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Music 251 Final Project Report

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Title: *Examining the Influence of Frequency Band Elevation in Spatial Audio Music Perception*

Abstract

In this study, spatial elevation of different frequency ranges and its affect on listeners' musical perception and preferences is investigated. Previous findings indicate that popular music right now is at a stand still in terms of differentiation between mixes. Songs have reached a standard of being loud, compressed, and lacking in dynamics. In this study, a new way to differentiate tracks from one another will be explored. Furthermore, previous findings indicate that listeners perceive pitches with strong tactile metaphors, and have preferences that vary based on differences in an audio's timbral qualities. Thus, I build off of these findings by adding an aspect of digital spatialization and seeing how pitch elevation alters listeners' audio perception. I extrapolate off of previous findings that show how pitch elevation is implied in human hearing, and prove that pitch elevation effects how listeners react to different sound stimuli. I also explore whether human's perceptions of different pitch elevation holds to be true not only in naturally occurring sounds, but in digital music, and if pitch elevation has an affect not only on listeners' perception, but also on their preference. In this study, listeners heard five different mixes of three different song arrangements that they were unfamiliar with. Listeners then rated each mix on a scale of 1-10 for how *Pleasing*, *Arousing*, and *Natural* they sounded. Entering this study, there were four main hypotheses: pitch elevation affects listeners' ratings for how pleasing, arousing, and natural they find the songs that they hear; mixes that have pitches separated in elevation are more pleasing, natural, and arousing than songs with all pitches at 0 degree elevation; mixes with pitch elevation correlating with natural occurring pitch placements (i.e. low pitches come from lower places than higher places) sound the most 'natural' to listeners; and mixes separated more dramatically (high and low frequencies at 90 and -90 degrees and vice versa) are more arousing to listeners.

Introduction

Eitan and Rothschild (2011) found that listeners perceive pitches with strong tactile metaphors and that pitch is related to height and timbre. In their study, listeners found that higher pitches were "significantly sharper, rougher, harder, colder, drier and lighter than lower pitches." The findings of this study link subjective descriptors like 'sharp' and 'rough' linked with certain pitches and pitch heights, which supports my hypothesis that pitch elevation affects how much listeners may perceive or enjoy audio stimuli. Also, listeners have specific timbral tastes (Dobrowohl et al, 2019) and their enjoinment of a musical piece is affected by the loudness (Vickers 2010).

In the study investigating timbral preferences (Dobrowohl et al., 2019), participants were able to mix multiple parts of various musical pieces by adjusting timbral aspects of synthesizers (lpf, sawtooth/square wave blend, distortion, and inharmonicity) and were then showed various mixes of the pieces, including their own mix, and asked to rate which mixes were their favorite. Listeners consistently chose their own mix as their favorite (even over professional mixes of the pieces), despite the fact that listeners were incapable of correctly identifying their own mix. These results prove that all listeners have different ears and perceptions that affect their preferences and how pleasing different mixes sound to them. This implies that changing pitch elevation (which will cause sounds to differ in timbre) will affect my participants preferences for different mixes.

In the study investigating loudness preferences (E. Vickers, 2010), researchers analyze the 'loudness war.' In the music industry, the 'loudness war' refers to the continual trend throughout the past decades that successful music tracks are increasing in loudness and decreasing in dynamic variability. This trend causes music in general to be hyper compressed and 'flat' due to lack of dynamics. Their findings reveal an increase in listening fatigue among listeners and a decrease in dynamic and emotional variance in songs due to a flattening of the sound from loudness increase and hyper compression.These findings indicate to me that the music industry will soon need new variance in mixes to create unique sounds that are captivating and change listeners' perceptions. As the industry seems to be at a stand-still with the 'loudness war,' this study adds a new way to vary listeners' perception through spatialization, and specifically, through pitch elevation.

The idea that pitch elevation affects listeners' perception has been investigated in other studies as well. In one previous study (Parise, Cesare V., et al., 2014), it was found that 'both sound localization behavior and ear anatomy are fine-tuned to the statistics of natural auditory scenes.' In the study, participants listened to sounds that were recorded in a natural environment. Then, the elevation-dependent-filtering of their outer ears were analyzed, and the frequent-dependent biases in their sound-localization was measured. It was found that, when listening to naturally occurring sounds in the real world, there is a clear mapping between frequency and elevation. It is worth investigating if their findings hold true when listeners hear sounds/songs that are *not* naturally occurring and listen to spatialized, produced music.

Another study that looked into the relationship between pitch and elevation (Jamal, Y. et al., 2017) found that there is a cross-modal correspondence between auditory pitch and visual elevation that strongly affects auditory elevation. In this study, participants were were shown multi sensory stimuli including high or low frequency bursts with bursts of white noise and a visual stimulus (a white circle). All of the stimuli could occur at high or low elevations, and could be congruent or incongruent in their elevations. Participants performed a 2AFC speeded classification of the perceived elevations that they thought the stimuli appeared at, and it was found that, although visual stimuli were always correctly assessed despite audio stimuli elevation, audio elevation perception was effected by visual and pitch differences. The results of this study shows that human minds have implicit biases when it comes to where we expect to hear different sounds based on their pitch and on our visual surroundings. These findings indicate to me that pitch elevation does have an effect on listeners' audio perception and could effect how much they enjoy a signal or find it pleasing, natural, or arousing.

As stated, this study will add onto the findings of all of the previous studies. Knowing that pitch elevation affecting human ear perception of sound is a naturally occurring process, that it has been shown to effect human's subjective descriptors of sound, and that it has generally shown to effect listeners' perceptions of audio signals, I will move forward to show how pitch elevation, in the context of digitally produced music, affects listeners perception and preference for music. The above studies show how different aspects of pitch and spatialization affect listeners' perception, but not how they affect listeners preferences. In this study, I look into preference in three aspects: how *pleasing* a mix sounds, how *natural* a mix sounds, and how *arousing* a mix sounds.

In this study, listeners heard five different mixes of three different song arrangements that they were unfamiliar with. The frequency arrangement in each of the five mixes for the three songs were as follows: Low, middle, and high frequencies all played at the same elevation in stereo; Low frequencies at -45 degrees, mid frequencies at 0 degrees (straight ahead), and high frequencies at 45 degrees; Low frequencies at -90 degrees, mid frequencies at 0 degrees (straight ahead), and high frequencies at 90 degrees; Low frequencies at 45 degrees, mid frequencies at 0 degrees (straight ahead), and high frequencies at -45 degrees; Low frequencies at 90 degrees, mid frequencies at 0 degrees (straight ahead), and high frequencies at -90 degrees. Listeners then rated each mix on a scale of 1-10 for how *Pleasing*, *Arousing*, and *Natural* they sounded. This task design allowed us to answer whether listeners held a preference for a mix of the same song based only on a difference in pitch spatialization, specifically based on change in pitch elevation.

The hypotheses that I explore and their expected results are the following: I hypothesized that pitch elevation would affect listeners' ratings for how pleasing, arousing, and natural they found the songs that they heard. Thus, listeners' ratings for pleasure, arousal, and naturalness of the mixes would differ from the 'flat' mixes (all frequencies played at 0 degree elevation), and the spatialized arrangements with high and low frequencies played at different elevations. I hypothesized that the mixes that had pitches separated in elevation would be rated more highly than songs that were played with all pitches at 0 degree elevation. Thus, listeners' ratings for pleasure, arousal, and naturalness of the mixes would be lower for the 'flat' mixes (all frequencies played at 0 degree elevation), than for the spatialized arrangements with high and low frequencies played at different elevations. I hypothesized that mixes with pitch elevation that correlates with naturally occurring pitch placements (i.e. low pitches come from lower places than higher places) would sound the most 'natural' to listeners. Thus, the mixes arranged in this way would receive the highest ratings for being perceived as 'natural' to the listeners. I hypothesized that the mixes that were separated dramatically would be perceived as more arousing to listeners. Thus, the mixes that have high and low frequencies at 90 and -90 degrees, and vice versa, would rank the highest in the category of arousal.

Methods

Participants
10 Stanford University undergraduate and graduate students. This group included musicians and non-musicians, all of whom had a normal history of hearing ability, and little-to-no experience with psychoacoustic tasks and audio mixing.

Stimulus
The stimuli were all 30 second clips of songs played in different spatial arrangements. Three songs were used, all original (never-before-heard) arrangements. None of the songs included vocal components. The first song's instrumentation included piano, guitar, chimes, and bird-sounds. The second song's instrumentation included a drum kit, bass, guitar, and synths. The third song's instrumentation included strings, a digital drum kit, a heart-beat, and synths. All stimuli were played at a sample rate of 44.1kHz. The stimuli were created in Logic X Pro, and then were specialized using Reaper, specifically using the ambix plug-in suite. Figure 1a shows an example of a the wav files in Reaper, and Figure 1b shows an example of the use of the ambix plug-ins utilized to alter the elevation of different pitches. There were five distinct spatialization for each song, each of which arranged the pitch frequencies differently. In the scope of this study, low frequencies are defined as frequencies that fall within 0-200 Hz, mid frequencies are defined as frequencies that fall within 200-2000 Hz, and high frequencies are defined as frequencies that are higher than 2000 Hz. The frequency arrangement in each of the five mixes for the three songs were as follows: Low, middle, and high frequencies all played at the same elevation in stereo; Low frequencies at -45 degrees, mid frequencies at 0 degrees (straight ahead), and high frequencies at 45 degrees; Low frequencies at -90 degrees, mid frequencies at 0 degrees (straight ahead), and high frequencies at 90 degrees; Low frequencies at 45 degrees, mid frequencies at 0 degrees (straight ahead), and high frequencies at -45 degrees; Low frequencies at 90 degrees, mid frequencies at 0 degrees (straight ahead), and high frequencies at -90 degrees. The mixes were all produced in ambisonics and the participants listened to the mixes using headphones in quiet spaces.

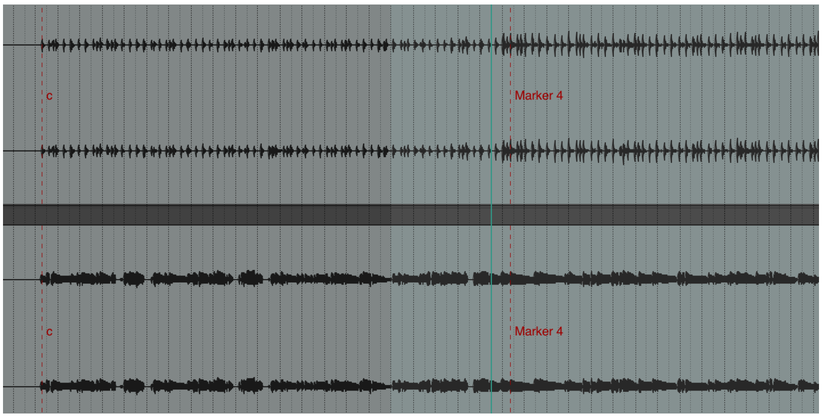

Figure 1a: Wav Files Stimuli Example

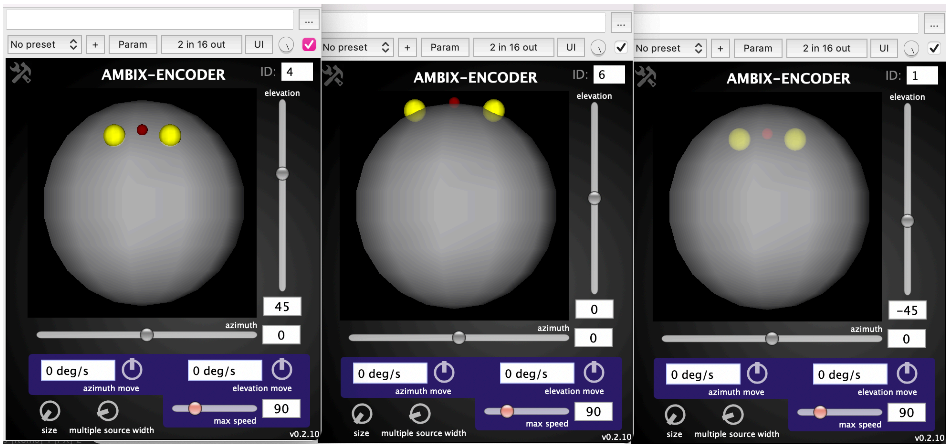

Figure 1b: Ambix Spatialization Stimuli Example

Procedures

The stimuli were all added to a Stanford Qualtrix Survey. The study's 10 participants were presented with five mixes of three different songs. The different songs were presented in blocks, but the mixes of each song depending on pitch elevation were presented in random order. After each mix was listened to, listeners had to rate the mix on a scale of 1-10 for how Pleasing, Natural, and Arousing they found it. There were 15 clips total and the study took about 20 minutes for each participant to complete. Figure 2 shows a task timeline diagram for this procedure.

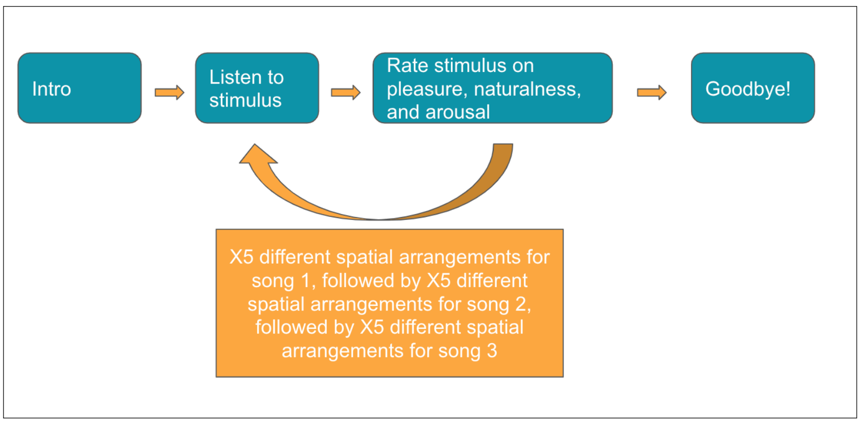

Figure 2: Task Timeline Diagram

Data collection and Analysis
The data collected is the ratings of each mix on scales of how pleasurable, arousing, and natural they were perceived to be by the listeners. Each listener's ratings of the different mixes were compared to one another for each song. Then, all of the listeners' answers were compared for all of the songs. I analyzed whether there is a difference between general ratings when pitch elevation is separated not at all (all at elevation zero), a little bit (highs and lows at 45 & -45 degrees and vice versa), and a lot (highs and lows at 90 & -90 degrees and vice versa). I also saw whether listeners generally preferred to have low frequencies lower in elevation and high frequencies higher in elevation or vice versa. Finally, I saw if listeners' preferences for the mixes that were spatially arranged in a certain way were consistent across all of the three songs presented.

Results

	ac	l-90	l90	l-45	l45
pleasing	6.73	7	6.18	6.55	6.09
	5.45	5.18	5.64	4.73	5.45
	5.55	5.27	5.18	5.27	5.09
natural	6.09	6.09	5.45	6.27	5.73
	3.91	3.91	4.55	3.73	3.91
	3.18	4.45	4.09	3.45	3.36
arrousing	5	4.55	4.45	4.36	4.55
	4.73	4.73	5	4.64	4.73
	7.09	5.55	4.91	4.73	4.45

	ac	l-90	l90	l-45	l45
p-t	5.91	5.816666667	5.666666667	5.516666667	5.543333333
n-t	4.393333333	4.816666667	4.696666667	4.483333333	4.333333333
a-t	5.606666667	4.943333333	4.786666667	4.576666667	4.576666667

Figure 3a: The mean rating for each of the three songs in each mixing condition. Ac = all frequency bands at elevation 0; l-90 = low frequencies at elevation -90, mid frequencies at elevation 0, high frequencies at elevation 90; l-90 = low frequencies at elevation 90, mid frequencies at elevation 0, high frequencies at elevation -90; l-45 = low frequencies at elevation -45, mid frequencies at elevation 0, high frequencies at elevation 45; l45 = low frequencies at elevation 45, mid frequencies at elevation 0, high frequencies at elevation -45. P-t is the average rating in the 'Pleasing' category for all three songs. N-t is the average rating in the 'Natural' category for all three songs. A-t is the average rating in the 'Arousing' category for all three songs. The figures highlights in yellow represent the highest ratings in their category, and the figures highlighted in blue represent the lowest ratings in their category.

standard deviations:		ac	l-90	l90	l-45	l45
	pleasing	2.14	1.81	2.04	2.06	2.07
		1.65	2.17	2.06	2	2.39
		1.44	1.76	1.95	2.05	1.88
	natural	2.02	1.31	1.78	2.3	1.96
		2.42	2.07	1.83	1.71	1.98
		1.34	1.97	1.93	1.56	1.77
	arrousing	1.95	1.97	2.02	1.97	2.06
		2.02	1.91	1.48	1.82	2.09
		1.5	1.5	1.68	1.86	1.37
		ac	l-90	l90	l-45	l45
	p-sd	1.743333333	1.913333333	2.016666667	2.036666667	2.113333333
	n-sd	1.926666667	1.783333333	1.846666667	1.856666667	1.903333333
	a-sd	1.823333333	1.793333333	1.726666667	1.883333333	1.84

Figure 3b: The standard deviation in each category corresponding with the means listed in figure 3A. All category markings are the same. The figures highlighted in yellow represent the rating with the highest standard deviation in its category, and the figures highlighted in blue represent the rating with the lowest standard deviation in its category.

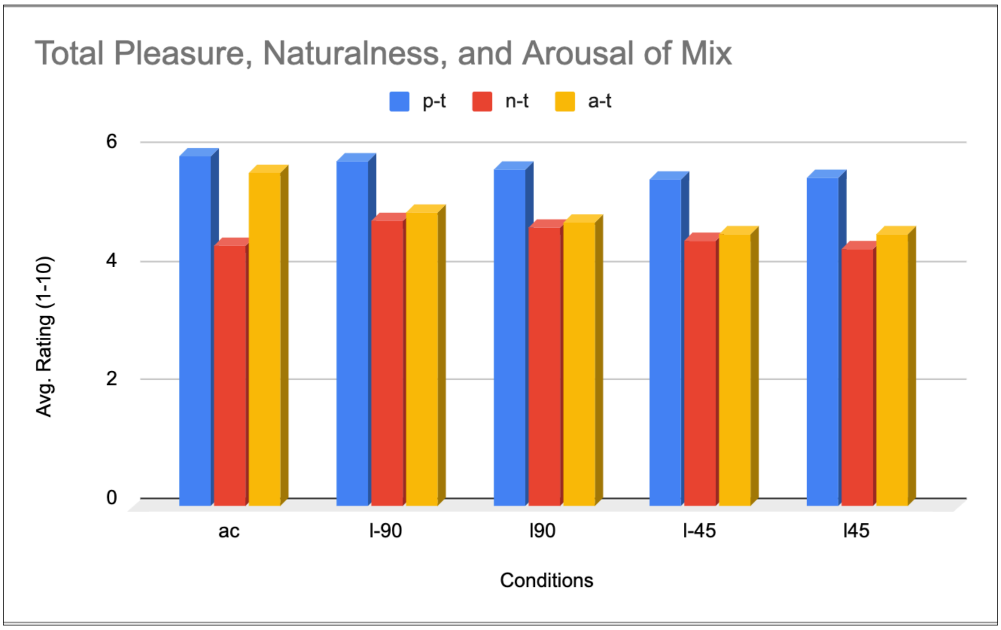

Figure 3c: Bar graph of results. P-t = average 'Pleasing' rating at each condition. N-t = average 'Natural' rating at each condition. A-t = average 'Arousing' rating at each condition. Condition labels marked share the same meaning as in Figure 3a.

Figures 3a and 3b show the average rating of each song at each mixing condition, and the standard deviation of the rating for each mix. These findings indicate that the difference in the mixes were not statistically significant considering the standard deviations, however, some hypothesized trends in the data did show to be true in the scope of this study.

Hypothesis one stated that pitch elevation would affect listeners' ratings for how pleasing, arousing, and natural they found the songs that they heard. Thus, listeners' ratings for pleasure, arousal, and naturalness of the mixes would differ from the 'flat' mixes (all frequencies played at 0 degree elevation), and the spatialized arrangements with high and low frequencies played at different elevations. This hypothesis does hold to be true in this study, as shown in figure 3c, as the ratings at each condition did prove to be different.

Hypothesis two stated that the mixes that have pitches separated in elevation would be rated more highly than songs played with all pitches at 0 degree elevation. Thus, listeners' ratings for pleasure, arousal, and naturalness of the mixes would be lower for the 'flat' mixes (all frequencies played at 0 degree elevation), than for the spatialized arrangements with high and low frequencies played at different elevations. This hypothesis was shown to be false, as the 'flat' mixes, labeled *ac* in figures 3a, 3b, and 3c, rated the highest for listeners' pleasure and arousal overall.

Hypothesis three stated that mixes with pitch elevation that correlates with naturally occurring pitch placements (i.e. low pitches come from lower places than higher places) would sound the most 'natural' to listeners. Thus, the mixes arranged in this way would receive the highest ratings for being perceived as 'natural' to the listeners. This hypothesis does hold to be true, as shown in figures 3a and 3c, as mixes following the l-90 arrangement, with low frequencies at -90 degrees elevation and high frequencies at 90 degrees elevation did receive the highest rating in the category of 'natural' sounding mixes.

Finally, hypothesis four stated that the mixes that were separated dramatically would be perceived as more arousing to listeners. Thus, the mixes that had high and low frequencies at 90 and -90 degrees, and vice versa, would rank the highest in the category of arousal. Along with hypothesis two, this hypothesis was shown to be false because the mixes under the condition of *ac* rated the highest in the categories of pleasure and arousal for listeners.

Discussion

These results show that there is a difference in listeners' perception and preference of spatialized versus stereo mixes, as the ratings of the different mixes varied by condition. Listeners rated stereo mixes (*ac* condition) as most pleasing and most arousing, which can be because spatial audio has not yet become main stream and listeners are accustomed to hearing stereo mixes with all pitch elevations at zero degrees. However, listeners rated mixes with low frequencies at -90 degrees elevation and high frequencies at 90 degree elevation as the most natural sounding, which supports the idea that humans find it 'natural' to hear pitches who's frequencies come from where they usually expect to hear them in nature (high places for high pitches, and low places for low pitches). It is interesting to note that listeners rated mixes with low frequencies at 90 degrees elevation and high frequencies at -90 degrees elevation to be second most 'natural.' This phenomena of pitch localization can occur in nature in certain events like when thunder strikes and causes low frequencies to come from above. However, this rating suggests that having pitches be generally separated by a larger degree sounds more natural to listeners than having pitches densely arranged. Further research would be required to determine whether there is a significant difference in how natural mixes sound with low frequencies coming from -90 degrees and high frequencies coming from 90 degrees, and mixes with low frequencies coming from 90 degrees and high frequencies coming from -90 degrees.

It is also important to note that other factors could have affected the overall ratings of the songs' mixes. For example, song 1 included bird sounds, and song 1 received the highest overall 'natural' rating. This implies that other factors, like instrumentation and use of animal sounds, could also influence listeners' perception of audio as 'natural.' Also, song three included a track that had the sound of a human heart beat as the beat, and this track received the highest rating for 'arousal.' This could be, again, because listeners already associate feeling or hearing a heart beat with a general sense of arousal. Overall, mixes with the low, medium, and high frequency ranges separated by only 45 degrees each, not zero or 90, were rated the lowest in all categories. This is interesting to note, as it shows that different degrees of separation yield different perceptual experiences and preferences in listeners, and can make a track sound better *or* worse than it does in stereo with all frequency bands at elevation zero.

Considering the previous studies, it makes sense that there is a difference in listeners' perception and preference of spatialized versus stereo mixes. Findings on timbral preferences (Dobrowohl et al, 2019) and pitch height connotations (Eitan & Rothschild, 2011) suggested that adjustments in a piece of music resulting in timbral shift or emphasis of certain frequencies would yield different audience perceptions. Further, it holds that listeners rated mixes with low frequencies at -90 degrees elevation and high frequencies at 90 degree elevation as the most natural sounding, as findings in previous studies on natural sounds (Parise, Cesare V., et al., 2014) showed that humans have an implicit mapping between pitch height and localization bias. Also, previous findings on pitch height and visual correspondence (Jamal, Y. et al., 2017) also yielded results showing that humans expect to hear different sounds from different elevations based on the sound's pitch and on their visual surroundings. Moreover, it is interesting to note that stereo tracks with all frequencies played at zero degree elevation were rated to be most pleasing and arousing. Looking at the previous study on listeners' preferences in the music industry today (E. Vickers, 2010), it makes sense that as successful music tracks are increasing in loudness and decreasing in dynamic variability, listeners are becoming more used to a specific type of music production/mix that often sounds the same, and may have a harder time becoming accustomed to or preferring something different, such as a spatialized mix.

One more previous study that could add to the understanding of my findings (D. Västfjäll, 2003) looked at 45 participants' perception of the same piece of music in different spatial configurations (mono, stereo, and six-channel reproduction). Their participants were asked to rank how they were feeling on six emotional scales before and then after hearing the piece (an instrumental song featuring an orchestra and a synth) in each configuration. Findings indicated that stereo and six-channel configurations resulted in significantly stronger changes in emotional reactions than the mono condition, with the six-channel configuration yielding the highest rating of presence and 'emotional realism.' Overall, the results 'suggested that both emotional reactions and ratings of presence increase with spatialized sound.' However, it is worth noting that this study was conducted in a listening room with one, two, and six speakers located around each participant as they listened, whereas this study was done via headphones (each participant was instructed to and trusted to use their own headphones). This finding suggests that the spatialized tracks should have ranked higher in all categories than the stereo (*ac*) tracks, as I hypothesized, but perhaps the deconstruction of the spatialized sound into binaural listening space took away from the immersive experience. Most headphones today are normalized to deal mainly with stereo audio, so it would make sense that headphones may reproduce stereo tracks better than spatial audio tracks. This could be looked into by reproducing my study in a listening room with speakers above and below listeners, as well as in front of them and at 45 degrees above and below their heads, and seeing if the findings remain.

Overall, the strength of this study lies in the small data trends that pose potential truths about how listeners perceive music. With further research, it can be determined that spatial audio influences listeners' musical perception and that songs with pitches at elevations correlating to their natural-occurring place in nature are perceived by listeners as more natural and perhaps even calming. Considering the task design and the obtained data, it is important to note the following limitations of the study: There was a small sample size (11 participants) making it hard to make any conclusive statements from their experience alone; there was a large standard deviation in all of the data categories with some outliers that made it difficult to tell if findings were displaying trends or were the result of data influenced by starkly differing opinions; there was one participant who (after submitting results) admitted to not using headphones as specified in the instructions which makes their contributions to the data invalid; the only elevation differences tested at in this study were 0, 45, and 90 degrees and there could be many more degrees of separation between frequency bands that result in a more optimal/pleasurable listening experience; all of the three songs used in this experiment were instrumental tracks in the style of pop music by the same composer, meaning that the results of this study can also be influenced by the niche style of music.

In future research, it would be interesting to repeat this study with different styles of music, different composers, and with songs that are not instrumental to see how voice may affect results. Also, it would be worth looking into whether there is a better degree of separation that yields more pleasurable/arousing/natural mixes, besides 0, 45, and 90 degrees. Moreover, further research can be done to explore whether there must be loudness matching between the binaural and stereo mixes, as shifting the elevation of pitches can affect the loudness of said pitches and of a whole mix. Therefore, the different mixes may have had slightly different dynamic variability and loudness levels in this study affecting the listeners' preference, as listeners usually prefer/are accustomed to mixes that are louder (E. Vickers, 2010). Finally, repetitions of these studies can all be done in binaural as well as in a live speaker-configuration (D. Västfjäll, 2003) to explore whether the experience of listening via headphones vs via speakers affects listeners' preferences.

Conclusion

Varying the spatial elevation of different frequency bands could effect audiences' perception of audio mixes. The results suggest that spatialized mixes *do* affect listeners' perception of audio samples and change their musical experience from when they are listening to audio clips mixed in stereo. The results also suggest that it may be difficult to get listeners to *prefer* spatial audio over stereo, at least via headphones, as that is what listeners are currently accustomed to. This is shown in the data as the stereo mixes were overall rated to be more pleasing and more arousing, on average, than any of the spatialized mixes. Finally, the findings suggest that a larger degree of spatial separation between the elevation of different frequency bands is preferable to smaller degrees of separation, and that largely separated audio mixes are perceived to be most 'natural' sounding to listeners. This is shown in the data as all mixes with 45 degrees of separation between the elevation of different frequency bands were rated lowest in the categories of how 'pleasing', 'arousing', and 'natural' the mixes sounded, and the mixes with 90 degrees of separation between the frequency band elevations yielded the highest ratings in the 'natural' category. Due to the small sample size and large standard deviations, no strong conclusions can be made from the research at this time. Future research can explore more varying degrees of pitch separation, different musical genres, spatialized music through loud speakers, and music with voices to continue exploring whether the trends in the data hold true and to build off of the ideas presented.

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