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# Unheard Sounds: A Manual for the Sonification of Emotional States in an Artistic Space

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When Alvin Lucier premiered his *Music for Solo Performer* in 1965, he became one of the earliest musicians to use brain signals for compositional and performance purposes (Straebel & Thoben, 2014). Since then, many more musicians, artists, and scientists have continued to study and develop concepts touched on by such a demonstration. Topics of continued interest include technical issues like accurately measuring biosignals and creating a sonification system, and more fundamental issues concerning the defining of emotions and aesthetics. As this discussion progresses through its more technical aspects, it will begin to resemble a manual of sorts; it will be more like a handbook for turning emotions into sounds, or the sonification of emotions, and incorporating these sounds into live performance. The aim of this paper is to offer theoretically grounded ideas for developing models and answering challenges to the concepts Lucier presented at his piece's premier.

## Emotions and Music

### What Are Emotions?

Emotions are something people experience every day, however, despite having an innate understanding of the phenomena, it becomes an obscure concept when defining it within scientific terms. Traditionally, there have been three models for understanding emotion. The first, developed by Ekman (1992, 2003) and Izard (1977, 1992), is the basic emotion theory, which suggests that a specific event triggers specific emotions and related response patterns (Scherer, 2009). The second, supported by James (1890), Schacheter and Singer (1962), Russell (2003), and Barrett (2006), is the constructivist theory of emotion, which defines emotions as acting on two planes: arousal (the level of physical response) and valence (the direction of the emotion) (Scherer, 2009). The third theory, developed by Arnold (1960) and Lazarus (1966, 1991), with ties to traditional philosophical thought, is the appraisal theory of emotion and suggests that emotions come about from a person's assessment of a situation or event (Scherer, 2009). While emotions may be explained by one theory or a combination of these theories, certain parts of it would be difficult to measure in real time, such as with an individual's judgement of a situation. To this end, it would be best to focus on measuring emotions through corporeal indicators, such as the arousal levels suggested in the constructivist theory.

For the purposes of simplicity, emotions will be defined as a set of chemical and neural responses caused by reaction to some specific stimuli (Damasio, 2000 as in Coutinho & Cangelosi, 2011). These responses are comprised of three components, which include a cognitive ability to feel emotion (subjective feeling), some physical changes, and physiological arousal (Oatley & Jenkins, 1996; Scherer & Zentner, 2001 as in Coutinho & Cangelosi, 2011). Of interest are the physiological changes, which include things like heart rate, respiration, and perspiration, since they can provide a direct measure of emotional response (Stemmler, 2003 as in Coutinho & Cangelosi, 2011). Also, due in part to the emergence of neuroscientific study within the past few decades and the advancements in the field of neuroimaging, it has become possible to observe specific areas of the brain as they relate to certain emotional responses. This has been observed with music, such as the activation of the amygdala in response to negative emotions, particularly those associated with "sad" or dissonant music, and activation of the left superior temporal gyrus in relation to "happy" music (Brattico & Pearce, 2013). Though the research in this specific area is promising, none are making a claim towards definitively mapping emotional reactions in the brain and instead suggest further research be conducted.

**Culture and Emotions in Music**

At this point, it would be of benefit to discuss the idea of "happy" or "sad" in music. The previously mentioned study and a few that are yet to be cited have made little note of the cultural background from which the research is being conducted: Western music and its notions of "happy" and "sad." Within the context of the current discussion, this would not be an issue had the nature of the work not lend itself to transcending cultural experiences. There is some research that suggests groups of people who have been culturally isolated from Western music can perceive basic emotions such as happiness, sadness, and fear (Fritz et al., 2009). However, researchers state that this familiarity in recognition does not satisfy the notion that music can universally express emotions (Fritz et al., 2009). The researchers explain that while participants – the Mafa people, who are an ethnic group of culturally isolated people living in the Extreme North of the Mandara mountain range–could assess emotion from musical examples within the experiment, their own culturally derived music may not intentionally convey emotional information (Fritz et al., 2009). The researchers bring this point up to warn against the idea that music is the "language of emotions," since some music might lack any emotional qualifiers or be for other utilitarian purposes (Fritz et al., 2009). This would be an issue to consider when moving proposed measurement/sonification systems across cultures that do not share Western ideals and aesthetics about their music.

A theoretical solution to this issue would not be as successful and fruitful as artistic development. This viewpoint stems from the philosophical underpinnings of postmodern music, specifically about the idea of *plurality*. Leonard Meyer (1967) described the latter half of the 20$^{th}$ century as a "fluctuating stasis," lacking a dominant artistic style. Within this constantly changing landscape, Meyer highlighted how new styles might be created or emerge: the ability of the composer(s) to write convincingly in a new style, the simulation of tackling new compositional dilemmas under a specific style, or through the creation of a new “conceptual model” that is connected to other art forms or fields of science (Meyer, 2010). The model/style presented in this paper fits into this paradigm, and as such, highlights the need for artists to creatively collaborate and explore the tools being presented here to reach their own consensus about what the music means and how it should sound. This involves not only tackling creative problems, but also working in an environment that needs to take cultural differences into consideration if it is to be successful. While this discussion speaks to problems with the flexibility of proposed systems, it also highlights issues with the nuances of interpretation, even within the same culture; here again, artistic development would be the best course of action.

**Musical Emotions**

As noted above in the attempt to establish a simple understanding of emotions, the relationship between music and emotions is not clear cut either. One of the questions that remains even after settling on subjective meaning is the concern with what exactly is being measured. When trying to measure and sonify emotions brought about by music, as we generally think of it, it is important to scrutinize the notion that music elicits “real” emotions. This argument is encapsulated in the “emotive” versus “cognitive” positions, which argue that music can make a person feel emotions while the latter suggests music allows for the perception of emotion (Lundqvist, Carlsson, Hilmersson, & Juslin, 2009). A permutation of this argument suggests that emotions invoked by music are different than everyday emotions (Swanwick, 1985 as in Juslin & Västfjäll, 2008). Juslin and Västfjäll (2008) instead argue that music elicits emotions through the same mechanisms as other emotion provoking stimuli, and though music may be thought of as eliciting a distinctive set of emotions, it does not validate the need to categorize these emotions as markedly different from every day emotions. Juslin and Västfjäll conclude that a unique aspect of musically induced emotions is that they are a result of stimulus that is designed to provoke an emotional response, rather than some of the other day-to-day stimulus that just happens to cause an emotional response.

**Emotions, Not Mood**

As the discussion continues, it is important to note that emotion and mood are two different things, though they are sometimes used interchangeably (Garrido, 2014). Adding to the definition of emotions, they are brief, intense, and immediate responses to a stimulus, in this case music, while mood is a somewhat weaker reaction that can be present long after the music has been played (Garrido, 2014). The importance of this distinction rests with the notion that each is activated by a separate set of mechanisms (Garrido, 2014). Some possible mechanisms that allow for emotion induced from music include: brain stem reflex (basic biological responses to sound as informed by primitive parts of the brain), emotional contagion (listener perceives certain emotion in music and adopts it as their own), episodic memory (music evokes a specific memory and related emotion), and musical expectancy (violations of a listener's musical expectations) (Juslin, Harmat, & Eerola, 2014). The mechanisms that influence mood on the other hand include: reflection (allowing a person to reflect on events in life), catharsis (emotional discharge), solace/connection (giving listener feeling of shared empathy), rumination (focus on negative events and emotions), and aesthetic pleasure (the stimulus serves as pure entertainment) (Garrido, 2014). This distinction is important to understand when attempting to measure/sonify emotion, as to not confuse different subjects that are very similar.

# Measurement and Sonification

## Methods for Measuring and Related Issues

What follows is a selective representation of different methods and techniques that have been used to record emotions. Though it may not be a comprehensive list, the aim of presenting these systems is to assess their use in a live musical performance.

**Self-report.** Instinctively the first manner of measuring emotional response to music would be to ask the person how they are feeling. In studies, this usually takes the form of a survey in which researchers have participants report their emotional state on a scale, such as in Zenter and Scherer (2008) whom designed their own measuring scale, the Geneva Emotional Music Scale. As simple as this might be to measure, it is important to note that these usually only measure the subjective experience of music and are recorded right after or close to the presentation of the stimulus, rather than in the moment of experiencing (Juslin & Sloboda, 2001). This would present issues when trying to measure a performer's emotional states, since it might require an interruption of the performance and withdrawal from the immediate emotional state.

**Physiological measures**. One of the more readily referenced methods is the measuring of physiological measures, such as heart-rate, galvanic skin response, skin temperature, blood pressure, and muscle tension. Of these, the most commonly used measure in studies that focus on music and emotion interactions is heart-rate and galvanic skin response (Coutinho & Cangelosi, 2011). These measures appear to have a relationship with emotional arousal of the autonomic nervous system, so that excitement or relaxation lead to measurable changes despite not being as predictable or constant (Lundqvist, Carlsson, Hilmersson, & Juslin, 2009). However, it must be noted that some of these recorded changes are in relation to strong emotional stimuli, bringing into question the need to consider the affective strength of the music or performance (Rickard, 2004). These variables would be easier to measure than the self-report since they involve the use of sensors that do not greatly inhibit mobility or flexibility on the performance stage.

**Brain activity measures.** With recent developments in neuroimaging, it has become possible to record brain activity as it relates to specific conditions. Within some of the studies, the most common methods have included fMRI, PET, and EEG. In studies that used fMRI or PET, they found activation of brain areas, such as the amygdala, hippocampus, and hypothalamus, corroborating with the results of other studies (Blood et al. as in Peretz, 2001; Koelsch, Fritz, Müller, & Friederici, 2006). In an EEG study, researchers could support past observations regarding an interesting phenomenon: the left half of the brain increased activity with more pleasant and “happier” music, whereas the right side of the brain increased activity when listening to “sad” music (Schmidt & Trainor, 2001). Neuroimaging techniques, it would seem, grant us the ability to observe and record emotional responses.

Human intracranial electrophysiology (HIE) presents another interesting method for observing brain activity. The process involves placing intracranial electrodes directly onto the brain, though it has mainly been limited to use with treating patients who suffer from epilepsy (Guillory & Bujarski, 2014). Though the use of HIE is beneficial in comparison to some of the others, such as providing greater resolution than an EEG and faster feedback than an fMRI, it is invasive to where a performance on as stage would not be feasible, while also possibly causing activation of the observational area due to the electrodes (Guillory & Bujarski, 2014). Like other technology, this show promise with further development.

## Methods for Sonifying and Related Issues

With a general framework for defining and measuring emotion laid out, the focus can shift towards turning data into sound. Sonification is defined as the inserting of data into certain processes that generate sound signals that reflect relationships in the data (Herman, 2008). One of the best and simplest examples of this process is a Geiger counter, which translates radioactivity data into sounds that can be interpreted to mean something. This means that the rate of clicks alerts the observer to pattern, in this case the strength of radiation levels around them, granting the observer an ability to further interpret these signals as meaning that their surroundings are either benign/safe or toxic/dangerous. This leads into the issue of translating raw biological data, such as brain signals and physiological measures, into sounds that can be interpreted in a meaningful manner. Though it might be easy to understand music as communicating emotion, the sonification of emotional states works on a different set of principles (Winters & Wanderley, 2014). Herman (2008), defines the distinction by stating that sonification must be “objective, systematic, reproducible and able to be used with different data” (as in Winters & Wanderley, 2014). Specific to the sonification of emotion, this means that data representing emotion must be repeatable and create recognizable patterns (Winters & Wanderley, 2014). The challenge that emerges here, then, is how to process the data to achieve this aim while presenting it as accurately as possible.

There are two generally accepted methods for processing this kind of data. The first is parameter-based sonification, which basically means that the data is laid out into specific sound parameters. For example, EEG alpha band activity could be paired with the intensity level of a sound (Ballora, 2014; Väljamäe et al., 2013). The second is model-based sonification, which relies on mathematical models to generate sound per the information that it receives (Ballora, 2014; Väljamäe et al., 2013). Though the parameter-model has been well used in past studies, the model-based is gaining more attention because of its flexibility with the variety of data that can be inputted (Väljamäe et al., 2013). The model-based strategy has also been shown to perform better than the parameter-based, though the parameter-based still performs well in terms of emotional communication (Winters & Wanderley, 2014). It should also be noted that another strategy is audification, by which the raw data is treated as sound waves by compressing it by large amounts, but is the oldest of the strategies and is no longer used as much (Balloara, 2014).

Along with much of this technology comes the need for a computer, specifically software. The programs that are used to create the sounds are varied and depend on preferences or needs. Some of the earlier users of the parameter-based system mapped the data into MIDI and produced melodies by assigning data points to MIDI note numbers, though it proved to be quite limited in terms of its availability of notes (Balloara, 2014). Now, many just tailor basic sound synthesis programs to their needs, such as SuperCollider, Csound, Max/MSP, and Reason (Balloara, 2014; Barrass, Whitelaw, & Bailes, 2006). There appears to be no general disagreement or issue with the type of software used, this is left to the researcher/performer.

## Performance Stage

### Lessons from the Past

This next section will present real-life application of some of the previously mentioned measurements and sonification techniques to present a performance in which brain activity is part of the piece. Though with some, their focus may have not been on expressing real-time emotional states, their experimentation with the medium provides some insight into the challenges of adopting these technologies.

**Alvin Lucier's "Music for Solo Performer."** This piece has been regarded as the first of its kind, the first to use real-time brain signals in a live performance (Straebel & Thoben, 2014). First performed in 1965, the piece features a solo performer sitting with a headband that fed their alpha brain wave patterns and signals into speakers that sympathetically vibrate percussion instruments (Straebel & Thoben, 2014). Straebel and Thoben (2014) point out that though it would be easy to think that the brain waves were causing the instruments to sound, there were a host of processes and decisions made from the EEG readings to the sonification of the information. The authors stress the importance of the assistant, who controlled the flow of signals from speaker to speaker, and though their role may not have been as obvious to the audience, this invisibility allowed for the illusion of the performer's brain waves directly acting on the machines (Straebel & Thoben, 2014).

**Richard Teitelbaum's "Spacecraft."** This piece, performed in 1967, continued the use of neurosignals and extended sonification techniques to other physiological measures (Teitelbaum, 1976). It was a piece performed by the Musica Elletronica Viva Group while on tour in Europe (Teitelbaum, 1976). The composer incorporated signals from his heartbeat, chest cavity, and throat into live musical sounds, and had EEG and EKG signals turned into audio using a Moog Synthesizer (Teitelbaum, 1976). He described the experience as:

> Proceeding neither from score, chart nor other external image, each musician rather carried on an inner search through the recesses of his own consciousness…a process of non-ordinary communication developed, guiding individual into collective consciousness, merging the many into the One (37-39).

His rather poetic description highlights an important facet of this new and developing genre, that it created a space for a unique collaboration.

**Erkki Kurenniemi and Dimi-S/Dimi-T.** Aside from incorporating sonification into an aspect of performance, Kurenniemi shifted the use of biosignals towards allowing the performer to "play" specifically designed instruments. After being exposed to Manford L. Eaton's ideas on using biosignals as musical material while attending an electroacoustic music conference in 1968, Kurenniemi designed two electronic instruments, the Dimi-S and the Dimi-T (Ojanen, Suominen, Kallio, & Lassfolk, 2007). The Dimi-S involved four people holding iron balls in their hands, which measured the galvanic skin response of a person being touched by another (Ojanen et al., 2007). The Dimi-T was like Lucier's in that EEG signals controlled the changes in the pitch of an oscillator (Ojanen et al., 2007).

**Contemporary Incarnations**

Though the previously mentioned examples came about a few decades ago, they directly influenced more recent projects. Such projects include: the *Listening to the Mind Listening (LML)* concert staged at Sydney Opera House Studio in 2004, which demonstrated the value of sonification as musical experiences and research possibilities (Barrass, 2012); the continued development of brain-computer interfaces (BCI), especially for extending musical activity to disabled individuals through a brain-computer music interface (BCMI) (Miranda & Brouse, 2005); the work of Palacio-Quintin towards sonifying movement with sensors measuring distance and pressure, which related to an expression of emotion through physical movement (Palacio-Quintin & Zadel, 2008); as well as a host of performing artists who use biosignals more as entertainment, such as *Lucky Dragons, The Heart Chamber Orchestra,* and *Manifold Motion* (Paalasmaa, Murphy, & Holmqvist, 2012). The piece that personally called my attention towards this topic was Daniel Dehaan's piece, "Intelligence in the Human Machine," premiered in 2014 with Chicago Symphony cellist Katinka Kleijin, which involved her performing from an interactive score while her brain waves were captured by an EEG headset and turned into electronic sounds (Sterbenz, 2014). Though the appearance of such works is promising, there is much work still to be done and many more advancements to be made.

## Discussion and Conclusion

With the technical and historical details laid out, the best models for measuring and sonifying a performer's emotional states during a live performance can now be conceptualized. The equipment, ideally, should allow the performer to artistically express themselves while not being restrictive in any way. Currently, use of an EEG is becoming popular, partly due to the portable nature of some of the commercial models and the affordable pricing (Christopher, Kapur, Carnegie, & Grimshaw, 2014). A system that uses this approach is the brain-computer music interface (BCMI), being developed by researchers like Eduardo Miranda and Andrew Brouse. The researchers have managed to develop a BCMI that is fed EEG signals and then uses the data to "play" a piano (Miranda & Brouse, 2005). The researchers point out that the system is not a direct presentation of brain activity, rather, the computer system can interpret the information and sonify it in its own way, in this case some patterns on a piano (Miranda & Brouse, 2005). However, this headset or cap system would also need supplementing with other sensors, such as galvanic skin sensors and heartrate monitors to balance out some of the previously mentioned limitations and to gain a clearer understanding of what is being experienced. These systems are taking shape, such as the BioMuse System, which uses kinematic sensors (measures motion of the body) and physiological sensors that measure somatic/autonomic activity with the aim of presenting the biosignals raw, without the level of musical interpretation as in the BCMI (Knapp, Jaimovich, & Coghlan, 2009).

While much of the discussion has centered on more technical terms and issues, the moving from the theoretical stage to the performance stage presents many artistic opportunities. Such an opportunity emerges when deciding the specific sound some the systems produce when the data is sonified. From the historical and current examples given, the sounds the sonified data takes on can be organized into two broad categories: concretely and musically. By concretely it is meant that the data is presented without any major alterations and usually in a form of electronic sound, such as the sounds of a Geiger counter or a heart rate monitor. The goal of this sonification is to present the data as clearly and through the simplest means possible. In contrast, sonifying the data musically results in alterations or enhancements, such as assigning specific phrases of music that play as they correspond to specific trigger events or changing the frequencies on the same data for musical purposes (i.e. the frequency of a resting heart rate sonification changes throughout a piece depending on its tonality). The concretely and musically sonifications can be thought of as playing static and active roles, respectively, depending on the needs of the performers. However, it should be noted that these two are not mutually exclusive and not definitive either, they are just tools for assisting with a discussion of the aesthetics of the sounds being produced. For example, while a heart rate might be easily sonified with an electronic blip, brainwave activity requires an assignment of specific frequencies or sounds for discerning specific activity (i.e. Alpha and Beta waves or frontal and temporal activity having different frequencies/sounds to know these are two different things). Ultimately, a performer/realizer has the liberty to have both elements together in a specific piece and with certain arrangements for these that are unique to each piece.

This ability to choose from the two also highlights new compositional opportunities that are open to the performer/realizer. While the performer or collaborators might have a clear idea of the aesthetic intent of the sonification, they have the liberty to choose the specific sounds that represent the data. This is the inherent advantage with using electronics to produce the sounds, the artists have a wider sonic pallet to work from that was limited before with traditional acoustical instruments. For example, if the artist thinks certain data would be more effectively presented through something that sounds like a hybrid of flute, saxophone, and siren timbres, they can create it electronically rather than attempting to marginally materialize the original concept acoustically, though it would be an interesting endeavor.

One critical aspect that was also touched upon with Lucier's, Teitelbaum's, Kurenniemi's, and others' pieces was the need for collaboration. Whether with the person who is controlling the electronics or live feedback tracks, or fellow performers/composers and audience members, this type of project/performance allows for the development of more intimate and personal interactions with all parties involved. Works that incorporate some of these elements have been bringing people from across disciplines together to tackle technical and aesthetics issues through dialogue. Such collaboration takes place in the eNTERFACE workshops, which have been held since 2005 across different cities in Europe (Brouse et al., 2006). While cooperation on these lager scales may not be readily viable, it should be fostered on smaller scales. As noted previously, these projects promote interaction between a diverse range of individuals, from scientists and technicians to audio engineers and composers. These projects allow for those usually thought of residing outside of the artistic realm a place to contribute and those not usually thought of as performers an opportunity to become part of the performing ensemble, as would be the case with an audio/computer engineer for example. This type of work unlocks the opportunity for everyone to contribute to an aspect of the ultimate experience.

Many of the authors mentioned here share the hope that continued advancements in this field, particularly in terms of technology, will be supported by new academics and musicians. Rather than being a passing fad, this area unlocks possibilities for scientific, medical, and artistic uses that are worth exploring. Ultimately, all of this adds up to granting artists the ability to tackle what is actually a poetic problem: taking the mind and turning into music.

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