sampling rate of 48,000 and at 24-bit depth.

3.3 Mixing Procedure

Between the seven different versions of samples one through three, fader levels and equalization were kept constant and placement of the channels in the mix did not change. Samples one through three were RMS normalized to -25 dBFS prior to presentation. Between the five different versions of samples three through six, fader levels and equalization were kept constant and placement of the channels in the mix did not change. Samples four through six were RMS normalized to -25 dBFS prior to presentation.

3.4 Listening Tests

3.4.1 Subjects

Subjects were fifteen Belmont University graduate students, all of whom had received graduate-level training in critical listening. Subjects were not made aware of the purpose of the study and were informed they would be taking ABX listening tests, along with doing preference and rating tasks. No subjects reported allergies, congestion, or other hearing impairment.

3.4.2 ABX Test Design & Interface

The test was a two-part paired-subject ABX identification test, with recording and mixing tests completed on separate days. The testing sessions were spread across multiple weeks and were performed on an ad hoc basis according to the subjects' availability. Subjects used a pair of headphones for all testing. A screenshot of the MATLAB [36] ABX testing interface can be seen in Figure 10.

For samples one through three, A and B were randomly assigned either the control or one of the following versions of the same sample: INC - REC, MIC, or PHASE. For samples four through six, A and B were randomly assigned either the control or one of the following versions of the same sample: INC - MIX, PAN, PLRTY, or TIMING. Tables 4 and 5 list the possible pairs of the samples for the ABX testing.

The independent variables were the sample and the version of the sample that was being used. The dependent variable was simply the subject's response. If a subject were unable to distinguish between the control and one of the other versions, responses would appear guessing and yielded a 50% chance at getting a hit. This test functioned off a null hypothesis that there would be no perceived differences between versions of samples that were mixed "correctly," using common methods of recording and mixing, over versions that were not.

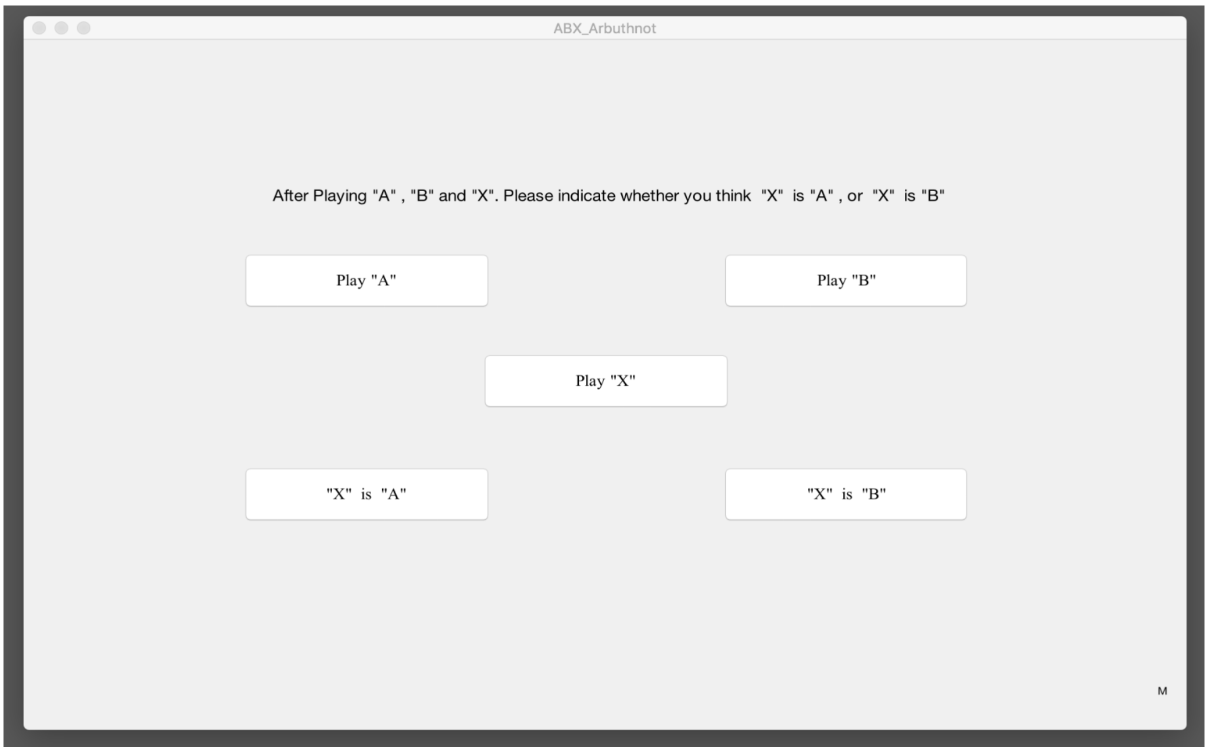

Figure 10. Screenshot of MATLAB ABX testing interface. Figure is not to scale.

Table 4. List of stimulus pairs for recording ABX test

Pair 1	Sample 1 Control	Sample 1 INC - REC
Pair 2	Sample 3 Control	Sample 3 MIC
Pair 3	Sample 2 Control	Sample 2 PHASE
Pair 4	Sample 1 Control	Sample 1 MIC
Pair 5	Sample 3 Control	Sample 3 INC - REC
Pair 6	Sample 2 Control	Sample 2 MIC
Pair 7	Sample 1 Control	Sample 1 PHASE
Pair 8	Sample 3 Control	Sample 3 PHASE
Pair 9	Sample 2 CORRECT	Sample 2 INC - REC

Table 5. List of stimulus pairs for mixing ABX test

Pair 1	Sample 4 Control	Sample 4 INC - MIX
Pair 2	Sample 6 Control	Sample 6 TIMING
Pair 3	Sample 5 Control	Sample 5 PLRTY
Pair 4	Sample 4 Control	Sample 4 TIMING
Pair 5	Sample 5 Control	Sample 5 INC - MIX
Pair 6	Sample 6 Control	Sample 6 PLRTY
Pair 7	Sample 4 Control	Sample 4 PLRTY
Pair 8	Sample 5 Control	Sample 5 PAN
Pair 9	Sample 6 Control	Sample 6 INC - MIX
Pair 10	Sample 4 Control	Sample 4 PAN
Pair 11	Sample 6 Control	Sample 6 PAN
Pair 12	Sample 5 Control	Sample 5 TIMING

3.4.3 Preference Test Design & Interface

A screenshot of the MATLAB [36] testing interface for preference testing can be seen in Figure 11. Buttons on the interface, Play A and Play B were randomly assigned to be one of the pairs for each trial, listed in Table 6.

The independent variables were the sample and the version of the sample that was being used. The dependent variable was simply the subject's response. This test functioned off a null hypothesis that subjects would not have a definitive preference for versions of samples that were mixed "correctly," using common methods of recording and mixing, over versions that were not.

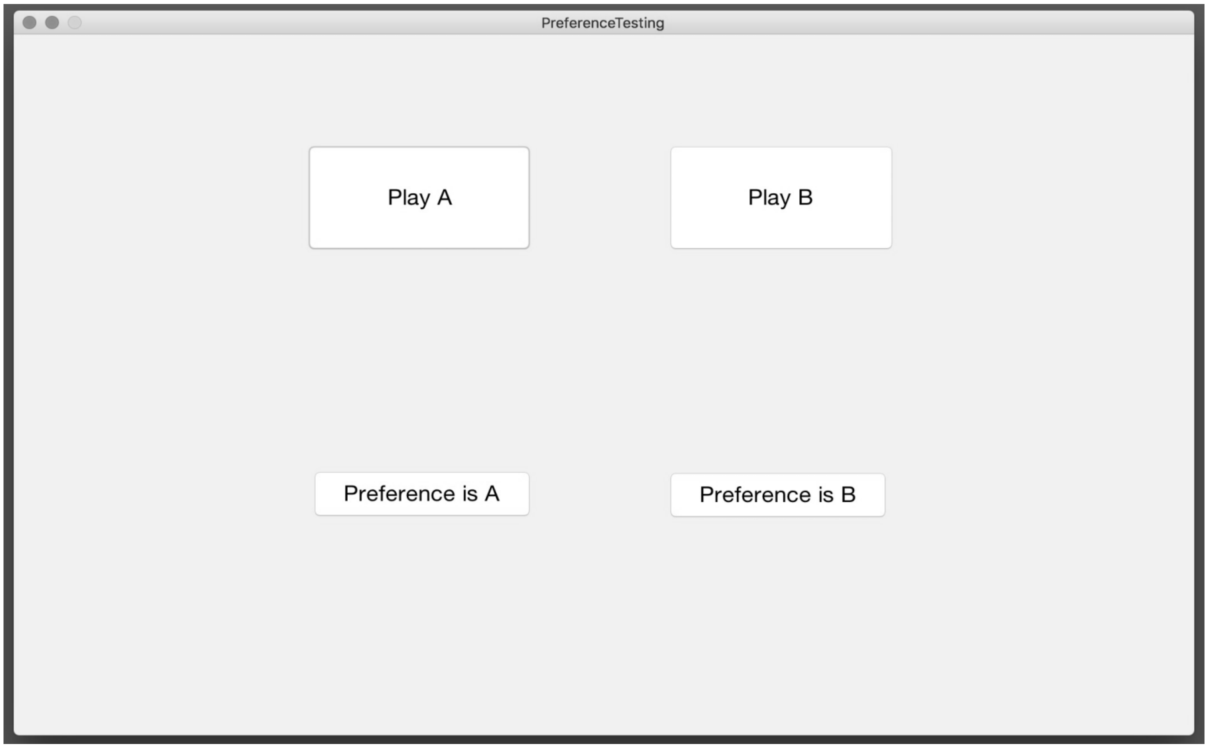

Figure 11. Screenshot of MATLAB preference testing interface. Figure is not to scale.

Table 6. List of trials for preference testing

Trial 1	Sample 4 Control	Sample 4 INC - MIX
Trial 2	Sample 5 Control	Sample 5 INC - MIX
Trial 3	Sample 6 Control	Sample 6 INC - MIX
Trial 4	Sample 1 Control	Sample 1 INC - REC
Trial 5	Sample 2 Control	Sample 2 INC - REC
Trial 6	Sample 3 Control	Sample 3 INC - REC
Trial 7	Sample 1 Glyn	Sample 1 Standard
Trial 8	Sample 2 Glyn	Sample 2 Standard
Trial 9	Sample 3 Glyn	Sample 3 Standard
Trial 10	Sample 1 Glyn	Sample 1 Excessive
Trial 11	Sample 2 Glyn	Sample 2 Excessive
Trial 12	Sample 3 Glyn	Sample 3 Excessive
Trial 13	Sample 1 Standard	Sample 1 Excessive
Trial 14	Sample 2 Standard	Sample 2 Excessive
Trial 15	Sample 3 Standard	Sample 3 Excessive
Trail 16	Sample 1 Control	Sample 1 Mic
Trial 17	Sample 2 Control	Sample 2 Mic
Trial 18	Sample 3 Control	Sample 3 Mic

3.4.4 Rating Task Design & Interface

Subjects were asked to rate the different versions of the samples based on clarity, spaciousness, and fidelity. Definitions were provided at the start of the experiment and subjects had the ability to review them at during the session by pressing the “Definition” button on the MATLAB [36] testing interface as seen in Figure 12. The rating scale was a

5-point scale as ITU-R BS.1534-1 recommends [37]. Table 7 lists the order of the task. The independent variables were the sample being played, the definitions, and the scale being used. The dependent variable was the collection of responses gathered from the subject rating the version. This test functioned off the null hypothesis that the “CORRECT” versions of the samples would not yield higher ratings for clarity, spaciousness and fidelity over those mixed incorrectly.

The definitions for the rating criteria were:

- Clarity: “Excellent” is where you can hear and distinguish different drums. The different drums are without distortion and you can perceive onsets, transients and other details in the music. The opposite is a reproduction, which can be characterized by words such as “diffuse,” “muddy,” “thick,” “mushy,” “noisy” and “distorted [1].”
- Spaciousness: “Excellent” is where the reproduction sounds open, has breadth and depth, fills up the room, gives a feeling of presence. The opposite is a reproduction that sounds” closed/shut up,” “narrow,” “without feeling of presence [1].”
- Fidelity: Refers to the similarity of the reproduction to the original sound. “Excellent” designates perfect fidelity, the music sounds exactly as if you heard it in the room it which it was performed. “Bad” means minimum fidelity, a “worse reproduction can hardly be imagined [1].”

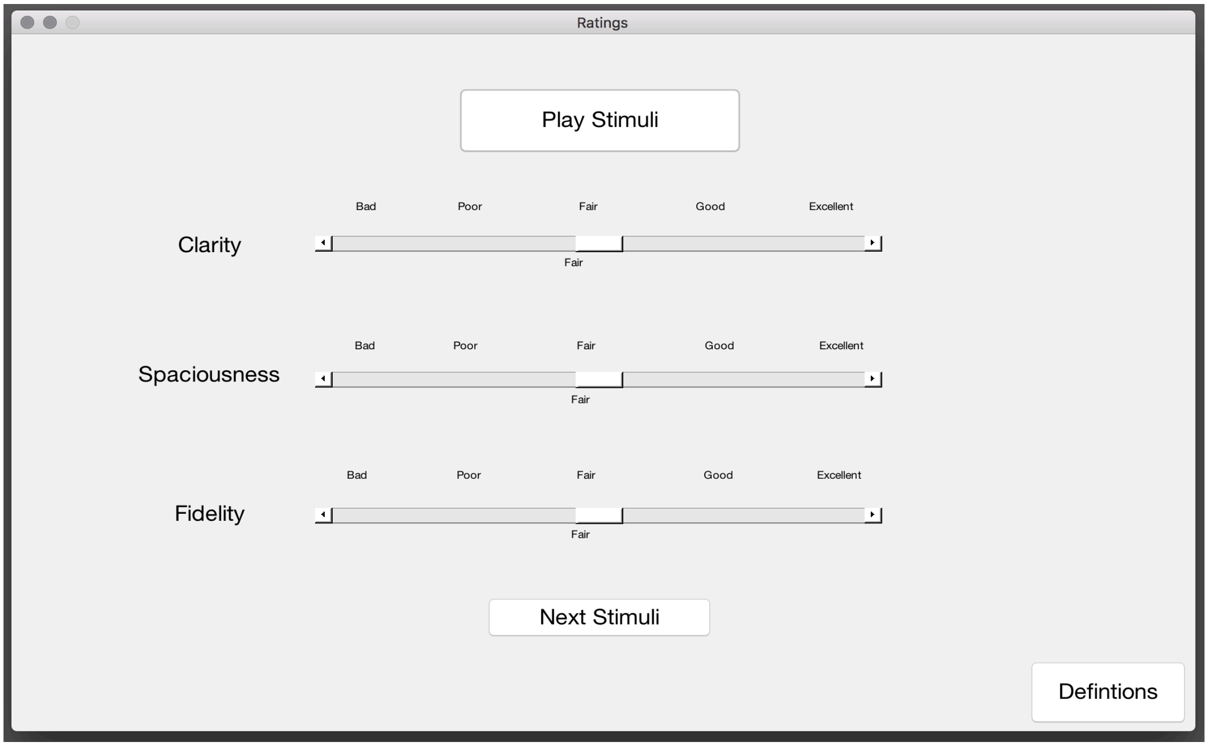

Figure 12. Screenshot of MATLAB rating interface. Figure is not to scale.

Table 7. List of trials for ratings

Trial 1	Sample 3 Mic
Trial 2	Sample 4 Control
Trial 3	Sample 5 Control
Trial 4	Sample 1 Mic
Trial 5	Sample 6 Control
Trial 6	Sample 2 Mic
Trial 7	Sample 1 Standard
Trial 8	Sample 2 Standard
Trial 9	Sample 3 Standard
Trial 10	Sample 4 INC - MIX
Trial 11	Sample 5 INC - MIX
Trial 12	Sample 6 INC - MIX
Trial 13	Sample 1 INC - REC
Trial 14	Sample 2 INC - REC
Trial 15	Sample 3 INC - REC
Trail 16	Sample 2 Glyn
Trial 17	Sample 3 Excessive
Trial 18	Sample 1 Glyn
Trial 19	Sample 2 Excessive
Trial 20	Sample 1 Excessive
Trial 21	Sample 3 Glyn

3.4.5 Trials

For the ABX identification tests, there were fifteen trials per stimulus pair. For the ABX session investigating recording techniques, there were 135 trials total. After every pair (15 trials) subjects would have a 60 second, minimum, break before continuing on with the session. The average session time was approximately 20 minutes.

For the ABX session investigating mixing techniques, there were 180 trials total. Similarly to the first session of the ABX testing, after every pair (15 trials), subjects had a 60 second break. The average session time was approximately 20 minutes. The preference testing session had 18 trials and subjects were able to proceed at their own pace. There were no breaks for this session. There were 21 trials for rating session. Subjects were able to proceed at their own pace.

4. RESULTS

4.1 ABX Tests

For binomial probability, the following equation was used to determine how many correct "hits" a subject must have to be significant at the 95% confidence level [38].

$$P\,(s) = \binom{n}{s} p^s (1-p)^{n-s}$$

(1)

Where:

n = number of trials
s = number of successes observed
p = probability of getting a correct response

For this thesis, a subject needed to correctly identify, greater than or equal to 11, or less than or equal to 4 out of the 15 ABX trials to have a significant p value.

Table 8. Results required for a 95% confidence level

Trials	13	14	15	16	17
≥	10	11	11	12	12
p (x)	0.03	0.02	0.04	0.03	0.05
≤	3	3	4	4	5
p (x)	0.03	0.02	0.04	0.03	0.05

4.1.1 Recording Results - ABX

Subjects could not identify the PHASE version from the control during the ABX testing. Figures 13 through 15 display the subjects' "hit" rate for the three samples. Samples 1 and 3 had seven subjects able to detect the version, while Sample 2 had six subjects.

Subjects could detect the INC – REC and MIC versions from the control during the ABX test with near perfect identification. Figures 23 through 28 in Appendix B present the "hit" rates per version.

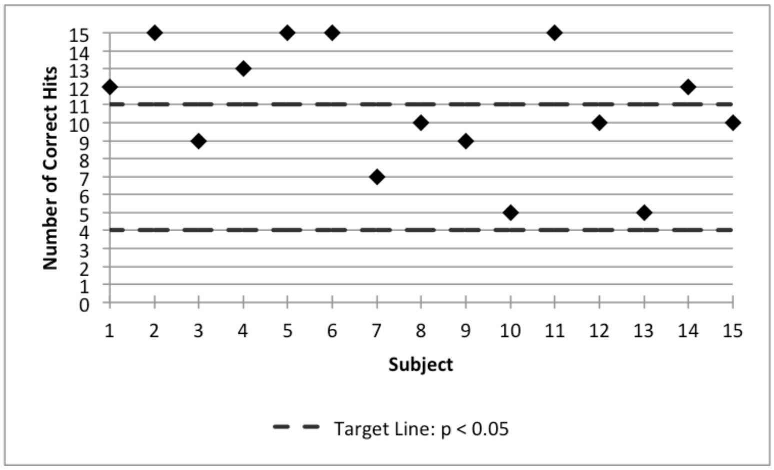

Figure 13. ABX Results Sample 1 PHASE

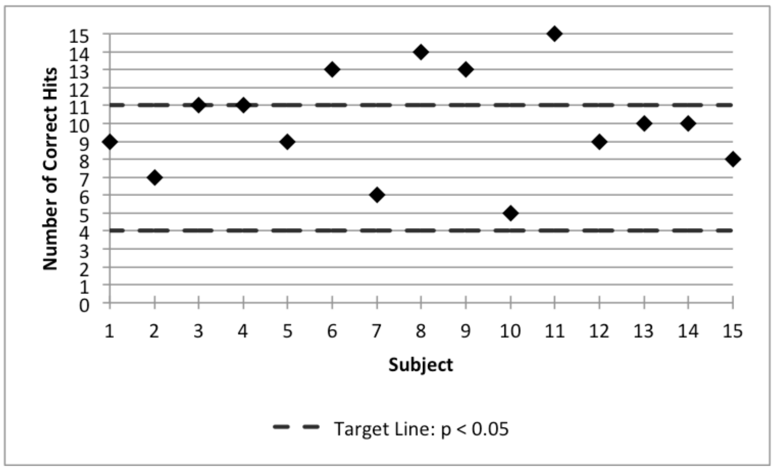

Figure 14. ABX Results Sample 2 PHASE

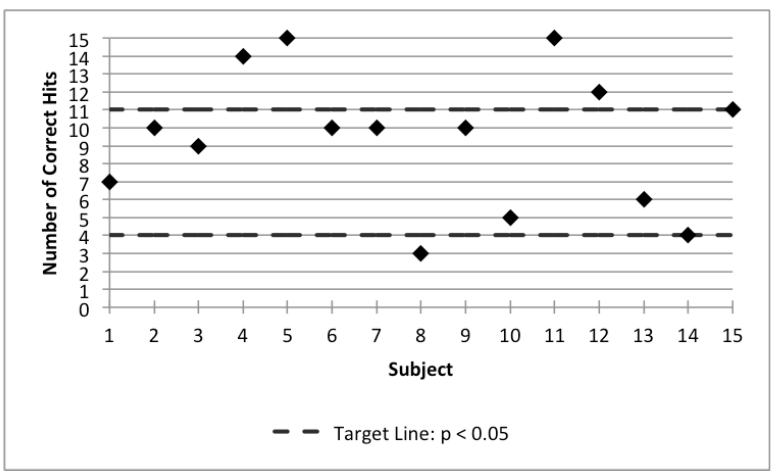

Figure 15. ABX Results Sample 3 PHASE

4.1.2 Mixing Results – ABX

Subjects could not detect the INC-MIX, PLRTY, and the TIMING versions from the control for Sample 4. Figures 16 through 18 display the results from the ABX test. The subjects could not identify the PLRTY and TIMING versions for Samples 5 and 6 (Figures 19 through 22).

Subjects could identify the PAN version for Sample 4 through Sample 6. Subjects could also detect the INC- MIX for Samples 5 and 6. Results are shown in Appendix B, Figures 29 through 33.

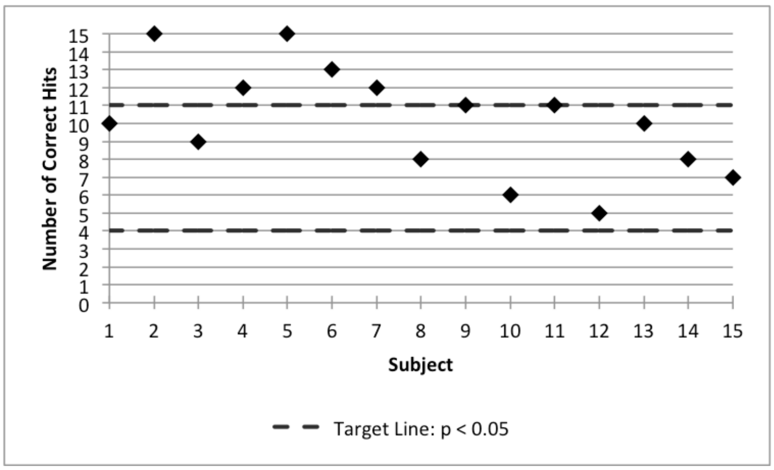

Figure 16. ABX Results Sample 4 INC - MIX

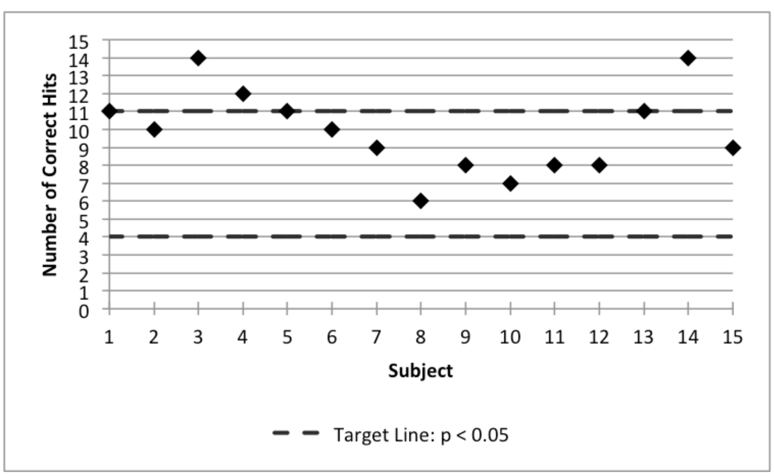

Figure 17. ABX Results Sample 4 PLRTY

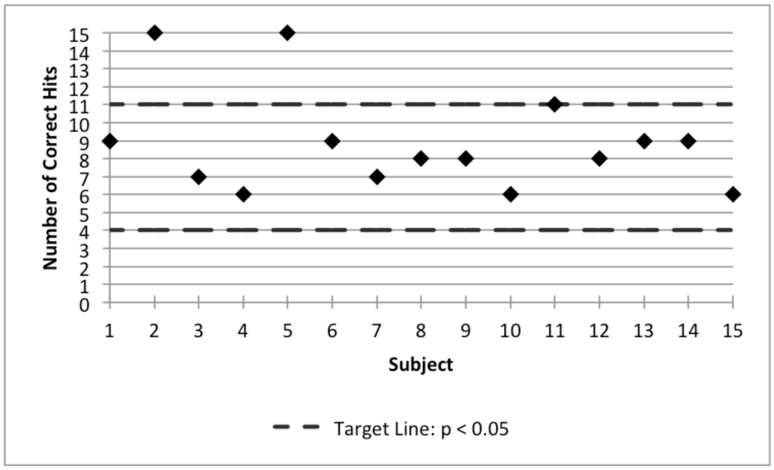

Figure 18. ABX Results Sample 4 TIMING

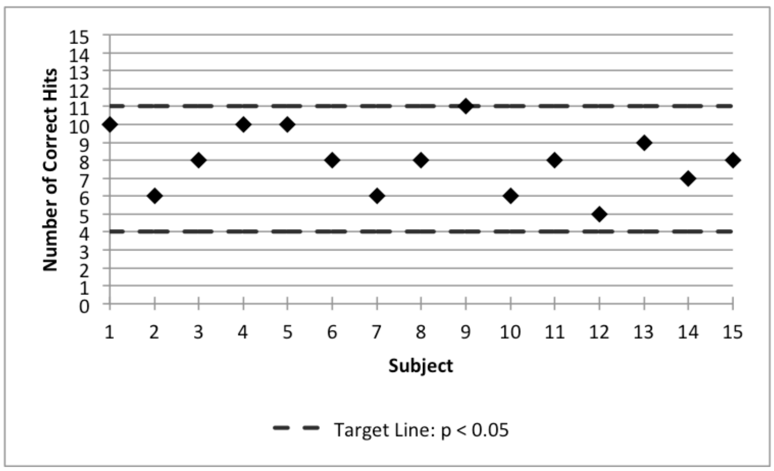

Figure 19. ABX Results Sample 5 PLRTY

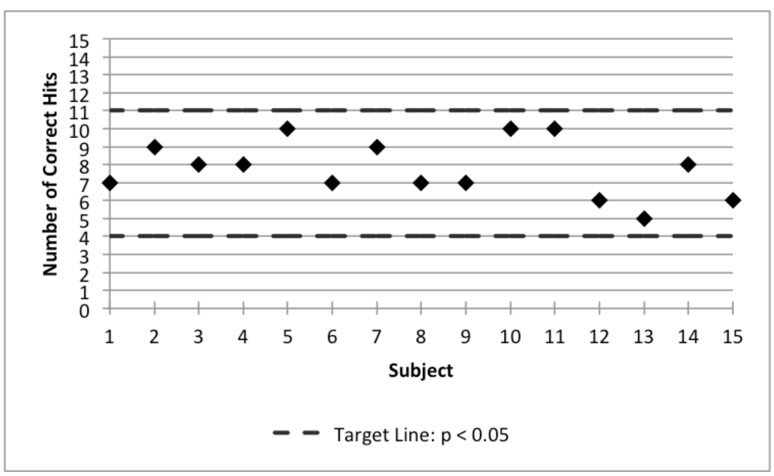

Figure 20. ABX Results Sample 5 TIMING

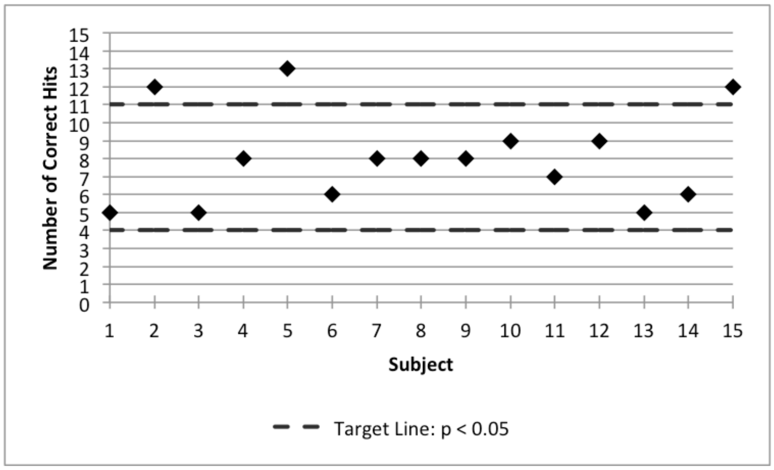

Figure 21. ABX Results Sample 6 PLRTY

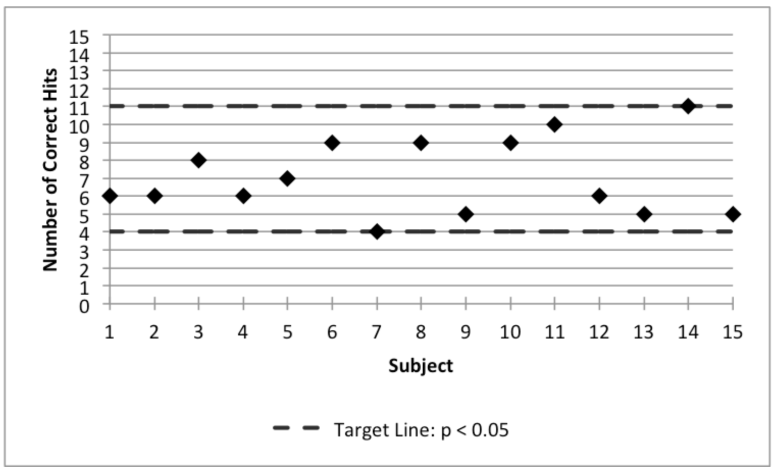

Figure 22. ABX Results Sample 6 TIMING

4.2 Preference Tests Results

Preference results were subjected to a binomial probability. To have preference as a group, eleven or more subjects needed to agree on their preference per trial. There was one instance where this occurred. Table 9 shows the only trial with a 95% confidence level and Table 13 in Appendix B lists the results broken down by preference per trial.

Table 9. Binomial probability for preference tests

Trial 2	Sample 5 Control	Preference	*p* (x)
	Sample 5 INC - MIX	Sample 5 Control	< 0.05

4.3 Rating Tests

The Inter-rater reliability (IRR) kappa statistic was calculated for the control and the experimental stimuli for each of the attributes being rated for all six samples. The IRR for all but GLYN spaciousness in Samples 1 and 2 were in fair agreement. The values for GLYN spaciousness were in slight agreement [39]. Table 14 in Appendix B lists the kappa statistics for each sample.

4.3.1 Recording Results - Ratings

A two-way analysis of variance (ANOVA) [40] found no significant effect between treatments for Sample 1. However, there were significant interactions between subjects for Sample 1 STANDARD & EXCESSIVE and Control & MIC for clarity, ($F(1,14) = 3.27$, $p = .04$, $F(1,14) = 3.81$, $p = 0.01$). There was also significant interaction for Sample 1 Control & Mic for spaciousness, ($F(1,14) = 4.59$, $p = .003$). Descriptive statistics and *Fisher LSD* for Sample 1 can be found in Appendix B, Tables 15 through 18 and Tables 29 through 31.

A two-way ANOVA found no significant effect between treatments for Sample 2. There were significant interactions between subjects for the Control & INC – REC Spaciousness, ($F(1,14) = 2.58$, $p = .04$). There was also a significant interaction for STANDARD & EXCESSIVE Clarity, ($F(1,14) = 2.77$, $p = .03$). Between STANDARD & EXCESSIVE and Control & MIC, there was a significant interaction for Fidelity, ($F(1,14) = 3.20$, $p = .02$) and ($F(1,14) = 2.59$, $p = .04$). Descriptive statistics and *Fisher LSD* for Sample 2 can be found in Appendix B, Tables 19 through 22 and Tables 32 through 35.

A two-way ANOVA found a significant effect between treatments for Sample 3 STANDARD & GLYN, Fidelity ($F(1,14) = 5.30$, $p = .04$). Relevant descriptive statistics for both are listed in Table 10. Descriptive statistics for the remainder of Sample 3 can be found in the Appendix B, Tables 23 through 25.

Table 10. Descriptive statistics for Sample 3 Standard & Glyn

	Control Mean	SD	Glyn Mean	SD	N
Clarity	3.20	1.41	2.67	1.11	15
Spaciousness	3.13	0.74	3.60	1.35	15
Fidelity	2.87	0.92	2.00	1.07	15

4.3.2 Mixing Results - Ratings

A two-way ANOVA found no significant effect of treatments for Sample 4 through Sample 6. Descriptive statistics can be found in the Appendix B, Tables 26 through 28. There was a significant interaction between subjects for Sample 6 Control & INC- MIX Clarity, ($F(1,14)$ = 7.40, p = .0003). *The Fisher LSD* can be found in Table 36 in Appendix B.

5. DISCUSSION

5.1 Recording Techniques Discussion

Listening tests found significant data in the detection of recording techniques in the ABX tests. Subjects could detect the INC – REC and MIC versions of the recording techniques stimuli. The null hypothesis assuming no perceived differences between mixes that employ common microphone selection and those that do not can be rejected. However, subjects could not identify the PHASE version during the ABX tests. There is insufficient evidence to reject the null hypothesis. The subjects' ability to distinguish the INC – REC can be attributed to the timbral changes of the microphone selection in the MIC version. The subtle changes of PHASE are harder for subjects to consistently hear.

Subjects did not have a preference between any of the styles of recording (STANDARD, EXCESSIVE or GLYN); the null hypothesis cannot be rejected. The only sample to achieve a significant effect of treatment was the GLYN version of Sample 3 for fidelity. This effect was not seen in the GLYN versions of Samples 1 and 2. The null hypothesis assuming no difference in ratings cannot be rejected. The ANOVAs did provide significant interactions between subjects for six trials. The variability of ratings between multiple subjects could be attributed to a lack of understanding of the definitions used or the subject's personal perception changing between samples when being presented the control and experimental stimuli. The IRR statistics, while in fair agreement, are relatively low.

5.2 Mixing Techniques Discussion

Listening tests found subjects could detect the PAN versions in Samples 4 through 6. Subjects could also identify the INC- MIX for Samples 5 and 6. The null hypothesis assuming no perceived differences in the routing of ambient room microphones can be rejected.

However, subjects could not detect the INC-MIX for Sample 4 and PLRTY and TIMING versions for Samples 4 through 6. There is insufficient evidence to reject the null hypothesis for the pre-delay on a snare reverb and inverting the polarity on the bottom snare drum microphone during the mixing process. The ability to distinguish the PAN and INC- MIX versions could be caused by spatial changes that may be easier to distinguish in the different mixes, while TIMING and PLRTY are more subtle changes that may be harder to hear in the drum recordings.

Subjects demonstrated a preference for the Control over the INC- MIX for Sample 5. Samples 4 and 6 had no preference. With the one preference, a difference in ratings between the versions would be expected to explain why subjects picked the control, but no significant difference in the ratings were found during the two-way ANAOVAs. The null hypothesis that subjects would not have a preference cannot be rejected based on the evidence collected. The null hypothesis that subjects would not rate the control differently from the experimental stimuli cannot be rejected.

6. CONCLUSIONS

ABX, preference and rating listening tests examined subjects' ability to identify the popularized methods of recording and mixing drums, assuming a null hypothesis of no perceptual sonic differences between mixes that employ the popularized techniques and mixes that do not. The three recording techniques were: aligning multiple tracks to achieve a coherent phase relationship, microphone selection, and the style of recording. The three mixing techniques were: inverting the bottom snare drum microphone to match the top snare drum microphone, having a pre-delay time on a reverb that matched the tempo of the sample, and routing the room microphones to the drummer's perspective.

Results from these listening tests provided mixed evidence. The null hypotheses can be rejected for using microphones commonly used for drum recording and routing the room microphones to the drummer's perspective to match the overhead microphones. The results also fail to reject the null hypotheses for: aligning multiple tracks to achieve a coherent phase relationship, inverting the bottom snare drum microphone to match the top snare drum microphone, and having a pre-delay time on a reverb that matched the tempo of the sample. Subtle alterations like polarity and timing changes are less likely to be perceived, whilst changes in the spatial positioning and timbral qualities have a greater chance of being detected.

6.1 Further Research

One limitation of the study is the relatively low number of subjects. To expand on this research, having more participants would help strengthen the results collected and could help clarify some of the results that are inconclusive.

One advantage of this study was that the subjects were all graduate-level and critically trained listeners. One possibility of further research would be to have untrained listeners in a non-audio program be the subjects of the study to see how typical music consumers would react to recording and mixing techniques in the mix, if at all.

An expansion of this study would be to include distinctly different genres of music i.e. orchestral drums, jazz drums, rock drums, etc. Investigating these different styles of music could better determine whether the gathered results from this study are limited to this selection of drum samples for this study or apply to all genres. Another avenue that could be explored would be the addition of other instruments such as bass, guitars, keys, horns and/or vocals. Exploring these samples with additional instruments could potentially change the outcome of subjects' preferences, ratings and ability to distinguish between versions of samples.

BIBLIOGRAPHY

Citations

[1] A. Gabrielsson and B. Lindström, "Perceived Sound Quality of High Fidelity Loudspeakers," in *Audio Engineering Society Convention 74*, 1983.
[2] Shure, "MICROPHONE TECHNIQUES," *A Shure Educ. Publ.*, 2017.
[3] Shure, "Dynamic vs Condenser Microphone - Operating Principle," *A Shure Educational Publication*. 2017.
[4] J. Haas, "Introduction to Computer Music : Volume One Chapter One : An Acoustics Primer," 2017
[5] P. Nichols, "5 Ways to Address Phase Issues in Audio" *iZotope*, 2017.
[6] M. Major, "Advanced Drum Mixing: Time-Aligning Your Drum Tracks for Better Phase Coherence," *Sonic Scoops*, 2017.
[7] C. Johnsen, "Proofs of an Absolute Polarity," in *Audio Engineering Society Convention 91*, 1991.
[8] J. Balding, "Advanced Drum Recording." Nashville, TN, 2018.
[9] "Best Microphones for Recording Snare Drums," *InSync*, 2017.
[10] M. Sorensen, "Microphones: Dynamics, Ribbons, and Condensers," *Acoustic Fields*, 2012.
[11] M. Henshall, " Microphone Basics: Transducers, Polar Patterns, & Frequency Response", A Shure Educational Publication, 2015.
[12] J. L. Butler, "Microphone Selection," in *Audio Engineering Society Convention 86*, 1989.
[13] "Polar Patterns," *A Shure Educational Publication* 2019.
[14] D. Rochman, "Multi-Pattern Microphones: What, Where and How?," *A Shure Educational Publication*, 2014.
[15] K. Becka, "The Best Mics To Use For Recording Drums," *Black Bird Acad.*, 2017.
[16] B. Brennan, "What You Need To Know About Drum Mics," *Modern Drummer*, 2011.
[17] M. Henshall, " How to Mic a Snare Drum with a Shure SM57", A Shure Educational Publication, 2014.
[18] "The Best Microphones for Recording Drums at Home" *E-Home Recording Studio*, 2018.
[19] "The 4 Best Overhead Drum Mics – Reviews 2019" *Song Simian*, 2019.
[20] K. E. Smith, "My Favorite Drum Mics," *KeithEveretteSmith.com*, 2010.
[21] "Acoustic Recording", Museum of Magnetic, Sound Recording, 2016.
[22] P. J. Stamler, "A historical walk through some of the greatest recordings of all time" *Recording Mag.*
[23] M. Carpenter, "HOW TO : BANG-ON RETRO DRUMS," *Audio Technology*, 2015.
[24] G. Johns, *Sound Man*. Plume, 2015.
[25] H. Robjohns, "Recording Drums," *Sound on Sound*, 2003.
[26] "Mic Position for Drum Kits", Hard Wired Media , 2012
[27] R. Stewart, "Polarity ? Phase ? What is the difference ? What is phase ?," *JustMastering.com*, 2018.
[28] H. Robjohns, "Q. Why should a snare bottom mic be polarity inverted?," *Sound On Sound*, no. October 2017.
[29] S. Bunting, "Phase or Polarity ?" *Total Pro Audio*, 2010.
[30] P. Nichols, "Reflecting on Reverb : What It Is and How to Use It," *iZotope*, 2018.
[31] S. Wiggins, "Add clarity to your audio mix using pre-delay" *Disc Makers*, 2016.
[32] R. Izhaki, *Mixing Audio: Concepts, Practices and Tools*, 2nd ed. Focal Press, 2011.

[33] S. Savage, *Mixing and Mastering in the Box: The Guide to Making Great Mixes and Final Masters on Your Computer*, 1st ed. Oxford University Press, 2014.
[34] M. Levine, "Use These Mixing Tools & Techniques, But Do It Judiciously," *Drum Magazine*, 2018.
[35] H. Robjohns, "How should I pan my multi-miked drums ?" *Sound On Sound*, 2004.
[36] MATLAB, version 9.4.0.813654 (R2018a). Natick, Massachusetts: The MathWorks Inc., 2018.
[37] "ITU-R BS.1534, Method for the subjective assessment of intermediate quality levels of coding systems" International Telecommunication Union, 2003.
[38] J. Boley and M. Lester, "Statistical Analysis of ABX Results Using Signal Detection Theory," Presented in *Audio Engineering Society Convention 127*, 2009.
[39] [1] A. J. Viera and J. M. Garrett, "Understanding Interobserver Agreement : The Kappa Statistic," *Fam. Med.*, no. May, pp. 360–363, 2005.
[40] StatPlus, version 6.7.03. Walnut, California: AnalystsSoft Inc., 2018.

Resources

"AES 20-1996," *Soc. Audio Eng.*, 1996
"Cut Sheet D112 MKII", AKG by Harman, 2015
D. Clark, "High-Resolution Subjective Testing Using a Double-Blind Comparator," *J. Audio Eng. Soc*, vol. 30, no. 5, pp. 330–338, 1982.
H. Burstein, "Transformed Binomial Confidence Limits for Listening Tests," *J. Audio Eng. Soc*, vol. 37, no. 5, pp. 363–367, 1989.
"Method for the subjective assessment of intermediate quality level of audio systems BS Series Broadcasting service (sound)," ITU-R, vol. 3, 2015
"Product Specifications Beta 52", Shure, 2015.
R. Jones, G. Davis, *The Sound Reinforcement Handbook*, 2nd ed. Yamaha, 1988.

APPENDIX

Appendix A

Table 11. Common Microphones for Drums – Input List

Description	Common Microphone	Pre-Amp
Kick In	AKG D112	API
Kick Out	Neumann FET 47	API
Snare Top	Shure SM57	API
Snare Bottom	AKG 451	Millennia
High Hat	Neumann KM84i	Millennia
Rack Top	Neumann FET 47	API
Rack Bottom	Sennheiser e604	Millennia
Floor Top	Neumann FET 47	API
Floor Bottom	Sennheiser e604	Millennia
Overhead - Drummers Left	AKG C414	API
Overhead - Drummers Right	AKG C414	API
Room - Drummers Left	Neumann U48	Millennia
Room - Drummers Right	Neumann U48	Millennia
Glyn Top	Neumann U67	API
Glyn Bottom	Neumann U67	API

Table 12. Uncommon Microphones for Drums – Input List

Description	Uncommon Microphones	Pre-Amp
Kick In	Shure SM7	API
Kick Out	Audix i5	API
Snare Top	Electro-Voice RE20	API
Rack Top	Shure SM63	API
Floor Top	Shure SM63	API
Overhead - Drummers Left	Shure SM57	API
Overhead - Drummers Right	Shure SM57	API
Room - Drummers Left	Sennheiser 421	Millennia
Room - Drummers Right	Sennheiser 421	Millennia

Appendix B

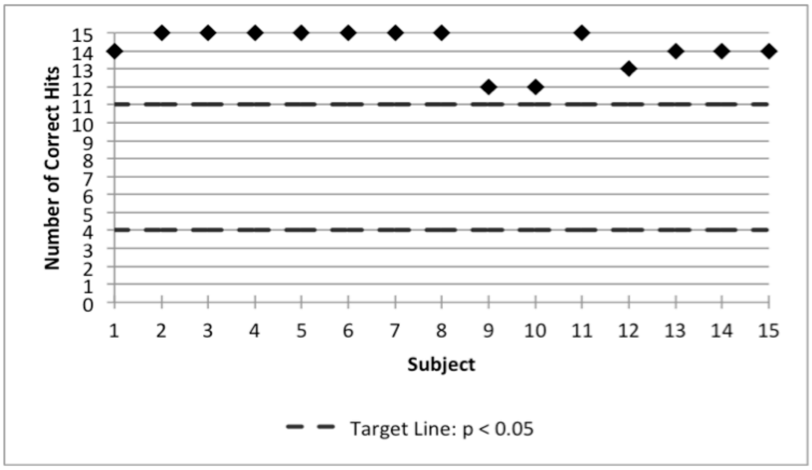

Figure 23. ABX Results Sample 1 INC - REC

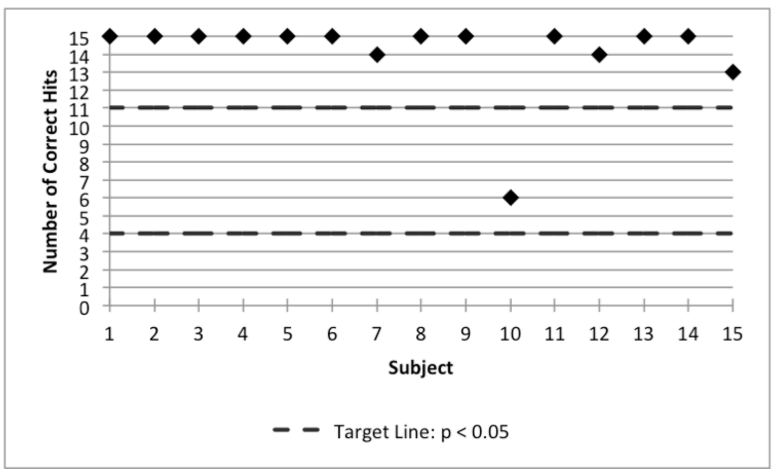

Figure 24. ABX Results Sample 1 MIC

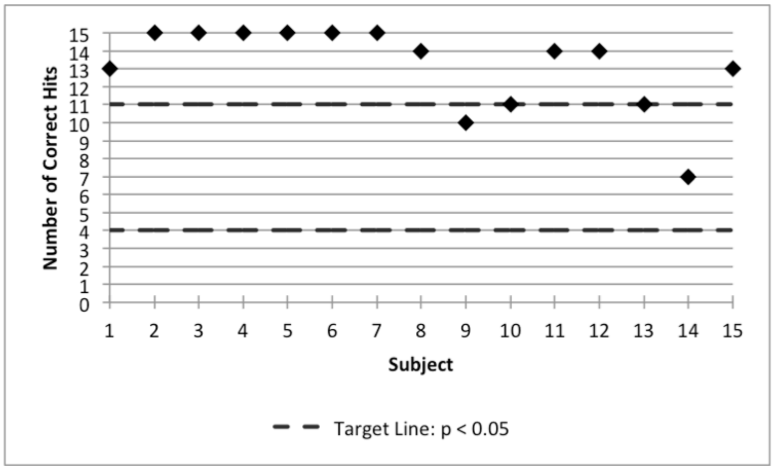

Figure 25. ABX Results Sample 2 INC - REC

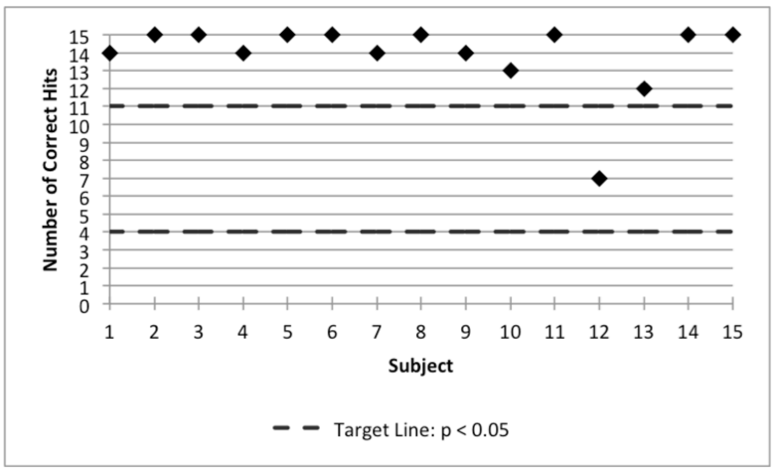

Figure 26. ABX Results Sample 2 MIC

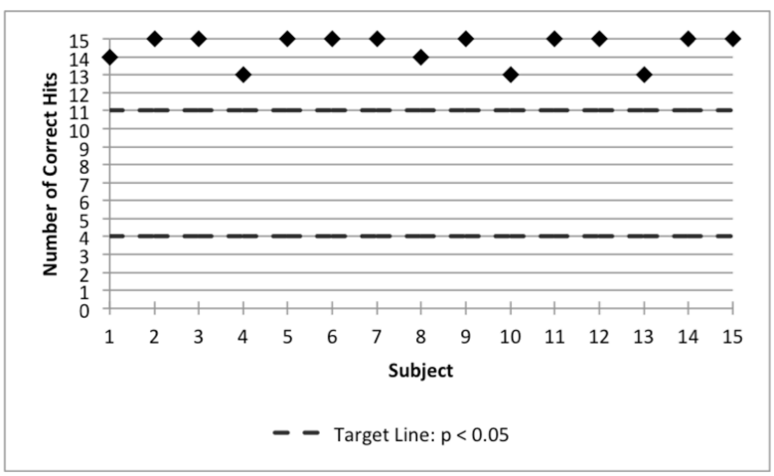

Figure 27. ABX Results Sample 3 INC - REC

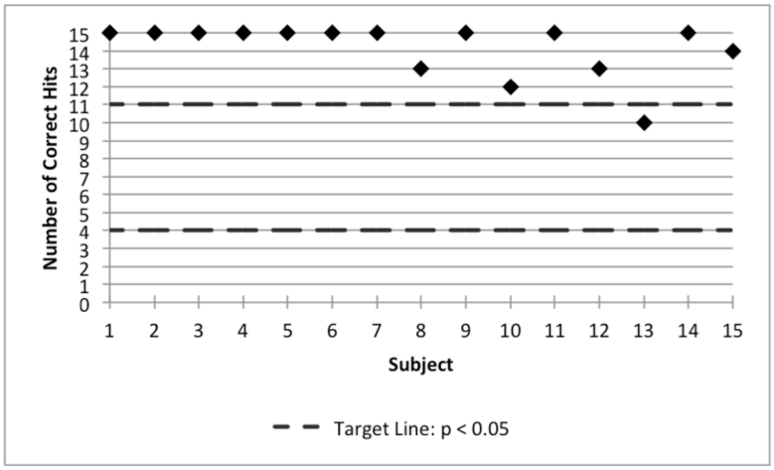

Figure 28. ABX Results Sample 3 MIC

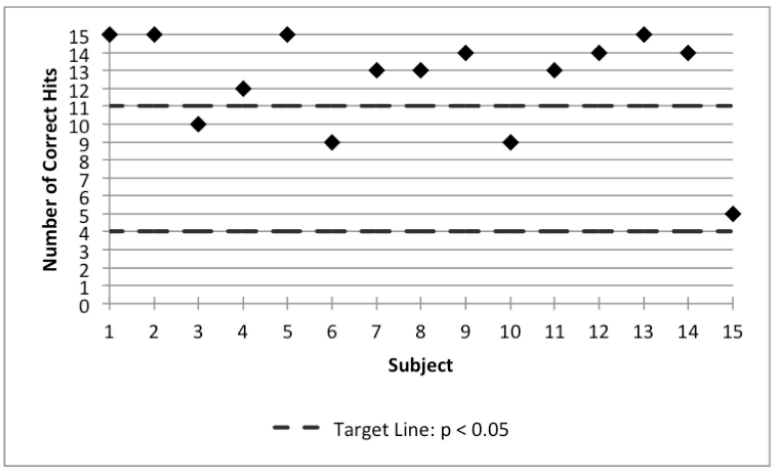

Figure 29. ABX Results Sample 4 PAN

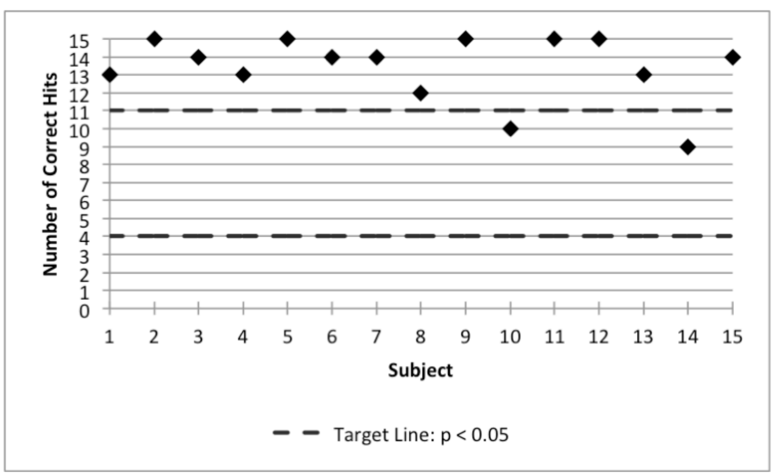

Figure 30. ABX Results Sample 5 INC - MIX

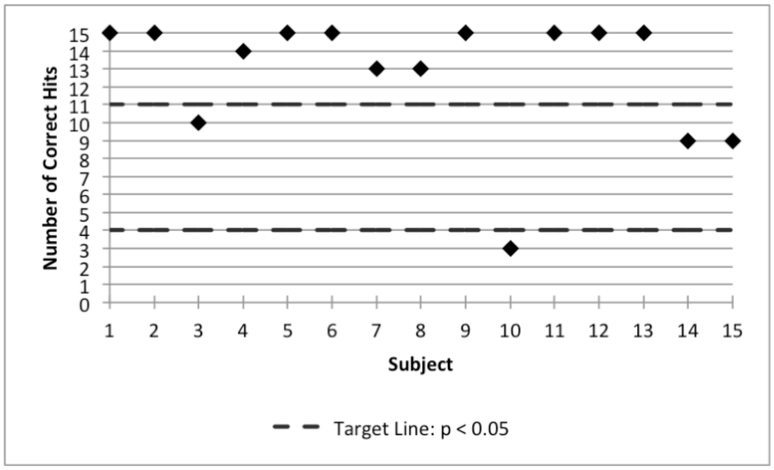

Figure 31. ABX Results Sample 5 PAN

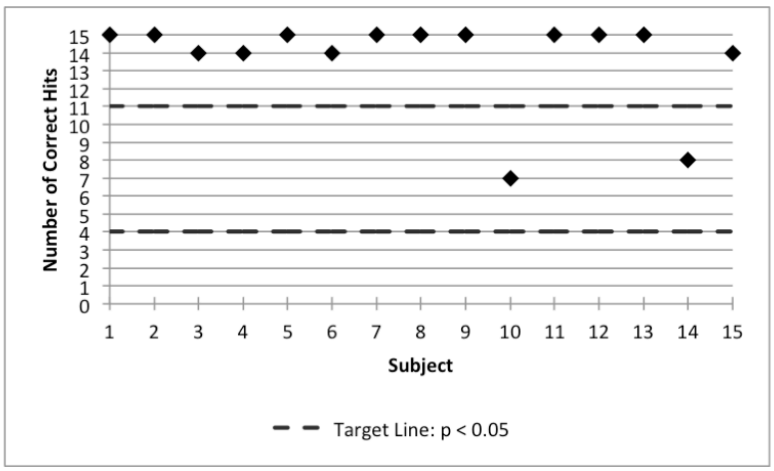

Figure 32. ABX Results Sample 6 INC – MIX

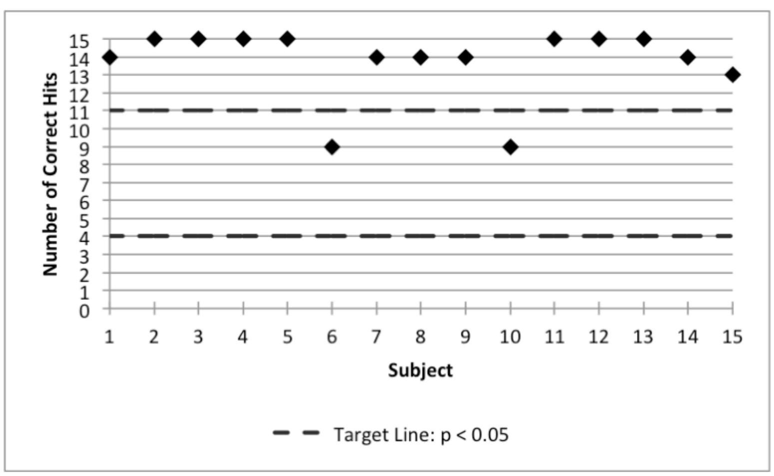

Figure 33. ABX Results Sample 6 PAN

Table 13. Preference tests results

Preference Test	A	B
Trial 1 Results	Sample 4 Control 8	Sample 4 INC - MIX 7
Trial 2 Results	Sample 5 Control 13	Sample 5 INC - MIX 2
Trial 3 Results	Sample 6 Control 8	Sample 6 INC - MIX 7
Trial 4 Results	Sample 1 Control 6	Sample 1 INC - REC 9
Trial 5 Results	Sample 2 Control 8	Sample 2 INC - REC 7
Trial 6 Results	Sample 3 Control 8	Sample 3 INC - REC 7
Trial 7 Results	Sample 1 Glyn 6	Sample 1 Standard 9
Trial 8 Results	Sample 2 Glyn 7	Sample 2 Standard 8
Trial 9 Results	Sample 3 Glyn 8	Sample 3 Standard 7
Trial 10 Results	Sample 1 Glyn 7	Sample 1 Excessive 8
Trial 11 Results	Sample 2 Glyn 9	Sample 2 Excessive 6
Trial 12 Results	Sample 3 Glyn 9	Sample 3 Excessive 6
Trial 13 Results	Sample 1 Standard 8	Sample 1 Excessive 7
Trial 14 Results	Sample 2 Standard 8	Sample 2 Excessive 7
Trial 15 Results	Sample 3 Standard 7	Sample 3 Excessive 7
Trial 16 Results	Sample 1 Control 9	Sample 1 Mic 6
Trial 17 Results	Sample 2 Control 7	Sample 2 Mic 8
Trial 18 Results	Sample 3 Control 8	Sample 3 Mic 7

Table 14. Kappa statistic table.

	Clarity	Spaciousness	Fidelity
Sample 1			
Control	0.25	0.24	0.32
INC - REC	0.27	0.31	0.33
Excessive	0.32	0.23	0.33
Glyn	0.24	0.17	0.23
Mic	0.30	0.23	0.31
Sample 2			
Control	0.27	0.32	0.32
INC - REC	0.38	0.29	0.29
Excessive	0.25	0.27	0.26
Glyn	0.26	0.19	0.23
Mic	0.33	0.40	0.31
Sample 3			
Control	0.30	0.31	0.32
INC - REC	0.29	0.29	0.27
Excessive	0.34	0.21	0.25
Glyn	0.21	0.22	0.26
Mic	0.30	0.31	0.32
Sample 4			
Control	0.30	0.31	0.32
INC - REC	0.29	0.29	0.27
Sample 5			
Control	0.33	0.34	0.27
INC - REC	0.31	0.38	0.40
Sample 6			
Control	0.29	0.33	0.35
INC - REC	0.33	0.40	0.35

Table 15. Descriptive statistics for Sample 1 Control & INC - REC

	Control Mean	SD	INC - REC Mean	SD	N
Clarity	2.93	1.16	3.33	0.90	15
Spaciousness	3.33	0.98	3.47	0.83	15
Fidelity	2.73	0.80	2.73	0.80	15

Table 16. Descriptive statistics for 1 Standard & Excessive

	Standard Mean	SD	Excessive Mean	SD	N
Clarity	2.93	1.16	3.47	0.99	15
Spaciousness	3.33	0.98	3.20	1.08	15
Fidelity	2.73	0.80	3.00	0.85	15

Table 17. Descriptive statistics for Sample 1 Standard & Glyn

	Standard Mean	SD	Glyn Mean	SD	N
Clarity	2.93	1.16	2.87	1.13	15
Spaciousness	3.33	0.98	3.47	1.30	15
Fidelity	2.73	0.80	2.13	1.06	15

Table 18. Descriptive statistics for Sample 1 Control & Mic

	Control Mean	SD	Mic Mean	SD	N
Clarity	2.93	1.16	3.13	1.06	15
Spaciousness	3.33	0.98	3.13	1.06	15
Fidelity	2.73	0.80	3.00	0.76	15

Table 19. Descriptive statistics for Sample 2 Control & INC - REC

	Control Mean	SD	INC - REC Mean	SD	N
Clarity	3.20	1.41	3.20	0.77	15
Spaciousness	3.13	0.74	3.13	0.99	15
Fidelity	2.87	0.92	3.07	0.88	15

Table 20. Descriptive statistics for Sample 2 Standard & Excessive

	Standard Mean	SD	Excessive Mean	SD	N
Clarity	3.20	1.41	3.13	0.99	15
Spaciousness	3.13	0.74	3.33	0.90	15
Fidelity	2.87	0.92	2.73	0.96	15

Table 21. Descriptive statistics for Sample 2 Standard & Glyn

	Standard Mean	SD	Glyn Mean	SD	N
Clarity	3.20	1.41	3.27	1.10	15
Spaciousness	3.13	0.74	3.67	1.29	15
Fidelity	2.87	0.92	2.60	0.99	15

Table 22. Descriptive statistics for Sample 2 Control & Mic

	Control Mean	SD	Mic Mean	SD	N
Clarity	3.20	1.41	3.73	0.80	15
Spaciousness	3.13	0.74	3.00	1.00	15
Fidelity	2.87	0.92	3.33	0.82	15

Table 23. Descriptive statistics for Sample 3 Control & INC - REC

	Control Mean	SD	INC - REC Mean	SD	N
Clarity	3.20	1.41	2.67	0.98	15
Spaciousness	3.13	0.74	3.00	0.85	15
Fidelity	2.87	0.92	2.67	0.90	15

Table 24. Descriptive statistics for Sample 3 Standard & Excessive

	Standard Mean	SD	Excessive Mean	SD	N
Clarity	3.20	1.41	3.27	0.71	15
Spaciousness	3.13	0.74	3.00	1.07	15
Fidelity	2.87	0.92	3.93	0.96	15

Table 25. Descriptive statistics for Sample 3 Control & Mic

	Control Mean	SD	Mic Mean	SD	N
Clarity	3.20	1.41	3.13	0.83	15
Spaciousness	3.13	0.74	2.80	0.86	15
Fidelity	2.87	0.92	3.13	0.74	15

Table 26. Descriptive statistics for Sample 4 Control & INC - MIX

	Control Mean	SD	INC - MIX Mean	SD	N
Clarity	3.53	0.83	3.80	0.77	15
Spaciousness	3.53	0.74	3.27	1.03	15
Fidelity	3.27	0.88	3.00	0.65	15

Table 27. Descriptive statistics for Sample 5 Control & INC - MIX

	Control Mean	SD	INC - MIX Mean	SD	N
Clarity	3.53	0.83	3.80	0.77	15
Spaciousness	3.53	0.74	3.27	1.03	15
Fidelity	3.27	0.88	3.00	0.65	15

Table 28. Descriptive statistics for Sample 6 Control & INC - MIX

	Control Mean	SD	INC - MIX Mean	SD	N
Clarity	3.40	0.91	3.40	0.99	15
Spaciousness	3.53	0.83	3.60	0.91	15
Fidelity	3.27	0.70	3.07	0.70	15

Table 29. Fisher LSD Sample 1 Standard & Excessive - Clarity

Group vs. Group (Contrast)	Difference	Test Statistic	p-value	Significant
S-1 vs S-15	3.	3.76969	0.00153	*Yes*
S-10 vs S-15	3.	3.76969	0.00153	*Yes*
S-11 vs S-15	2.	2.51312	0.02234	*Yes*
S-12 vs S-7	-2.	2.51312	0.02234	*Yes*
S-12 vs S-8	-2.	2.51312	0.02234	*Yes*
S-13 vs S-15	3.	3.76969	0.00153	*Yes*
S-14 vs S-15	2.	2.51312	0.02234	*Yes*
S-15 vs S-4	-2.	2.51312	0.02234	*Yes*
S-15 vs S-5	-2.	2.51312	0.02234	*Yes*
S-15 vs S-6	-2.	2.51312	0.02234	*Yes*
S-15 vs S-7	-3.5	4.39797	0.00039	*Yes*
S-15 vs S-8	-3.5	4.39797	0.00039	*Yes*
S-15 vs S-9	-2.5	3.1414	0.00595	*Yes*
S-2 vs S-7	-2.	2.51312	0.02234	*Yes*
S-2 vs S-8	-2.	2.51312	0.02234	*Yes*
S-3 vs S-7	-2.	2.51312	0.02234	*Yes*
S-3 vs S-8	-2.	2.51312	0.02234	*Yes*

Table 30. Fisher LSD Sample 1 Control & Mic - Clarity

Group vs. Group (Contrast)	Difference	Test Statistic	p-value	Significant
S-1 vs S-14	2.	2.78887	0.0126	Yes
S-1 vs S-15	2.5	3.48608	0.00283	Yes
S-1 vs S-2	2.	2.78887	0.0126	Yes
S-1 vs S-3	2.	2.78887	0.0126	Yes
S-11 vs S-7	-2.	2.78887	0.0126	Yes
S-11 vs S-8	-2.	2.78887	0.0126	Yes
S-13 vs S-14	2.	2.78887	0.0126	Yes
S-13 vs S-15	2.5	3.48608	0.00283	Yes
S-13 vs S-2	2.	2.78887	0.0126	Yes

S-13 vs S-3	2.	2.78887	0.0126	Yes
S-14 vs S-6	-2.	2.78887	0.0126	Yes
S-14 vs S-7	-2.5	3.48608	0.00283	Yes
S-14 vs S-8	-2.5	3.48608	0.00283	Yes
S-15 vs S-6	-2.5	3.48608	0.00283	Yes
S-15 vs S-7	-3.	4.1833	0.00062	Yes
S-15 vs S-8	-3.	4.1833	0.00062	Yes
S-15 vs S-9	-2.	2.78887	0.0126	Yes
S-2 vs S-6	-2.	2.78887	0.0126	Yes
S-2 vs S-7	-2.5	3.48608	0.00283	Yes
S-2 vs S-8	-2.5	3.48608	0.00283	Yes
S-3 vs S-6	-2.	2.78887	0.0126	Yes
S-3 vs S-7	-2.5	3.48608	0.00283	Yes
S-3 vs S-8	-2.5	3.48608	0.00283	Yes
S-4 vs S-7	-2.	2.78887	0.0126	Yes
S-4 vs S-8	-2.	2.78887	0.0126	Yes
S-5 vs S-7	-2.	2.78887	0.0126	Yes
S-5 vs S-8	-2.	2.78887	0.0126	Yes

Table 31. Fisher LSD Sample 1 Control & Mic - Spaciousness

Group vs. Group (Contrast)	Difference	Test Statistic	p-value	Significant
S-1 vs S-11	1.5	2.46124	0.02484	Yes
S-1 vs S-13	2.	3.28165	0.0044	Yes
S-1 vs S-14	1.5	2.46124	0.02484	Yes
S-1 vs S-2	2.	3.28165	0.0044	Yes
S-1 vs S-5	2.	3.28165	0.0044	Yes
S-10 vs S-13	1.5	2.46124	0.02484	Yes
S-10 vs S-2	1.5	2.46124	0.02484	Yes
S-10 vs S-5	1.5	2.46124	0.02484	Yes
S-10 vs S-9	-1.5	2.46124	0.02484	Yes
S-11 vs S-6	-2.	3.28165	0.0044	Yes
S-11 vs S-8	-1.5	2.46124	0.02484	Yes
S-11 vs S-9	-2.5	4.10206	0.00074	Yes
S-12 vs S-13	1.5	2.46124	0.02484	Yes
S-12 vs S-2	1.5	2.46124	0.02484	Yes
S-12 vs S-5	1.5	2.46124	0.02484	Yes
S-12 vs S-9	-1.5	2.46124	0.02484	Yes
S-13 vs S-4	-1.5	2.46124	0.02484	Yes
S-13 vs S-6	-2.5	4.10206	0.00074	Yes
S-13 vs S-7	-1.5	2.46124	0.02484	Yes
S-13 vs S-8	-2.	3.28165	0.0044	Yes
S-13 vs S-9	-3.	4.92248	0.00013	Yes

S-14 vs S-6	-2.	3.28165	0.0044	Yes
S-14 vs S-8	-1.5	2.46124	0.02484	Yes
S-14 vs S-9	-2.5	4.10206	0.00074	Yes
S-15 vs S-6	-1.5	2.46124	0.02484	Yes
S-15 vs S-9	-2.	3.28165	0.0044	Yes
S-2 vs S-4	-1.5	2.46124	0.02484	Yes
S-2 vs S-6	-2.5	4.10206	0.00074	Yes
S-2 vs S-7	-1.5	2.46124	0.02484	Yes
S-2 vs S-8	-2.	3.28165	0.0044	Yes
S-2 vs S-9	-3.	4.92248	0.00013	Yes
S-3 vs S-6	-1.5	2.46124	0.02484	Yes
S-3 vs S-9	-2.	3.28165	0.0044	Yes

Table 31. (Continued) Fisher LSD Sample 1 Control & Mic - Spaciousness

Group vs. Group (Contrast)	Difference	Test Statistic	p-value	Significant
S-4 vs S-5	1.5	2.46124	0.02484	Yes
S-4 vs S-9	-1.5	2.46124	0.02484	Yes
S-5 vs S-6	-2.5	4.10206	0.00074	Yes
S-5 vs S-7	-1.5	2.46124	0.02484	Yes
S-5 vs S-8	-2.	3.28165	0.0044	Yes
S-5 vs S-9	-3.	4.92248	0.00013	Yes
S-7 vs S-9	-1.5	2.46124	0.02484	Yes

Table 32. Fisher LSD Sample 2 Control & INC - REC - Spaciousness

Group vs. Group (Contrast)	Difference	Test Statistic	p-value	Significant
S-10 vs S-15	2.5	3.81881	0.00137	Yes
S-10 vs S-2	2.	3.05505	0.00716	Yes
S-11 vs S-15	2.	3.05505	0.00716	Yes
S-12 vs S-15	2.5	3.81881	0.00137	Yes
S-12 vs S-2	2.	3.05505	0.00716	Yes
S-14 vs S-15	2.5	3.81881	0.00137	Yes
S-14 vs S-2	2.	3.05505	0.00716	Yes
S-15 vs S-3	-2.	3.05505	0.00716	Yes
S-15 vs S-7	-2.5	3.81881	0.00137	Yes
S-2 vs S-7	-2.	3.05505	0.00716	Yes

Table 33. Fisher LSD Sample 2 Standard & Excessive - Clarity

Group vs. Group (Contrast)	Difference	Test Statistic	p-value	Significant
S-1 vs S-14	2.	2.73861	0.014	Yes
S-1 vs S-15	2.	2.73861	0.014	Yes
S-1 vs S-3	2.	2.73861	0.014	Yes

S-10 vs S-14	2.	2.73861	0.014	Yes
S-10 vs S-15	2.	2.73861	0.014	Yes
S-10 vs S-3	2.	2.73861	0.014	Yes
S-11 vs S-6	-2.	2.73861	0.014	Yes
S-11 vs S-7	-2.	2.73861	0.014	Yes
S-14 vs S-6	-2.5	3.42327	0.00324	Yes
S-14 vs S-7	-2.5	3.42327	0.00324	Yes
S-15 vs S-6	-2.5	3.42327	0.00324	Yes
S-15 vs S-7	-2.5	3.42327	0.00324	Yes
S-2 vs S-6	-2.	2.73861	0.014	Yes
S-2 vs S-7	-2.	2.73861	0.014	Yes
S-3 vs S-6	-2.5	3.42327	0.00324	Yes
S-3 vs S-7	-2.5	3.42327	0.00324	Yes

Table 34: Fisher LSD Sample 2 Standard & Excessive - Fidelity

Group vs. Group (Contrast)	Difference	Test Statistic	p-value	Significant
S-10 vs S-14	2.	3.08957	0.00665	Yes
S-11 vs S-6	-2.	3.08957	0.00665	Yes
S-11 vs S-7	-2.	3.08957	0.00665	Yes
S-12 vs S-14	2.	3.08957	0.00665	Yes
S-14 vs S-5	-2.	3.08957	0.00665	Yes
S-14 vs S-6	-2.5	3.86196	0.00125	Yes
S-14 vs S-7	-2.5	3.86196	0.00125	Yes
S-14 vs S-8	-2.	3.08957	0.00665	Yes
S-15 vs S-6	-2.	3.08957	0.00665	Yes
S-15 vs S-7	-2.	3.08957	0.00665	Yes
S-2 vs S-6	-2.	3.08957	0.00665	Yes
S-2 vs S-7	-2.	3.08957	0.00665	Yes
S-3 vs S-6	-2.	3.08957	0.00665	Yes
S-3 vs S-7	-2.	3.08957	0.00665	Yes

Table 35. Fisher LSD Sample 2 Control & Mic - Fidelity

Group vs. Group (Contrast)	Difference	Test Statistic	p-value	Significant
S-1 vs S-8	-2.	3.08957	0.00665	Yes
S-10 vs S-15	2.	3.08957	0.00665	Yes
S-11 vs S-8	-2.	3.08957	0.00665	Yes
S-13 vs S-8	-2.	3.08957	0.00665	Yes
S-15 vs S-5	-2.	3.08957	0.00665	Yes
S-15 vs S-7	-2.	3.08957	0.00665	Yes
S-15 vs S-8	-2.5	3.86196	0.00125	Yes
S-2 vs S-8	-2.	3.08957	0.00665	Yes
S-3 vs S-8	-2.	3.08957	0.00665	Yes

Table 36. Fisher LSD Sample 6 Control & INC - MIX - Clarity

Group vs. Group (Contrast)	Difference	Test Statistic	p-value	Significant
S-1 vs S-11	2.	4.32049	0.00046	Yes
S-1 vs S-14	1.5	3.24037	0.00481	Yes
S-1 vs S-2	2.	4.32049	0.00046	Yes
S-1 vs S-9	2.	4.32049	0.00046	Yes
S-10 vs S-11	2.	4.32049	0.00046	Yes
S-10 vs S-14	1.5	3.24037	0.00481	Yes
S-10 vs S-2	2.	4.32049	0.00046	Yes
S-10 vs S-9	2.	4.32049	0.00046	Yes
S-11 vs S-12	-1.5	3.24037	0.00481	Yes
S-11 vs S-15	-2.	4.32049	0.00046	Yes
S-11 vs S-3	-1.5	3.24037	0.00481	Yes
S-11 vs S-4	-2.	4.32049	0.00046	Yes
S-11 vs S-5	-2.	4.32049	0.00046	Yes
S-11 vs S-6	-2.5	5.40062	0.00005	Yes
S-11 vs S-7	-2.5	5.40062	0.00005	Yes
S-11 vs S-8	-1.5	3.24037	0.00481	Yes
S-12 vs S-2	1.5	3.24037	0.00481	Yes
S-12 vs S-9	1.5	3.24037	0.00481	Yes
S-13 vs S-6	-1.5	3.24037	0.00481	Yes
S-13 vs S-7	-1.5	3.24037	0.00481	Yes
S-14 vs S-15	-1.5	3.24037	0.00481	Yes
S-14 vs S-4	-1.5	3.24037	0.00481	Yes
S-14 vs S-5	-1.5	3.24037	0.00481	Yes
S-14 vs S-6	-2.	4.32049	0.00046	Yes
S-14 vs S-7	-2.	4.32049	0.00046	Yes
S-15 vs S-2	2.	4.32049	0.00046	Yes
S-15 vs S-9	2.	4.32049	0.00046	Yes
S-2 vs S-3	-1.5	3.24037	0.00481	Yes
S-2 vs S-4	-2.	4.32049	0.00046	Yes
S-2 vs S-5	-2.	4.32049	0.00046	Yes
S-2 vs S-6	-2.5	5.40062	0.00005	Yes
S-2 vs S-7	-2.5	5.40062	0.00005	Yes
S-2 vs S-8	-1.5	3.24037	0.00481	Yes
S-3 vs S-9	1.5	3.24037	0.00481	Yes
S-4 vs S-9	2.	4.32049	0.00046	Yes
S-5 vs S-9	2.	4.32049	0.00046	Yes
S-6 vs S-9	2.5	5.40062	0.00005	Yes
S-7 vs S-9	2.5	5.40062	0.00005	Yes
S-8 vs S-9	1.5	3.24037	0.00481	Yes

Institutional Review Board Consent Form

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Belmont University Institutional Review Board
CONSENT TO PARTICIPATE IN RESEARCH

Listener Evaluation of Common Drum Track Processing, Mixing, and Recording Techniques

We invite you to participate in a research study conducted in the MSAE program. Your participation in this study is voluntary. Please read all of the information below and ask questions about anything you do not understand before deciding whether or not to participate. If you desire to participate, sign and date this consent form. Instructors Wesley Bulla, Doyuen Ko, and Eric Tarr are the faculty advisors for this study, if you need further clarification or more information, please contact one of the faculty advisors.

PURPOSE OF THE STUDY

The purpose of this study is to determine whether a selection of common methods of processing, mixing and recording drum tracks as promoted by sound engineers in the popular press influence the perceptual "quality" of a drum mix. Specifically, whether or not switching the electronic polarity on the bottom snare drum microphone to be the same as the top microphone during the mixing process, and also verifying that the drum tracks are all being recorded in phase. In the mixing process, whether timing the reverberation "pre-delay" to the musical pulse of the song and panning the left- and right-overhead and ambient room microphones together in the stereophonic image, alters listeners' judgment of the perceived clarity, naturalism, and spaciousness. Recommended microphone selection, quantity and placement from esteemed publications will also be examined for quality and listener preference.

DURATION AND LOCATION

Your participation in this study will last approximately 60 minutes. This study will be conducted at campus in the computer lab or work bays on the 3rd floor of the Johnson Center (JOHNCT 343 – 434), and/or in the anechoic chamber (JOHNCT 444.

PROCEDURE

Your perception of sound will be evaluated by a non-invasive listening test. During this study, we will ask you to do the following things:

1. You will be scheduled for a listening session where you will be asked to listen to a brief sound or a series of sounds via loudspeakers or headphones.
2. The loudness of the sound(s) will be set to a safe listening level or you may be allowed to control the loudness by setting a reference sound to a comfortable listening level.
3. You will then be asked to listen to two audio clips and use an ABXer to determine which clip is which, you will also be asked to complete a survey after listening to the audio clips.
4. Steps 2 and 3 will be repeated until the test is complete.
5. We may or may not reveal to you your individual results from your listening test(s).

POTENTIAL RISKS AND DISCOMFORTS

There are no known direct psychological or social risks associated with this study. This test involves the use of sound samples presented via loudspeakers or headphones. As such, there is the potential for exposure to excessive sound levels. However, all sound levels will be electronically limited to never exceed what is considered by OSHA (Occupational Safety and Health Administration, United States Department of Labor) to be a safe listening level. Additionally, we will ask you how you feel several times throughout the procedure. If at any time, you feel uncomfortable or fatigued, you are free to rest or to stop your participation in this study.

ANTICIPATED BENEFITS TO SUBJECTS

While you may gain insight into what it is like to be a subject in a psychometric auditory experiment, there are no known direct benefits to you.

Belmont University IRB

This protocol was approved on: 10/10/2018

This protocol will expire on: 10/09/2019

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CONSENT TO PARTICIPATE IN RESEARCH

MEDICAL CARE FOR RESEARCH RELATED INJURY
In the unlikely event of an injury resulting from the research procedures described herein, no form of compensation (i.e., payment) is available from Belmont University. Medical treatment may be provided at your own expense or at the expense of your health care insurer. If you have questions, you should contact your insurer.

CONFIDENTIALITY
Your participation in this study is confidential. Personal identifiers are not associated with the data gathered from this study. Where your individual responses are tracked across listening tests your responses will be identified by an assigned numerical code, such as S-1, S-2, etc. Code numbers will not be linked or associated with your identity. If the results of this research are published or discussed in a public venue, such as a professional conference or academic symposium, no information will be included that would reveal your identity or participation in the study. Your information on this form will be kept secure by locking this form in a file box. If photographs, videos, or audio recordings of you are used for archive or educational purposes, your identity will be protected or disguised. All data entered into computers will be password protected. This information will be stored and may be destroyed after three years.

PARTICIPATION AND WITHDRAWAL
Your participation in this research is voluntary. If you decide to participate, you are free to withdraw your consent and discontinue participation at any time without prejudice. If you choose not to participate your relationship with Belmont University staff and faculty will not be affected.

WITHDRAWAL OF PARTICIPATION BY THE INVESTIGATOR
In order to protect your health and safety, the investigator of this study may withdraw you from participating in this research if circumstances arise which warrant doing so. Even if you indicate you would like to continue, the investigator will make the final decision as to whether or not it is possible for you to continue.

NEW FINDINGS
During the course of the study you will be informed immediately of any new findings or information that may cause you to change your mind about continuing in the study. If/when new information is discovered, your participation will halt and your consent to continue in this study will be reconsidered and re-obtained.

IDENTIFICATION OF INVESTIGATORS
If you have any questions about this study, please contact one of the faculty advisors; Dr. Wesley Bulla (wesley.bulla@belmont.edu) at (615) 460-5729; Dr. Doyuen Ko (doyuen.ko@belmont.edu) at (615) 460-5726; or Dr. Eric Tarr (eric.tarr@belmont.edu) at (615) 460-5722.

YOUR RIGHTS
You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, please contact the Office of the Provost at Belmont University at 615 460-6400 or Dr. Sarita Stewart (sarita.stewart@belmont.edu) at 615 460-6517.

OFFER TO ANSWER QUESTIONS
If you have any questions about this study, you may call Dr. Wesley Bulla (wesley.bulla@belmont.edu) at (615) 460-5729; Dr. Doyuen Ko (doyuen.ko@belmont.edu) at (615) 460-5726; or Dr. Eric Tarr (eric.tarr@belmont.edu) at (615) 460-5722. If a research related injury occurs, you should contact the Office of the Provost at Belmont University at 615 460-6400 and at least one of the faculty advisors listed above.

Belmont University IRB

This protocol was approved on: 10/10/2018

This protocol will expire on: 10/09/2019

Institutional Review Board Consent Form Page 3

Belmont University Institutional Review Board
CONSENT TO PARTICIPATE IN RESEARCH

ACKNOWLEDGMENT AND SIGNATURE
I have read the information provided above. I have been given an opportunity to ask questions and all of my questions have been answered to my satisfaction. I have been given a copy of this form.

______________________	______________________	______
Subject name (print)	*Signature*	*Date*

____
Contact information

______________________	______________________	______
Investigator name (print)	*Signature*	*Date*

Belmont University IRB
This protocol was approved on: 10/10/2018
This protocol will expire on: 10/09/2019

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AUTHOR BIOGRAPHY

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