TEMPORAL IMAGERY FOR AURAL DIVERSITY: AUDITORY DISPLAYS AS ARTIFACTS OF SONIC ART ENCOUNTERS BETWEEN UNAIDED AND COCHLEAR IMPLANT LISTENERS.

Sharath Chandra Ramakrishnan

School of Art & Design
University of Illinois Urbana-Champaign
scram@illinois.edu

ABSTRACT

This paper advocates for the position that aurally diverse methodologies for designing auditory displays are needed, that not only take into account varied hearing capacities, but also conceive of a participatory and trans-disciplinary approach for collectively engaging diverse forms and conversations about listening, and shared associations with auditory imagery. Further, in light of the complex history that the notion of hearing disability and the evolution of commercial sound technology has had within the normalizing agenda of medical institutions, a call for methods of engagement that necessarily depart from the ubiquitous model of clinical testing for the ideal 'ear' is made. The paper illustrates this position by extrapolating possibilities within the context of a subset of machine mediated listening, specifically cochlear implant based listening. It proceeds by speculating how auditory displays that rely on temporal perception may produce shared associations in auditory imagery, and a meeting ground for unaided listening and cochlear implant based listening in the social acoustic world. Building upon previous work by scholars who originally conceptualized the notion of auraldiversity, the paper identifies a list of creative propositions to serve as a guide to shape outcomes and participatory modes of engagement using sonic arts practices. These include methods from sound art practitioners that have creatively dealt with affordances of sound to question normative listening, explore new aesthetics of sound, and blend collaborative processes with cognitive aspects of social listening through a collective elicitation of auditory imagery. By diversifying the process of designing auditory displays, we can challenge and contrast traditional models of testing for the 'ideal' ear, to re-route auditory display research and design towards embracing hearing diversity. The paper invites the reader and the wider auditory display community to frame more such opportunities to adopt participatory methodologies for designing sonification for aural diversity.

1. INTRODUCTION

1.1. Sonification catering to a spectrum of diverse hearing abilities

Some researchers have been trying to understand how the auditory display community fills an inter-disciplinary niche around a common interest in sound, while operating in an increasingly visually dominant culture. These studies have noted that auditory display researchers highlight the efficacy of sonification, by pointing out the often overlooked but unique perceptual and discriminatory characteristics of auditory perception [1]. But what pair ears are assumed to possess these unique perceptual qualities? This is a question that has vexed many researchers in sound studies ever since the proclamation of the 'primacy of the ear' by Pierre Schaeffer [2]. Indeed, the assumed pair of ears across most disciplines related to acoustics, from engineering and sound studies to hearing science, has been the 'normal' set of ears that correspond to a predetermined audiometric norm of young adults. In reality, not only do two persons never have the same hearing characteristics, but what we hear also depends on a variety of external factors such as the environment that surrounds us, context of conversation, as well as age, gender and other social factors [3]. Further, various hearing differences involving sensorineural hearing effects, as well as hyperacusis (an increased sensitivity to sound) constitute a spectrum of aural divergences and associated auditory imagery typical to these conditions of listening. Composer, Andrew Hugill, refers to the diverse hearing capacities of a variety of listeners, and multitude of affordances provided by our surrounding acoustic environment to constitute a vast fabric of 'aural diversity' [3, 4]. Hugill observes as a music composer, how aural imagination and access to auditory imagery continues to enable a possible route to communicate an internal acoustic world to the social acoustic world of others (or an audience) to navigate aural diversity [2]. This paper proceeds with this understanding that a shared understanding of the diversity of auditory imagery thus serves as a meeting place where points of articulating different hearing experiences can occur.

1.2. Implant listening in aural diversity

The concept of auraldiversity includes non-human audition by listeners across species and even hearing machines, like hearing aids and cochlear implants, that listen to the world in unique ways [2]. The position of cochlear implant based listening is particularly unique, in the sense that it is the only known neural interface that bridges the social acoustic world with sensorineural signals in the brain of the listener. It is also a highly debated technology, as on one hand, Deaf Culture scholars and activists, warn that it could bring about the end to sign language use, while others posit a 'deaf futurism', where the implant heralds the coming of a new era of human machine cognitive interfaces that places implant listeners at the vanguard of this transformation [5]. While all the nuances and politics of identity formation and technocultures around cochlear implant listening is not within the scope of this paper, what is interesting is that the implant listener, to whom auditory displays were not thought to matter to before implantation, is now attempting to attune to the sonification of everyday life. Similar to how 'hearing' and 'not hearing' binaries were challenged using creative sound arts practice that used infrasonic (< 20 Hz) frequencies to elicit universally perceivable tactile sensations to sound [6], experiencing auditory displays that work on the shared perceptual capacities of implant listening are bound to create fruitful conversations regarding shared auditory imagery and accessibility.

1.3. Designing beyond the normative listener

A general assumption in psychoacoustic studies, including the design and evaluation of auditory displays, is an assumption of otologically normal listeners with a balanced set of 'healthy' ears as defined by the International Standards Association [7]. The sensory exclusion of 'abnormal' hearing participants from psychoacoustic evaluations of sonification designs, has led to a widening mismatch between the designed acoustic world and its interaction with diverse listeners. Technologies of sonification, that include the synthesis of sound, as well its reproduction and analysis, owe their existence to the otological institution, which, abetting the dominant medical model of hearing, was convinced that measuring, segregating and normalizing hearing perception must be the zeal of a developed society [8]. Persons with and without hearing loss, partook in mass audiological examinations, and those with hearing loss collaborated in extensive visual speech experiments [9]. The subsequent cross purpose collaborations between scientific and medical institutions, resulted in the invention of visual forms of spectrum representation, namely the spectrograph and eventually the vocoder (voice decoder), that apart from being a quintessential part of telephony and encrypted wartime communication, was also central to the design of the cochlear implant's speech processor [10].

This article takes the position that the path forwards towards aural diversity, especially a diversity mediated by techniques and technologies of sound synthesis and auditory perception, must not only take into account different hearing abilities but must also conceive of radically different methods of engaging listeners into the design and co-evaluation of auditory displays. Aiding this extrapolation, the creative propositions set forth in the work of John Levack Drever, provide the basis for conceiving aurally diverse methodologies for engaging listeners [2]. Specifically, the creative propositions by Drever taken forward in this paper include :

- Firstly, to embrace our own auraldiversity and empathetically that of others, for that is what our auditory experience is predicated on and that is our auditive commonality with others.
- Next, to identify, problematize and challenge auraltypical archetypes in our acoustic practice.
- And finally, devise new first person and/or co-composed work that celebrates (and does not deny) the varied spectra of hearing offered by humanity [2].

The paper proceeds to translate these creative propositions as a scaffolding to support its call to design new methods of engaging diverse listeners, that include cochlear implant listeners to explore possibilities of shared associations with auditory imagery.

2. COCHLEAR IMPLANTS AND THE SOCIAL ACOUSTIC WORLD

2.1. The Vocoder and its lasting influence

The set of diverse listeners comprising the assemblage of aural diversity, extends beyond cross-species hearing to include machine based hearing, as machines also hear in ways differently to humans [3]. Listeners of cochlear implants undergo a process of acclimatizing themselves to a new auditory aesthetic mediated by the cochlear implant. In what is essentially a human machine interface that enables customization of signal processing parameters, the cochlear implant becomes a real-time soundscape arrangement, attuned chiefly to speech perception [11]. Cochlear implantation is in itself part of a longer techno-cultural trajectory, seeking to 'normalize' deafness through the 'gift' of speech based communication with the hearing world. Particularly, the invention of the vocoder and its lasting influence on the cochlear implant, is integrally connected to the socio-technical factors that burgeoned its existence, innovation and deployment. The socio-cultural factors scripted into the operation of the vocoder consisted of notions surrounding the normalization of hearing disability, namely, privileging speech perception and verbal communication over all other environmental sounds, music and other non-speech sound perception [12]. Telecom engineers continued the trajectory of prioritizing speech processing, encountering success if their automatic speech recognition models were evaluated in ideal conditions, where the perception of speech was unencumbered by the presence of other non-speech confounds like environmental sounds and music [10]. The historical emphasis placed on speech and speaking as purported by the medical model of disability, continues to dominate auditory rehabilitation, and has put other contexts like music and melody perception to the back seat. Therefore, it is no coincidence that listeners of cochlear implants face various constraints in the perception of the non-speech acoustic world.

Cochlear implants are not attuned to perceive non-speech acoustical sounds like music and environmental sounds. These include everyday sonifications like commonly encountered ringtones, earcons, notifications of domestic appliances and other auditory icons. The constraints of the cochlear implant are due to the limitations of a component that is central to its working, the vocoder (or voice encoder). These limitations of the vocoder translate into perceptual limitations faced by listeners of cochlear implants. The main limitation is the lack of pitch perception due to no representation of temporal fine structure in acoustic processing by the vocoder. Further, there is no perception of timbre conveyed by cochlear implants, which is needed for identifying a sound source. This could often lead to confusing one sound event from another. For instance, cochlear implant listeners often confuse the sounds of a dog barking with a car horn [13]. Further, the design of the cochlear implant interface has excluded the needs and voices of the very listeners it was designed for. Instead, the design delegates the act of individual customization to the audiologist, further disempowering listeners by transferring control of their own acoustic parameters to the medical industrial complex, regulated by audiologists and biomedical engineers.

In summary, the following are limitations that the cochlear implant vocoder imposes on the interaction of implant listeners with the social acoustic world. These limitations are listed as enabling and disabling features of the vocoder, rather than attributing it to the inherent capacities of the listener:

- Black-boxed hearing technologies are enabled and listener-customizable interfaces are disabled.
- A privilege over speech is enabled and perception of all other environmental sounds, music and other non-speech sounds is disabled.
- Quiet listening conditions are enabled over noisy and naturalistic environments.
- Perceptions of commonly encountered, pitch, timbre and melody based sound designs like critical alarms and notifications are disabled.
- Augmenting or modifying the design of core components of hearing technologies is disabled.

2.2. Bridging the gap using auditory displays for environmental sound awareness

The limitations of the cochlear implant vocoder translate to a limited perceptual capacity for a range of non-speech sounds in the daily world. For instance, implant listeners have expressed the need for knowledge of novel acoustic sounds encountered outside of the home as it was too diverse for them to perceive without assistance from a fellow co-worker, member of the public or a trained hearing assistant dog [14]. Listeners reported several situations like running or driving outside home, where they wanted a keener sense of environmental sound awareness to detect other cars honking, bicycles approaching from behind them or dogs barking [14]. A review of discussions by the author in a cochlear implant forum maintained by listeners of an anonymized cochlear implant manufacturer, has revealed the need for various domestic alerting systems as well as limitations of existing ones. Some commercially available systems include Safe Awake, which combines a strobe light and bed shaker in one bedside device. The Home-Aware Master signaling strobe and bed shaker system can be integrated with a wide variety of interfaces like smoke detectors, fire alarms, doorbell systems, and mobile phones. Many implant listeners lived with trained 'hearing dogs' that provided assistance by barking or nudging the implant listener when somebody visits their home or rings their doorbell. A recent study involving implant listeners found that environmental sound cues related to social interaction (such as a doorbell or the presence of others) as well as early warning events (such as fire alarms, microwave oven) were considered extremely important to be perceivable [15]. Aided listeners are also early adopters of modern speech-based technologies like conversational assistants. These devices primarily communicate with their listeners using speech recognition for understanding a speaker's query, and respond using speech synthesis modules that verbally communicate results or suggestions to the listener. Research into the interaction between hearing aid and implant listeners and speech synthesis technologies like conversational agents, has revealed the need for being able to modify the formant characteristics of the conversational agent's voice to be comfortably compatible with a implant's or hearing aid's signal processing characteristics [16].

2.3. Leveraging temporal cues for designing cochlear implant compatible auditory displays

Although the vocoder does not provide any discrimination of pitch, temporal aspects of the acoustic world are still represented, as cochlear implants still provide its listeners with fairly robust temporal information and rhythmic cues. Recent research has revealed that implant listeners as well as unaided listeners are able to keep accurate time using bodily movements to drum sounds in percussive and rhythmic music, thereby displaying entrainment to musical beat [17]. Cochlear implant listeners were found to even surpass unaided listeners in tempo discrimination and complex rhythm discrimination tasks [18]. Other studies have found that cochlear implant listeners perform well in tasks that depend on rhythmic perception [19], and along with unaided listeners, scored high in tests measuring the temporal aspects of music that include rhythm and meter [20]. Cochlear implant listeners have been able to use purely temporal changes to encode pitch information as well as discriminate between melodies in experiments involving single electrode stimulation that vary pulse rates to values lower than 300 pulses per second [21]. Given the affordance for designing auditory displays that take into account temporal perceptual capacities of cochlear implant listeners, brings us back to the positional question forwarded by this paper. That designing auditory displays must not only take into account different hearing abilities but must also conceive of significantly different methods for collectively engaging with diverse forms and modalities of listeners, in this case, by developing shared associations with temporal auditory imagery. Revisiting the first of the three creative propositions towards auraldiversity provided by Drever, that is, the need to embrace our own auraldiversity and empathetically that of others, we might consider that a unifying impetus that could bring the sonification community closer to aided listeners is through a shared acknowledgement. Specifically, this involves the acknowledgement of the fact that the normalizing agenda of clinical models of hearing diagnosis were driven by a movement that prioritized speech above all other sounds. This outset, strangely, also provides a probable reason to the auditory display community, as to why sonification has been rendered a backseat in our daily interaction with technology, and the most widespread use of sonification continues to remain speech based conversational agents. Addressing the second creative proposition, involves identifying and challenging auraltypical archetypes in the practice of auditory display design within the context of designing accessible sonification for cochlear implant listeners. This re-configuration of the compatibility of cochlear implants with the social acoustic world should necessitate a re-consideration of the socio-cultural configuration within which it originated and continues to operate. The question before us is then, while responding to the need for developing sonification that is compatible with the perceptual capacities of cochlear implants, if there are alternate ways to co-design sonification outside of the traditional experimenter-subject model? And finally the third creative proposition of Drever directs us to devise novel first person and/or co-composed work that celebrates and does not deny the varied spectra of opportunities to hear that humanity offers. The subsequent section of the paper contributes to framework and methods that promote inclusive and aurally diverse practices by referring to sonic arts practitioners and acoustic designers who have considered a similar context of interaction.

3. AURALDIVERSITY THROUGH A SHARED UNDERSTANDING OF TEMPORAL AUDITORY IMAGERY

Rephrasing Drever's creative propositions [2] into an actionable strategy for designing auditory displays compatible with the perceptual capacities of cochlear implants, would involve defining the objectives for engaging in co-creation, co-composition and co-perception of temporal qualities of auditory perception. These could be envisioned as objectives to:

- Elicit perception of environmental sounds, music and other non-speech sounds and allow for a shared understanding of such auditory imagery across diverse listeners.
- Experiment collectively with alternate aesthetics and manipulation of characteristics of the noise vocoder.
- Enable the design of sonification experiences in naturalistic listening conditions as opposed to controlled environments.
- Look for opportunities to co-design in the temporal domain, enhancing perception of rhythm and time.
- Make the design and evaluation process respond to diverse sensory capacities of listening, be participatory, or community based and be conducted in social acoustic scenarios, outside the confines of a clinical environment.

The following sections suggest some methodologies inspired from both practitioners in sound art and music, that take into account participatory and cognitive aspects of sound as a social process in shared listening spaces. The methods are chosen for their relevance in questioning normative listening, signifying temporal perception for cochlear implant based listening, and enabling the sharing of auditory imagery and experience through conversation and other modes of multimodal interaction. Readers are encouraged to treat these as suggestions or catalysts towards a broader consideration of aurally diverse design methodologies.
The topic of listening diversity and hearing 'loss', has indeed been addressed by various sound artists and performers who have thought of listening as a social practice. The works referenced in this section demonstrate a range of aesthetic experiences for listening differently. These experiences forge novel ways of engaging participants with the act of hearing, themselves and with each other using frameworks that are both sensorial and technologically mediated. Unifying factors across these listening experiences are an emphasis on the experience of non-tonal modalities like rhythm and vibration, and a social engagement that is centered around a collective elicitation of temporal auditory imagery.

3.1. Challenging norms: re-thinking auditory display design through artistic practices

A sound art work that specifically addresses hearing loss and hearing diversity, is the installation 'Tonotopia' (2018) by artist and composer Tom Tlalim, that was curated at the Victoria and Albert Museum in London. The exhibition engaged visitors with the topic of hearing diversity by presenting multi-modal screens and sonic experiences that shared interviews, sounds, and objects that Tlalim sourced from cochlear implant listeners. One of the interactive experiences in 'Tonotopia', relevant to this paper, is an immersive listening shell sculpture where visitors enter and sense abstract vibrating textures. The sculpture featured a noise cancellation micro-environment with bilateral speakers that presented rhythmic variations, to combine unrecognizable sounds in particular temporal patterns [22]. The short documentation of the composition of sounds can be accessed in the hyperlink here. Tlalim remarks on how the specific sound was designed to enable people with varied hearing and listening capacities to enjoy sound in different ways. Tlalim suggests that music can be enjoyed in many ways beyond prescriptive tonality, and he opens up an artistic space for both aided and unaided listeners to share a common space for hearing differently. Tlatlim's work is generally concerned with sensory experience and sensory outreach, and its interconnection with new hybrid technologies. He explains:

> As health services, biomedical industries, scientific research bodies and tech companies compete for access to the new goldmine of the body, new legal and ethical questions are emerging on what constitutes subjectivity, agency, and intelligence within the hybrid continuum of the human-non-human apparatus.

[22] In an attempt to shape artistic experiences to be accessible and enjoyed by diverse listeners, the project asks several pertinent questions like what is deemed as normative or natural listening and who decides what these factors and parameters should be? How are technologies of listening empowering or disavowing the deaf, and what forms of subjectivity emerge from the increase in embodied integration and hybridization of humans and technology? These questions point to relevant concerns over technologically extended hearing, and multi-modal and multi-perceptual access to information about the sonic world.
Another series of sound artwork are the technical explorations of vocoder-based technologies by the artist Alvin Lucier. Lucier is well known in the sound art world for his work in the mid-1960s that involved technical mediation of sonic environments and acoustic spaces, to produce sounds that are never encountered in ordinary circumstances. Lucier was one of the first sound artists to experiment with the limitations and artifacts of the vocoder in his 1967 piece titled 'The North American Time Capsule'. Experimenting with the 'other wordly' artifacts of the speech vocoder, this piece is metaphorically described by Lucier, "as a message to listeners who don't know about us" [23]. In this piece, sounds produced by the Brandeis University Chamber Chorus using speech, musical instruments, and sonorous objects were modified using the vocoder into an abstract sound and texture [24]. The listening characteristics of the vocoder were modified by Lucier, to liquidate speech and to abolish the identity of the speaking subject, shattering all syntax, and transforming every phoneme into fluid sonic matter [24]. Yet another piece by Alan Lucier, 'I am sitting in a room (1969)' dealt with the physical aspects of sound and its interaction with acoustic spaces. This piece features the artist's voice reading a text, which is replayed and re-recorded until the original audio loses its distinctive individuality, then fades from recognition as a human voice towards a rich tonal and rhythmic experience [25]. The full text of the piece is the following:

> I am sitting in a room different from the one you are in now. I am recording the sound of my speaking voice and I am going to play it back into the room again and again until the resonant frequencies of the room reinforce themselves so that any semblance of my speech, with perhaps the exception of rhythm, is destroyed. What you will hear, then, are the natural resonant frequencies of the room articulated by speech. I regard this activity not so much as a demonstration of a physical fact, but more as a way to smooth out any irregularities my speech might have. [26]

Lucier noted that rhythm was probably the quality of sound that would remain perceivable, even in the absence of any other identifiable characteristic of his speech. Indeed, once the voice has become audible frequencies, around minute 10:00 into the sound piece, the emerging sounds lack association with pitch, and instead transmits a multitude of rhythmic sensations. These rhythms have some variation in volume due to the echoing of frequencies in space, in relation to the location of the recording device. This piece, which lasts approximately forty-five minutes, is an example of a technological breaking into the interrelation between the person, technology, and space, making room for the creation of a new aesthetic of sound that embraces emergent temporal qualities, which are immediately perceivable by cochlear implant listeners. This fact was further ascertained in work involving experimental musicians and scientists who collaborated to create music specifically designed for cochlear implant listeners. One such project titled, 'New music for the bionic ear', featured a concert and qualitative feedback collected from the audience about their enjoyment of music. Their findings also called for opportunities to use such temporally enhanced timbral variations to augment musical perception for cochlear implant listeners as well as unaided listeners [27]. The performative aspects of sound art, hardware and computer based parametric synthesis hold the potential for the development of a shared aesthetic between aided and unaided listeners, by creating dialogue and conversations about normative hearing.

3.2. Participatory sense-making for building shared understanding of aural diversity

Sense-making as a general concept refers to meaning making through sensory interaction with the external world. Participatory sense-making as a methodology, extends sense-making into a collaborative and coordinated framework involving multiple individuals coming together to use their past experiences to embody new collective experience and make meaning [28]. Prior to the work described in this paper, participatory sense-making has been used as a methodology in collaborative contexts in social science, and other contexts that require negotiating sensory diversity, for instance in social and clinical interventions with autistic individuals [29, 30]. The concept of participatory sense-making was introduced as an extension of the concept of enactive sense-making into the domain of social interaction [28]. Here, enactive sense-making refers to cognition as an embodied, ongoing, and situated activity of meaning-making from a dynamic of relations [31, 32]. When enacted as a social relation between individuals, participatory sense-making becomes a dynamic and ongoing process of social understanding where, "sense-making of interactors acquires a coherence through their interaction and not just in their physical manifestation, but also in their significance" [28, p. 497]. The scope of coordinated interaction between individuals extends beyond the physical, to also include the coordination of intentional activity in the planned interaction [33]. One of the objectives of an encounter based on methodology of participatory sense-making is shared-sense making using tools like conversation.
Previous studies incorporating participatory sense making, for instance, with a group of children with diverse abilities, has similarly observed how participants, used their past experiences to embody current experiences and meaning making [34]. Each individual gains a perspective that in-turn translates to how the group sees the world. Consequently, new facets of social sense-making are created, resulting in collective meanings and realizations that were not available to individuals alone. Within the framework of participatory sense-making as a methodology, social interaction between participants can range from brief and superficial encounters to something more deep and sustained. Interactions can be staged using verbal and conversational interactions as tools of sharing sense-making [28]. These interactions might often include verbal descriptions of auditory imagery and its associations. Attempts to understand how temporal information is encoded into auditory imagery has resulted in several researchers pointing towards a ubiquitous temporal image formation, often with cross-modal references as seen in motored finger-tapping to keep time with both perceived music as well as imagined melodies [35]. Incorporating participatory sense-making within the context of temporal based sonification would allow access to a shared understanding of auditory imagery, especially when the sense-making is mediated by implant listeners themselves. Interaction between participants at an affective level may lead to a change in perspective or an emergence of a shared understanding depending on how the interaction is designed. More recent work has explored interaction between musicians as a form of "participatory sense-making" [36]. Such projects have explored participatory sense-making in joint musical practice, and posit that the way in which musicians play together may be best understood as 'mutual incorporation' [36]. Here sense-making is always participatory in nature, "because both the object and the dynamical process shaping it are possible only through the systematic and recursive influence of each individual on another [36]. Within the context of co-designing auditory displays with implant listeners, participatory sense-making through collaborative music making could be one way in which a shared aesthetic of sound could emerge from the complex dynamics that entail the improvisational process of music creation, along with the dialogic and participatory nature of music in interaction [36].

3.3. Embodied perception and sonic awareness through participatory listening

This section reviews the work of Pauline Oliveros, American composer, accordionist and important figure in the development of post-war experimental and electronic music. Pauline Oliveros is credited with her coinage of the phrase 'deep listening', that refers to a state of registering sonic awareness to the multitude of sound sources that one encounters at any given instant in time. Sonic awareness is a concept that Oliveros began to experiment with in the early 1970s through the design of her project Sonic Meditations. The methodology used in this project starts with individual sonic awareness, and includes a participatory listening framework within the context of collaborative sound and music making. The diagram below represents a fourfold procedure of hearing sound, which Oliveros treated as a framework of possibilities for listening based awareness [37]. Sonic awareness works in two registers: 'Focal' and 'Global' [37]. By tuning attention to different modalities of internalizing and externalizing sound, each listening session produces a specific tuning that yields some predictable musical results, and leads to collective realizations and awareness of diversity in the sonic world. According to Oliveros, the use of focal and global attention intend to create a parallel and continuous process of receiving stimuli (from present moment or from memory) and performing an action (either through imagination or actively making sound). For instance, one of the exercises involves focal attention to mental image of each performer, and global attention of singing a tone to that person. Listening sessions that involve some form of rhythm or tempo pose the challenge of consistency and sustainment over time. In her work with percussionists, Oliveros would prompt them to imagine the sound of their instrument, its rate, intensity and quality of a single stroke, and to allow the ac-

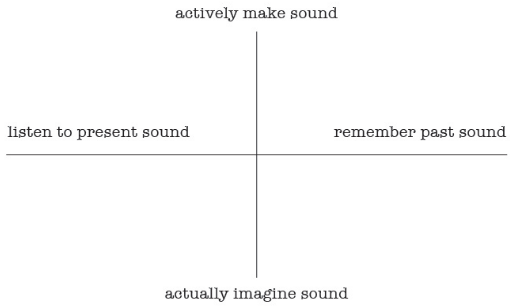

Figure 1: Olivero's fourfold procedure of hearing sound. Adapted from [37]

tual roll to begin involuntarily as a result of imagining it. The task was to keep the actual roll matching the original imaginary roll for the duration of the performance [37]. Through this technique, Oliveros exploits the relationship between rhythm and embodied perception, bringing mental auditory imagery as a stimuli for the creation of sustained temporal signatures. Each listening session involves a variation of multimodal stimuli toying with the possibilities in the fourfold diagram above. Oliveros created a score for each listening session that she called a 'Sonic meditation', as well as a set of instructions, which she perfected over time. One of her meditations had the instruction, "Take a walk at night. Walk so silently that the bottoms of your feet become ears", directly referring to the body's tactile capacity to perceive auditory stimuli as vibration. And yet, in a participatory exercise, while the sense of vibration is shared it is not identical across individuals, and , "even within 'one' individual, sense ratios and relations may shift and mix synesthetically. Phenomenologies of vibration are not singular [5]. This uniqueness of acoustic perception is even more significant with implant listeners, whose, "musical perception rooted in hearing depend on the capacities and limits of the prosthetic device, the compatibility between device and listener, and the unique musical preferences of the listener [38].

4. CONCLUSION

This paper has argued for a paradigm shift in auditory display design, moving from a singular focus on 'normal' hearing to embracing the rich tapestry of aural diversity. Apart from taking into account diverse hearing abilities, designing auditory displays must also conceive of new participatory encounters to engage listeners in a collective engagement with shared associations of auditory imagery in relation to the social acoustic world. Cochlear implant listeners are identified as a specific example of a group with unique temporal auditory perceptual capacities that are often overlooked in traditional auditory display design practice. Consequently, trans-disciplinary methods from participatory sonic art practices with an emphasis on temporal perception are discussed with the objective of creating meeting points within shared perceptual capacities of unaided listeners and implant listeners. The paper extends upon three, previously proposed creative propositions for fostering aural diversity in design practices [2]: embracing our own aural diversity, challenging auraltypical archetypes, and co-creating experiences that celebrate the varied spectra of human hearing. These tenets were re-synthesized into specific design objectives linked to artistic practices that presented aurally diverse ways of engaging with temporal auditory perception.

The artistic examples presented in this paper directly respond to John Drever's creative propositions. The installation 'Tonotopia' by Tom Tlalim exemplifies the first proposition, fostering empathy for diverse listening experiences by presenting unfamiliar and abstract rhythmic textures for exploration. Alvin Lucier's work with vocoders embodies the second proposition, questioning the dominance of speech-based listening and revealing the rich aesthetic potential of manipulating temporal qualities of sound. These artistic interventions also demonstrate the power of co-creation and shared exploration of sound, aligning with Drever's third proposition. Furthermore, the work of Pauline Oliveros in sonic meditation and deep listening practices offers a valuable methodological contribution that relates to Drever's creative propositions. Oliveros' techniques encourage active listening and exploration of sound in all its forms, fostering a deeper appreciation for aural diversity. This aligns with the concept of participatory sense-making, where individuals with diverse hearing experiences come together to co-create soundscapes and share their unique auditory perspectives.

A key element that cuts across all the methodologies discussed in this paper is the role of auditory imagery. Regardless of the type of hearing, everyone possesses the ability to generate, imagine, or perceive sounds within their mind. In cases where auditory imagery or associations to previously heard sounds may not be possible, imagery might take the form other modalities, like tactility that resonates with the vibrational aspects of sound. This internal soundscape, unique to each individual, offers a rich source of inspiration for creating and training using auditory displays that resonate with a wider range of listeners. Conversation and open dialogue about these internal auditory experiences become a central part of any aurally diverse agenda of interaction. By fostering a space for sharing and understanding these diverse soundscapes, auditory display designers and listeners can work together to create meaningful auditory experiences. Disciplinary challenges do exist and the field of auditory imagery lost traction within the auditory community in the 1980s, as documented by Daniel Reisberg in a most complete compilation [39]. This was primarily due to the disagreement between musicians and psychologists, on a shared understanding of perceived pitch and its cognitive representation. Fortunately, interest in the field of auditory imagery has re-emerged, giving the auditory display community to consider auraldiverse encounters through which diverse imagery can be understood and related to by communities of diverse listeners.

Finally, this paper posits that the journey towards aural diversity necessitates a trans-disciplinary approach. The insights from artistic practices, offer valuable inspiration for challenging established norms and co-creating experiences that celebrate the full spectrum of human hearing. Methodologies like participatory sense-making provide a framework for fostering open dialogue and shared exploration of the internal soundscapes that each individual possesses. By embracing these trans-disciplinary approaches, the field of auditory display design can move beyond the limitations of the past and create auraldiverse futures by bringing into conversations, listeners of cochlear implants and other hearing technologies. Further research is needed to explore how Drever's propositions can be translated into practical auditory display design principles and how participatory design workshops can be structured to leverage the strengths of diverse listening experiences. This collaborative effort holds the promise of an aurally diverse social acoustic soundscape for all.

5. REFERENCES

[1] A. Supper, "Lobbying for the ear, listening with the whole body: the anti-visual culture of sonification," *Sound Studies*, vol. 2, no. 1, pp. 69–80, 2016.

[2] J. L. Drever, "'primacy of the ear'–but whose ear?: The case for auraldiversity in sonic arts practice and discourse," *Organised Sound*, vol. 24, no. 1, pp. 85–95, 2019.

[3] A. Hugill, "Aural diversity: noise control and a sustainable future." in *INTER-NOISE and NOISE-CON Congress and Conference Proceedings*, vol. 265, no. 6. Institute of Noise Control Engineering, 2023, pp. 1610–1614.

[4] J. L. Drever and A. Hugill, "Aural diversity: General introduction," in *Aural Diversity*. Routledge, 2022, pp. 1–12.

[5] M. Friedner and S. Helmreich, "Sound studies meets deaf studies," *The Senses and Society*, vol. 7, no. 1, pp. 72–86, 2012.

[6] E. P. Fowler, "A method for the early detection of otosclerosis: A study of sounds well above threshold," *Archives of otolaryngology*, vol. 24, no. 6, pp. 731–741, 1936.

[7] U. Berlin, "Normal equal-loudness level contours-iso 226: 2003 acoustics international organization for standardization (iso)."

[8] L. J. Davis, *Enforcing normalcy: Disability, deafness, and the body*. Verso, 1995.

[9] M. Mills, "Deafening: Noise and the engineering of communication in the telephone system," *Grey Room*, no. 43, pp. 118–143, 2011.

[10] X. Li and M. Mills, "Vocal features: from voice identification to speech recognition by machine," *Technology and Culture*, vol. 60, no. 2, pp. 129–160, 2019.

[11] M. Kytö, "Soundscapes of code: Cochlear implant as soundscape arranger," in *Aural Diversity*. Routledge, 2022, pp. 73–81.

[12] M. Mills, "Do signals have politics? inscribing abilities in cochlear implants," 2011.

[13] C. M. Reed and L. A. Delhorne, "Reception of environmental sounds through cochlear implants," *Ear and Hearing*, vol. 26, no. 1, pp. 48–61, 2005.

[14] T. Matthews, J. Fong, F. W.-L. Ho-Ching, and J. Mankoff, "Evaluating non-speech sound visualizations for the deaf," *Behaviour & Information Technology*, vol. 25, no. 4, pp. 333–351, 2006.

[15] L. Findlater, B. Chinh, D. Jain, J. Froehlich, R. Kushalnagar, and A. C. Lin, "Deaf and hard-of-hearing individuals' preferences for wearable and mobile sound awareness technologies," in *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, 2019, pp. 1–13.

[16] J. Blair and S. Abdullah, "It didn't sound good with my cochlear implants: Understanding the challenges of using smart assistants for deaf and hard of hearing users," *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, vol. 4, no. 4, pp. 1–27, 2020.

[17] J. Phillips-Silver, P. Toiviainen, N. Gosselin, C. Turgeon, F. Lepore, and I. Peretz, "Cochlear implant users move in time to the beat of drum music," *Hearing Research*, vol. 321, pp. 25–34, 2015.

[18] Y.-Y. Kong, R. Cruz, J. A. Jones, and F.-G. Zeng, "Music perception with temporal cues in acoustic and electric hearing," *Ear and Hearing*, vol. 25, no. 2, pp. 173–185, 2004.

[19] K. Gfeller, C. Olszewski, M. Rychener, K. Sena, J. F. Knutson, S. Witt, and B. Macpherson, "Recognition of "real-world" musical excerpts by cochlear implant recipients and normal-hearing adults," *Ear and Hearing*, vol. 26, no. 3, pp. 237–250, 2005.

[20] W. B. Cooper, E. Tobey, and P. C. Loizou, "Music perception by cochlear implant and normal hearing listeners as measured by the montreal battery for evaluation of amusia," *Ear and Hearing*, vol. 29, no. 4, p. 618, 2008.

[21] H. J. McDermott and C. M. McKay, "Musical pitch perception with electrical stimulation of the cochlea," *The Journal of the Acoustical Society of America*, vol. 101, no. 3, pp. 1622–1631, 1997.

[22] T. Tlalim, "Tonotopia," https://www.arshake.com/en/interview-tom-tlalim-2, 2005, accessed on May 5, 2023.

[23] L. Alvin, "Alvin lucier: Vespers and other early works," 2023, accessed on May 31, 2023. [Online]. Available: https://www.newworldrecords.org/products/alvin-lucier-vespers-and-other-early-works

[24] C. Cox, "The alien's voice: Alvin lucier's north american time capsule en mainframe experimentalism," 2009.

[25] E. Strickland, *Minimalism: origins*. Indiana University Press, 2000.

[26] N. Collins, "Album notes alvin lucier," https://web.archive.org/web/20170818075049/http://www.lovely.com/albumnotes/notes1013.html, 1990, accessed on May 31, 2023.

[27] H. Innes-Brown, A. Au, C. Stevens, E. Schubert, and J. Marozeau, "New music for the bionic ear: An assessment of the enjoyment of six new works composed for cochlear implant recipients," in *12th International Conference on Music Perception and Cognition (ICMPC) 8th Triennial Conference of the European Society for the Cognitive Sciences of Music (ESCOM)*, 2012.

[28] H. De Jaegher and E. Di Paolo, "Participatory sense-making: An enactive approach to social cognition," *Phenomenology and the Cognitive Sciences*, vol. 6, pp. 485–507, 2007.

[29] C. Hermans, "Let's dance: Participatory sense-making in an eight-year-old boy with autism," *Journal of Dance Education*, vol. 19, no. 1, pp. 23–33, 2019.

[30] H. De Jaegher, "Seeing and inviting participation in autistic interactions," *Transcultural Psychiatry*, 2021.

[31] E. Rosch, L. Thompson, and F. J. Varela, "The embodied mind: Cognitive science and human experience," 1991.

[32] T. Fuchs and H. De Jaegher, "Enactive intersubjectivity: Participatory sense-making and mutual incorporation," *Phenomenology and the Cognitive Sciences*, vol. 8, pp. 465–486, 2009.

[33] D. F. Moores, "Partners in progress: The 21st international congress on education of the deaf and the repudiation of the 1880 congress of milan," *American Annals of the Deaf*, vol. 155, no. 3, pp. 309–310, 2010.

[34] S. Agostine, K. Erickson, and C. D'Ardenne, "Sensory experiences and children with severe disabilities: Impacts on learning," *Frontiers in Psychology*, vol. 13, p. 875085, 2022.

[35] B. H. Repp, "Effects of music perception and imagery on sensorimotor synchronization with complex timing patterns," *Annals of the New York Academy of Sciences*, vol. 930, no. 1, pp. 409–411, 2001.

[36] A. Schiavio and H. De Jaegher, "Participatory sense-making in joint musical practices," *The Routledge companion to Embodied Music Interaction*, pp. 31–39, 2017.

[37] H. Von Gunden, *The Music of Pauline Oliveros*. Metuchen, NJ: Scarecrow Press, 1983.

[38] M. Chorost, "Helping the deaf hear music," 2008.

[39] D. Reisberg, *Auditory Imagery*. Psychology Press, 2014.