Applied and Proposed Installations with Silent Disco Headphones for Multi-Elemental Creative Expression

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ABSTRACT
Breaking musical and creative expression into elements, layers, and formulas, we explore how live listeners create unique sonic experiences from a palette of these elements and their interactions. Bringing us to present-day creative applications, a social and historical overview of silent disco is presented. The advantages of this active listening interface are outlined by the author's expressions requiring discrete elements, such as binaural beats, 3D audio effects, and multiple live music acts in the same space. Events and prototypes as well as hardware and software proposals for live multi-listener manipulation of multi-elemental sound and music are presented. Examples in audio production, sound healing, music composition, tempo phasing, and spatial audio illustrate the applications.

Keywords
wireless headphones, music production, silent disco, headphone concert, binaural beats, multi-track audio, active music listening, sound healing, mobile clubbing, smart-phone apps

1. INTRODUCTION
As musicians and event producers trying to expand the toolset we use to entertain, our team purchased a large number of wireless headphones to start a silent disco company. This allowed us to express group sound healing techniques that cannot be expressed without headphones such as binaural beats for brainwave entrainment, not to mention a live drummer at a 4am party with two other EDM DJs simultaneously. It also allowed our audience to be more active listeners. This paper presents a personal documentary, historical overview, and a proposal of future possibilities for this technology.

Generally, sound and music are delivered to a group through a shared delivery system such as a set of loudspeakers. This delivery mechanism is limited in many ways. Everyone is at the mercy of the physical space, the sound engineer, and noise ordinances. Using headphones and related technology, listeners can use preferences to better connect to the underlying music production. The result is a shared experience that can be very personal and interactive in ways not physically possible without every listener having their own set of headphones.

2. SILENT DISCO TECHNOLOGY
2.1 Silent Disco Headphones
"Silent Disco" is a term used to describe an event where, instead of having loudspeakers, each listener is issued a pair of wireless headphones. An early documented prototype of this is in the 1969 Finnish science fiction film, *Ruusujen Aika* [20]. Silent discos broadcasting DJs and bands have been mainstream since the early 21st century [3,5]. Bands such as The Flaming Lips [9], Kid Koala [22], and our band, ToasT [34] have implemented headphones in live concerts, using the term "Headphone Concert" to describe the experience. Our project, Austin Silent Disco [2] utilized headphones for a 2013 album release at the South by Southwest music conference for an Australian band. At the event, attendees could only hear the new album through the headphones, adding mystique. Theater companies have also utilized headphones in theater productions [17]. For mobile events like the Decentralized Dance Party [6], a large battery takes the silent disco to the streets.

Unlike normal speakers, headphones deliver discrete content to each ear. This allows listeners to experience technologies such as binaural beats. Binaural beats are a perceptive phenomenon occurring when sine waves of differing frequencies are presented to each ear. The difference of these waves is perceived as a third "beating" frequency when the human brain combines the two sounds. This "phantom frequency" of binaural beats has been used for brainwave entrainment, which is a process to guide a person's brainwave frequencies to desired states. Listening to binaural beats through headphones has been shown to alter a listener's biofeedback of brainwave patterns [12,29]. Brainwave entrainment has shown great potential for human health [19,30]. The author's Guided Meditation Treks [15] uses brainwave entrainment. This musical project incorporates spoken word, sound healing, and ambient music into productions delivered through wireless headphones with an intention of self-improvement and spiritual progression. Brain Wave Fitness [4] incorporates audio/visual entrainment. Clients interested in getting the most out of the modern lifestyle are trained to consciously access states of focus, creativity, relaxation, and sleep. PTSD veterans and formerly incarcerated benefit from these treatments that involve headphones, lights, and biofeedback.

Another advantage of headphones is that we can utilize 3D effects. 3D audio effects can make the listener perceive sound as if it is in front of their face or behind their head. In a guided meditation, we can make sounds appear to come from the throat, third eye, or crown chakra. While not as extensive as spatial sound, headphone-based 3D sound has been used for 3D Human Computer Interaction for the blind [25].

2.2 Channel-Switching Headphones
Each broadcast channel offered by a silent disco is from an FM transmitter. Specific carrier frequencies vary throughout the world based on radio spectrum allocations from government agencies [11]. Early versions of the headphones were capable of only one stereo channel. This allows each listener to get a clear stereo mix for which they could individually control the volume. Today, silent disco headphones incorporate 3 or more stereo channels, allowing the listener to have choices and even "channel surf" in the moment for content.

Austin Silent Disco's first event was a multi-faceted production for 300 attendees. The venue had a large outdoor area, a piano lounge, and our band with full acoustic drums and electric

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instruments in a small auditorium holding only 70 people. A soundboard feed was transmitted. Two DJs broadcasted on the other channels from the outdoor patio. Listeners could enjoy the band from inside the auditorium through the speakers or with a higher fidelity through headphones. With headphones, they could also enjoy the choices from the courtyard.

We explored multiple channels at an event where listeners watched a movie and heard the movie soundtrack on one of the channels. DJs mixed the movie feed into their performances on the other channels, creating live movie soundtrack remixes. Listeners could choose their level of movie or music focus.

Another application of multi-channel technology is to allow the listener to select from different prepared mixes of the same musical work, such as the same song with a different vocalist on each channel. Multi-lingual applications for sporting events or academic lectures are apparent. We can create a guided meditation that allows the listener to select a language for the spoken words while the background sounds remain the same and the experience unfolds for everyone simultaneously.

3. END-LISTENER MIXING

The next evolution of multiple channel technology is to give each listener the ability to blend or mix multiple elements, in addition to simply switching between them. The listener may use separate volume controls for each element, or the elements can be automatically blended and mixed based on criteria such as the listener's location or biofeedback. Outlined below are implementations using different approaches to accomplish this goal. The hardware implementation is a real prototype; the software implementation is a software analysis and design based on prior experience in the software engineering field and current research into the technology.

3.1 Hardware Implementation

Austin Silent Disco has implemented a prototype to allow multiple simultaneous listeners to mix content from two different elemental sources. Our headphones have an internal wireless receiver that can select from one of multiple channels and control the volume for the selection, as well as a 3.5mm line-in. Plugging in a device such as an mp3 player allows the sound from the external device to be blended with what is received by the wireless receiver inside the headphones. The receiver and volume control also exist as a separate device on different frequencies with a 3.5mm line-out for external headphones. By sending the line-out of a external receiver into the line-in of the headphones and controlling the volume of each independently, the listener can create a custom live mix from multiple elements. This is outlined in Figure 1.

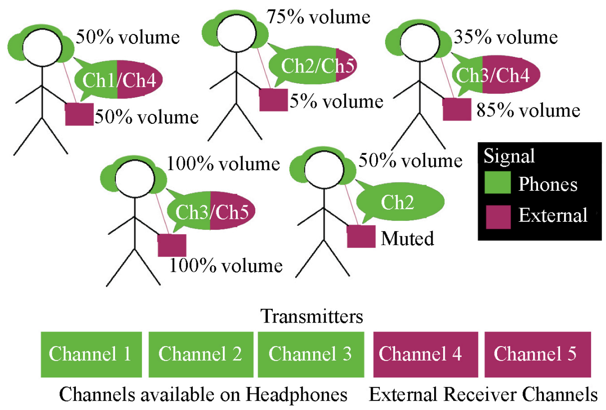

Figure 1. Multi-Listener Manipulated Multi-Elemental Sound Installation example with 5-channels.

FM Transmitters broadcast signals on 5 separate stations. The receiver inside of the headphones can toggle between channels 1, 2, and 3. The external receiver can toggle between channels 4 and 5. The external receiver feeds its output to the headphones with a 3.5mm cable. Discrete volumes on each of the two receivers (internal and external) allow listeners to create a custom mix in their headphones by selecting from channels 1, 2, or 3; combining that signal with either channel 4 or 5; and managing the two independent volume controls.

A mix matrix of possible blends is outlined in Table 1. Conceivably, this can be extended to multiple external receivers with a split 3.5mm cable, adding another table dimension.

Table 1. Listener Mix Options

Phones/ Receiver	**Channel 1**	**Channel 2**	**Channel 3**	**Muted**
Channel 4	Ch1:Ch4	Ch2:Ch4	Ch3:Ch4	Ch4
Channel 5	Ch1:Ch5	Ch2:Ch5	Ch3:Ch5	Ch5
Muted	Ch1	Ch2	Ch3	Silence

3.2 Software Implementation

In this proposed scenario, the listeners provide their own hardware, such as a smart phone or tablet computer, as well as their own set of headphones to attach. This alleviates the need to provide each listener with a set of hardware. It would also shift the limitations of the system from hardware technology to software technology, which is generally easier to upgrade. In this scenario, instead of receiving the signal from FM transmitters, their device would be connected to a wireless network to receive the broadcast.

3.2.1.1 Centralized Broadcasting

Whereas an FM transmission approach allows separate transmitters, a digital streaming solution would require all channels to be bundled and delivered on a single live stream to ensure synchronization for the listener. This is known as multiplexing. Existing organizations have instituted multiplexing technology standards for multi-track streaming. Ogg Opus [37] is a low-latency audio codec to facilitate the broadcast of multiplexed audio over IP-based networks like the Internet, 4G, and wireless routers. Bluetooth, mesh networks, and one-way digital transmissions like those used by digital television and digital radio may also be viable for broadcast, hardware permitting. Each broadcasting approach has its pros and cons as it pertains to distance efficacy, audio latency, sound fidelity, and programmability.

Le Placard Headphone Festival [23] offers an example of an online one-channel streaming silent disco. The event is broadcast over the Internet worldwide. London-based fyidisco [13] uses the HTTP Live Streaming protocol to create pop-up silent discos over a wifi network. Listeners bring their own smart-phones with ear buds to the event and connect.

To introduce multi-elemental sound manipulation to such an installation, we can consider technologies developed for home theater regarding interactive listening scenarios [32]. These include multiplexed audio objects that can be positioned or move through the 3-dimensional surround-sound field of a typical 5.1 home surround-sound system. Similarly, many sporting events such as the National Football League already broadcast in Dolby Digital 5.1 and isolate the announcers into the center channel. This gives home viewers the ability to turn them down in favor of stadium noise broadcast over the surround speakers. These are just some existing samples of multi-elemental sound technology that can be applied.

3.2.1.2 Receiving and Interactive Broadcasting

Software installed on each of the listeners' smart-phones could receive the multiplexed data and decode it to separate stations and/or separate channels within each station. The Web Audio API [36] allows a web browser host the application, or smart-phone operating system APIs can be used to develop custom apps. On the user interface of the device, the software could present the listener with a graphical mixer of faders, allowing them to blend and pan the channels into their final mix. The number of channels available and the ways in which they can be manipulated are limited only by the bandwidth and hardware capabilities of the phone and network. To make the expression more interactive, all of these mix preferences could be shared between listeners. Also, listening statistics and feedback can be sent from the listeners to the broadcasters for later analysis of the group experience. Finally, the app could allow listeners at the event to take turns being the DJ. A cloud-based approach like turntable.fm [35] can be used, or the smart-phone app can present users with virtual turntables and effects to generate a live stream from their phone's onboard music library.

Related to this proposal is a concept called "mobile clubbing," where individuals at an event each bring their own personal music device and listen to their own music library. Computational music analysis can increase the shared experience of the mobile clubbing situation. Apple has applied for a patent [24] featuring an app that interacts with users' iTunes collections, matching attributes such as genre or tempo so that people are at least listening to similar music. Other organizations such as the Echo Nest [7] and Gracenote employ more in-depth systems of computational music analysis to relate musical works.

4. INSTALLATIONS

4.1 Elemental Sound Installation Examples

The list of possibilities of content to deliver is endless. Here are specific installations that others and we have implemented or may wish to implement to explore the concepts.

4.1.1 Listener-Mixed Audio

The technology could be utilized at a supergroup concert where some listeners want more keyboards, and some want more guitar. Bands like the Flaming Lips have explored this by releasing multiple albums meant to be played at the same time so that the elements can be adjusted [10]. Nine Inch Nails offers open-sourced multi-track elements of some of their work that can be reformulated by listeners to create personal mixes [28]. Erasure released a single that included a software package to let fans blend the isolated tracks to create their own remixes and upload them to the Erasure website [8]. This concept can also be applied to studio recording sessions, where every musician requires a different mix to better hear specific elements of the session as they play. Google's software product, Chrome Jam [14], features real-time multi-track music production and mixing with cloud-based virtual instruments.

4.1.1.1 Spoken Word Content

Spoken word guided meditations such as those created by Guided Meditation Treks [15] have many elements, each of which may be more or less effective for an individual. For example, some people are immediately put into a Zen-like state when listening to binaural beats, whereas others develop high levels of anxiety. Some people want to hear the guide's voice loudly and clearly, and others just want to hear running waterfalls. Active listening interfaces provide a way for composers to better express and convey feelings of relaxation and modes of healing by allowing listeners to customize elements of the mix for their own comfort and desire. This helps listeners explore and find which path works best for them to become immersed in their own personal meditative state.

4.1.2 Sound Healing Tables

Extending elemental sound to other physical installations, practitioners from Transformational Resonance [26] and Guided Meditation Treks are creating meditative programs that incorporate four discrete audio tracks. In addition to the headphones, two low-frequency transducers are installed in a massage table to physically vibrate the listener. Each is controlled discretely in a 4-track mix.

4.1.2.1 Active Spatial Sound

Active scenarios like the smart-phone app pull data from the listeners, making them contributors instead of just spectators. A musician using a separate microphone during a performance to communicate with other band members via earpieces is another illustration of interactive sound. Hyperinstruments and headphone-based spatial sound [1] are other examples.

When listening to instruments in a room, your mix changes based on where you are physically located in the room. There are technology solutions [33] to encode the spatial information of the music (such as the locations of each instrument in a panorama), as well as the listener (for example, their head movements and location). This information can be used to automatically change the panning of the sound for individual listeners so that their experience changes based on their position as well as any movements and/or locations of the performers. There are existing patents on specific implementations of headphone-based systems for spatial sound reproduction [18] that incorporate multiple speakers in each headphone as well as the design of the human ear to allow the listener to perceive sound elements as coming from anywhere in physical space. We can combine all of these technologies to express a virtual acoustic reality.

4.1.2.2 Other Multi-Elemental Sound Applications

There are several ways we can combine sound elements to create a whole greater than the sum of its parts, as is the case with binaural beats. By allowing channel switching and elemental-manipulation, we can better explore these ideas.

African polyrhythms illustrate the idea of breaking sound down into elements that can be separated within references like time signature and tempo. The XCHOX project [31] adds another dimension of reference by mixing two or more elements with differing beats per minute (BPM) in real-time. Over time, when the common denominations of the two BPM scenarios line up, the music snaps in and out of phase. This is known as tempo phasing. Related to the silent disco application, a spectator can witness tempo phasing effects by watching dancers tuned into different BPM on different broadcast stations on the dance floor. They appear to dance with each other in and out of synch over time.

For tonality and music theory, Roland Finch in Austin and others [21,27] have created modal harmony algorithms that mathematically spell out how various key signatures and modes can be blended together. By studying adept musicians and empirically comparing modes and their relationships, these algorithms can be used to generate elements that can change the overall feel or mood of a work. In a live implementation, for example, a listener can choose between a more "happy" version of a song with major chords and a "sad" version based on minor chords. The selection can also be made with biofeedback data from the listener's response to the music. Using harmony algorithms, various scenarios can be calculated, formulated, and automatically generated for the listener. Technologies such as these show how mathematically combining sound elements can result in unique and unconventional experiences greater than the sum of their parts. Headphone technology allows everyone to individually explore these facets, yet within a shared group setting.

4.1.2.3 Sensory Convergence

With the addition of a visual component such as virtual reality goggles, we can extend these concepts to the sense of sight. This technology is already being developed for the video gaming [16] and brainwave entrainment [4] fields. Senses of touch, smell, and others can be explored as well with hardware.

5. CONCLUSION

Wireless headphones are valuable tools in the arsenal of musical expression, giving the listener more opportunity to be involved in how they perceive the elements expressed by composers and performers. Working with a palette of elements and personal preference or biofeedback, listeners integrate themselves into the work, allowing them to better connect to it.

6. ACKNOWLEDGMENTS

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