How people who are deaf, Deaf, and hard of hearing use technology in creative sound activities

Keita Ohshiro
ko89@njit.edu
New Jersey Institute of Technology
Newark, New Jersey, USA

Mark Cartwright
mark.cartwright@njit.edu
New Jersey Institute of Technology
Newark, New Jersey, USA

ABSTRACT

Creative sound activities, such as music playing and audio engineering, are said to have been democratized with the development of technology. Yet, the use of technology in creative sound activities by people who are deaf, Deaf, and hard of hearing (DHH) has been underexplored by the research community. To address this gap, we conducted an online survey with 50 DHH participants to understand their use of technology and barriers they face in their creative sound activities. We find DHH people use four types of technology — hearing devices, sound manipulation, sound visualization, and speech-to-text — for three purposes — to improve sound perception via auditory and visual means, to avoid hearing fatigue, and to better communicate with hearing people. We also find their barriers to technology: unknown availability, limited options, and limitations that technology can solve. We discuss opportunities for more inclusive design specific to DHH people's creative sound activities, as well as facilitating access to information about technology.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in accessibility**.

KEYWORDS

accessibility, deaf, Deaf, hard of hearing, audio engineering, music

ACM Reference Format:
Keita Ohshiro and Mark Cartwright. 2022. How people who are deaf, Deaf, and hard of hearing use technology in creative sound activities. In *The 24th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '22), October 23–26, 2022, Athens, Greece.* ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3517428.3550396

1 INTRODUCTION

It is said that creative sound activities, such as music playing and audio engineering, have been democratized with the development of technology [13, 25]. Nowadays, these activities are not only limited to professionals working with high-end studio equipment but also opened to amateurs and novices using personal computers and audio production software called Digital Audio Workstations (DAWs) [29]. Those who engage in creative sound activities enjoy performing, producing, and distributing their works in audio-related fields including music, film, TV, radio, and podcasting [23].

However, they have not been democratized for all in the context of accessibility and disability. With a growing interest in the accessibility of audio and sound technologies [17], we have begun to see research on creative sound activities by people with disabilities, for example, by people who are blind or have low vision [42, 44]. Yet, the research community has underexplored how people who are deaf, Deaf, and hard of hearing (DHH) [8, 26] use technology in creative sound activities. In 2021, the World Health Organization reported that more than 1.5 billion people (1 in 5 people) worldwide are affected by some degree of DHH, and they estimated that this number will increase to nearly 2.5 billion people (1 in 4 people) by 2050 [40]. Given this increasing DHH population and that creative sound activities are often primarily auditory, we feel it is important to develop an understanding of the current state of accessibility by DHH people in creative sound activities.

In this paper, we aim to understand how DHH people use technology in their creative sound activities and what barriers they may face. We present our findings from an online survey with 50 responses by DHH people who engage in creative sound activities. We conclude by discussing future research directions to make technology more available and inclusive of DHH people.

2 RELATED WORK

DHH people often have difficulty perceiving sound characteristics such as pitch, loudness, timbre, and spatial information [15, 16, 48]. Some use medical hearing devices such as hearing aids (HA) or cochlear implants (CI) to improve auditory perception, yet they can cause additional challenges such as worsening pitch perception or increasing noises [9, 14, 27, 30–32, 43]. Issues such as tinnitus, hearing fatigue, and hearing fluctuation can also affect their quality of hearing [24, 47]. To overcome these limitations of their auditory system, DHH people often rely more on other senses such as vision and touch to experience sound [46].

Prior work has offered understanding of DHH people's experiences in creative sound activities. DHH musicians utilize visual and physical cues as well as music theory to develop musical self-efficiency [18]. Social and cultural factors affect how DHH people approach their creative sound activities as being DHH [11]. Stories by DHH individuals show their unique experience in creative sound activities as being DHH [2, 10, 15, 19, 22, 48]. For example, Richard Einhorn shared how he was able to continue his professional audio engineer career after becoming deaf later in his life [15]. There also are organizations that support DHH people's creative sound activities [1, 34–37, 39]. For example, the Frequalise Project by Music

ASSETS '22, October 23–26, 2022, Athens, Greece

ACM ISBN 978-1-4503-9258-7/22/10.
https://doi.org/10.1145/3517428.3550396

and the Deaf [34] demonstrated the effectiveness of technology to provide positive music learning experience to 63 young DHH people through 26 sessions of workshops [33]. In addition, research on Accessible Digital Music Instruments (ADMI) has been exploring the design and evaluation of how technology can be used for DHH people to play music and collaborate with other DHH and hearing people [6, 17], such as Music Aid [45] and Felt Sound [7].

While this related work gives an idea of how DHH people are using technology in creative sound activities, it remains partial and sparse because it consists mainly of individual stories, the use of technology is not the primary focus, and its scope is limited to music-specific activities. Focusing on technology with a broader scope, our work extends past work to understand the current state of accessibility in creative sound activities by DHH people.

3 METHODS

We conducted an online survey targeting DHH people who engage in creative sound activities. To understand their experience with technology, we asked about their use of technology to make their activities accessible and the challenges they face in using and choosing the technology. Using snowball sampling, we recruited survey participants via individuals and online communities related to DHH, accessibility, music, and audio engineering. All participants were fluent in English and over 18 years old. The survey took approximately 20 minutes. Participation was voluntary and not compensated. The study received the New Jersey Institute of Technology IRB approval.

50 participants completed the survey (Table 1). The degree of hearing loss [12] of the participants varies from mild to profound, and the time of becoming DHH varies from birth to adulthood. Their creative sound activities largely consist of music playing and audio engineering (Table 2). Music playing includes singing and playing musical instruments. Audio engineering includes recording, editing, mixing, mastering for music, radio, film, podcast, as well as transcribing and captioning. We analyzed the survey data using a thematic analysis approach [4, 5, 28, 38].

4 FINDINGS

4.1 Use of Technology

We found participants use four types of technology — hearing devices, sound manipulation, sound visualization, and speech-to-text — and for three purposes — to better perceive sound through auditory and visual means, to avoid hearing fatigue, and to communicate with others and understand speech.

The most commonly reported technologies are hearing devices. Many use one or a combination of medical and non-medical hearing devices such as HA, Bone-Anchored HA [3], CI, headphones, earbuds, and speakers. They use hearing devices primarily to improve auditory perception. To hear more clearly, some use them together with Bluetooth, noise cancelling features, and neck loops (a loop of wire worn around the neck that transmits audio signals to hearing devices). However, the use of hearing devices can also induce hearing fatigue and physical and mental overload. Thus, some people choose not to wear HA and CI all the time because they become overwhelmed by the unwanted effects such as distortion and muffling, especially when listening to music rather than speech. For example, P12 sometimes switches from HA to bone conduction headphones to rest his ear.

Participants also commonly use sound manipulation technology to improve auditory perception. Some use equalization to boost or cut certain frequencies. P27, an advanced amateur musician, octave-shifts the pitch with an octave pedal when writing songs with his electric guitar and bass. To hear sound from their non-DHH side ear, many of the single-sided DHH participants use technology such as signal routing and mono-to-stereo conversion. Single-sided DHH audio engineers also use stereo flipping (swapping the left and right channels) to check stereo-field panning and phase cancellation.

Participants use visualizations both to better perceive sound and to avoid hearing fatigue. For example, participants who engage in audio engineering commonly reported using waveform (i.e., time-amplitude) and a few also use spectrum (i.e., frequency-amplitude) and spectrogram (i.e., time-frequency) displays. Such visualizations allow them not only to supplement their auditory perception, but also to edit sound with their eyes so that they can rest their ears. P29, a professional audio engineer for podcasts, said "*I can sometimes do edits with no headphones and a script, because I can edit sound by sight.*" For music playing, some use a tuner and metronome to visually ensure that pitch and tempo were correct. Also, P34 uses a piano roll to visually see the notes and P12 uses sound waves as a metronome to see the click sound when it was difficult to hear.

With one exception, all participants who practice audio engineering reported the use of DAWs. We assume participants who reported the use of DAWs are also familiar with some use of the technology mentioned above such as equalization and waveform / spectrum / spectrogram displays, as they are basic features in DAWs. In contrast, the use of DAWs was typically not reported by participants who only play musical instruments or sing but do not practice audio engineering.

Some participants use speech-to-text technology for communication with hearing people during their activities, such as Google's Live Transcribe [21] and Otter.ai [41]. At online meetings, they also use an auto caption feature in video conference software such as Zoom [49] and Google Hangouts [20].

No participants use the technology specialized for tactile feedback. However, P42, an electric bass player who is Deaf, reported the usefulness of tactile feedback with his instrument and amplifier. He said "*a five strings bass helps me feel the pulsating bass line to the backbeat... Musical amplifiers are the best instrument to feel the beat for me.*"

4.2 Barriers

While some participants reported their use of technology, others described barriers to technology such as unknown availability, limited options, and limited solutions that it can provide. In fact, when we asked about the technologies that make their activities more accessible, more than one-third of participants (n=19) did not specify any technologies.

Some participants reported not knowing if technology that would make their activity accessible is available in the first place. P8, an intermediate amateur musician, expressed his frustration saying "*Don't even know what's available. Ignorance.*" They feel difficulty in finding the right technology for their hearing and activities. P4,

Table 1: Participant Demographics. (Numbers in parentheses are the number of participants)

Gender	Male (26), female (19), non-binary/non-conforming (3), transgender male (2)
Age	18-24 years old (6), 25-34 (18), 35-44 (8), 45-54 (6), 55-64 (6), 65-74 (4), 75-84 (1), 85+ (1)
DHH identity	Hard of hearing (25 including three single-sided), deaf (18 including six single-sided), Deaf (4), others (3)

Table 2: Participants' Activity and Level of Experience. (beg = beginner; int = intermediate; adv = advanced)

Activity	Amateur beg	Amateur int	Amateur adv	Professional	N/A	Total
Music playing	4	12	8	14	2	40
Audio engineering	1	4	7	12	1	25

a professional musician and audio engineer, said "*I am not aware of any technology/tools developed specifically for my problem.*" Whereas, P16 expressed reluctance to try using technology: "*Since I can't hear well, I haven't even tried using most technology from a musical perspective.*"

Even when the challenge seems solvable or improvable with technology, the limited variety of products do not solve the challenges unique to each individual. P22, an advanced amateur musician and audio engineer, expressed a sense of resignation by saying "*the idea... is so niche that it's not something product designers tend to think about or cater for.*" Some wish to have more inclusive products. A few use DIY solutions specific to their hearing and activity. However, that is not a feasible solution for others who are unfamiliar with technology: "*Software is still a mystery to me.*" (P6).

Participants reported limited solutions that current technology may provide for certain tasks. P9, who became deaf after establishing his career as a professional audio engineer, said "*I can't master as well as I used to and no tool will fix that.*" P30, who started audio engineering for podcasts after becoming deaf, said "*There are definitely times when I just cannot do a specific task — creating certain kinds of sound effects or soundscapes, or I don't always catch if speech isn't as clear as it should be or if it fully 'matches' the audio from other actors, etc. It's simply not a thing I can always do.*"

With these barriers, technology still cannot ease participants' lack of confidence. P2 said "*Most of my challenges come from lack of confidence that what I am hearing is accurate.*" It also created a concern for their professional career. P48, who works as a Digital Signal Processing (DSP) engineer, said "*I feel I am held back when learning advanced DSP and filter design since I can't properly hear... (I) don't feel like I can advance super far in that field.*" To deal with the lack of confidence, many mentioned seeking hearing people's feedback as a workaround. P27 said "*I must get a second opinion. Must.*" However, the availability of hearing people is a challenge. They need to be familiar with creative sound activities to provide valid feedback. Scheduling them is also not easy. Otherwise, participants had to rely on guessing. P48 said "*I'm always second guessing my ears*". P16 said "*(I'm) trusting it sounds ok... I have no idea how I actually sound.*"

5 DISCUSSION

Our study found participants' current use of technology and the barriers they face in creative sound activities. Aside from HA/CI, most of the technology was not specifically designed for their specific DHH situations and activities. For future research, we recommend researchers to work closely with DHH users to identify specific challenges in their activity and design inclusive technologies. We also see an opportunity for research that facilitates community where both hearing and DHH people who engage in creative sound activities can exchange knowledge and information about technology. That would help raise awareness of available technologies and how to use them effectively.

6 CONCLUSION

In this work, we provide early insight into DHH people's use of technology and its barriers in creative sound activities. To support these activities, we found DHH people use four types of technology — hearing devices, sound manipulation, sound visualization, and speech-to-text — and for three purposes — to better perceive sound through auditory and visual means, to avoid hearing fatigue, and to communicate with others and understand speech. We found DHH people also have barriers to technology in terms of its availability, limited options, and limitations that technology can solve. In future work, we plan on conducting interviews that focus on more specific tasks of creative sound activities that DHH people find challenging.

ACKNOWLEDGMENTS

We thank all participants, organizations, and communities that contributed to this study.

REFERENCES

[1] Audiovisability. 2022. *Audiovisability.* Retrieved June 23, 2022 from https://www.audiovisability.com/

[2] Swann Barrat. 2020. I'm a sound technician. Losing my hearing was devastating. *CBC News* (24 Nov. 2020). Retrieved June 23, 2022 from https://www.cbc.ca/news/canada/british-columbia/i-m-a-sound-technician-losing-my-hearing-was-devastating-1.5813327

[3] Ricardo Ferreira Bento, Alessandra Kiesewetter, Liliane Satomi Ikari, and Rubens Brito. 2012. Bone-anchored hearing aid (BAHA): indications, functional results, and comparison with reconstructive surgery of the ear. *International archives of otorhinolaryngology* 16, 03 (2012), 400–405.

[4] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative research in psychology* 3, 2 (2006), 77–101.

[5] Virginia Braun and Victoria Clarke. 2013. *Successful qualitative research: A practical guide for beginners.* sage.

[6] Doga Cavdir. 2022. Touch, Listen,(Re) Act: Co-designing Vibrotactile Wearable Instruments for Deaf and Hard of Hearing. In *NIME 2022.* PubPub.

[7] Doga Cavdir and Ge Wang. 2020. Felt sound: A shared musical experience for the deaf and hard of hearing. In *Proceedings of the 20th international conference on new interfaces for musical expression (nime-20).*

[8] Anna Cavender and Richard E Ladner. 2008. Hearing impairments. In *Web accessibility.* Springer, 25–35.

[9] Marshall Chasin and Frank A Russo. 2004. Hearing aids and music. *Trends in Amplification* 8, 2 (2004), 35–47.

[10] Wendy Cheng and Au.D. Willia Horowitz. 2021. *Making Music with a Hearing Loss: Strategies and Stories* (2nd ed.). AAMHL Publications, Gaithersburg, MD, USA.

[11] Warren N Churchill. 2016. *Claiming musical spaces: Stories of deaf and hard-of-hearing musicians*. Ph. D. Dissertation. Teachers College, Columbia University.

[12] John G Clark. 1981. Uses and abuses of hearing loss classification. *Asha* 23, 7 (1981), 493–500.

[13] Bill Crow. 2006. Musical creativity and the new technology. *Music Education Research* 8, 1 (2006), 121–130.

[14] Harvey Dillon. 2008. Hearing aids. Hodder Arnold.

[15] Richard Einhorn. 2012. Observations from a musician with hearing loss. *Trends in Amplification* 16, 3 (2012), 179–182.

[16] Leah Findlater, Bonnie Chinh, Dhruv Jain, Jon Froehlich, Raja Kushalnagar, and Angela Carey Lin. 2019. 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*. 1–13.

[17] Emma Frid. 2019. Accessible digital musical instruments—a review of musical interfaces in inclusive music practice. *Multimodal Technologies and Interaction* 3, 3 (2019), 57.

[18] Robert Fulford, Jane Ginsborg, and Juliet Goldbart. 2011. Learning not to listen: the experiences of musicians with hearing impairments. *Music Education Research* 13, 4 (2011), 447–464.

[19] Evelyn Glennie. 2003. *How to truly listen.* Retrieved June 23, 2022 from https://www.ted.com/talks/evelyn_glennie_how_to_truly_listen

[20] Google. 2022. *Google Hangouts.* Retrieved June 23, 2022 from https://hangouts.google.com/

[21] Google. 2022. *Live Transcribe | Speech to Text App | Android.* Retrieved June 23, 2022 from https://www.android.com/accessibility/live-transcribe/

[22] Alinka Greasley. 2017. From a Musician with a Hearing Loss. *Hearing Aids for Music* (3 Jan. 2017). Retrieved June 23, 2022 from https://musicandhearingaids.org/2017/01/03/musician-hearing-loss/

[23] Michaela Hoare, Steve Benford, Rachel Jones, and Natasa Milic-Frayling. 2014. Coming in from the margins: amateur musicians in the online age. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 1295–1304.

[24] Jack A Holman, Benjamin WY Hornsby, Fred H Bess, and Graham Naylor. 2021. Can listening-related fatigue influence well-being? Examining associations between hearing loss, fatigue, activity levels and well-being. *International Journal of Audiology* 60, sup2 (2021), 47–59.

[25] Brian J Hracs. 2012. A creative industry in transition: the rise of digitally driven independent music production. *Growth and Change* 43, 3 (2012), 442–461.

[26] Raja Kushalnagar. 2019. Deafness and hearing loss. In *Web Accessibility*. Springer, 35–47.

[27] Mariana C Leal, Young Je Shin, Marie-laurence Laborde, Marie-noëlle Calmels, Sebastien Verges, Stéphanie Lugardon, Sandrine Andrieu, Olivier Deguine, and Bernard Fraysse. 2003. Music perception in adult cochlear implant recipients. *Acta oto-laryngologica* 123, 7 (2003), 826–835.

[28] Jessica Nina Lester, Yonjoo Cho, and Chad R Lochmiller. 2020. Learning to do qualitative data analysis: A starting point. *Human Resource Development Review* 19, 1 (2020), 94–106.

[29] Andrew Leyshon. 2009. The Software Slump?: digital music, the democratisation of technology, and the decline of the recording studio sector within the musical economy. *Environment and planning A* 41, 6 (2009), 1309–1331.

[30] Valerie Looi, Hugh McDermott, Colette McKay, and Louise Hickson. 2008. The effect of cochlear implantation on music perception by adults with usable preoperative acoustic hearing. *International journal of audiology* 47, 5 (2008), 257–268.

[31] Sara MK Madsen and Brian CJ Moore. 2014. Music and hearing aids. *Trends in Hearing* 18 (2014), 2331216514558271.

[32] Hugh J McDermott. 2004. Music perception with cochlear implants: a review. *Trends in amplification* 8, 2 (2004), 49–82.

[33] Music and the deaf. 2016. *The Frequalise Report: A project by Music and the Deaf.* Retrieved June 23, 2022 from https://network.youthmusic.org.uk/file/27500/download?token=4_rxCK37

[34] Music and the Deaf. 2022. *Music and the Deaf | West Yorkshire | MatD.* Retrieved June 23, 2022 from https://www.matd.org.uk/

[35] Drake Music. 2022. *Drake Music | Leaders in Music, Disability & Technology.* Retrieved June 23, 2022 from https://www.drakemusic.org/

[36] Youth Music. 2022. *Youth Music Home Page.* Retrieved June 23, 2022 from https://youthmusic.org.uk/

[37] Deaf Professional Arts Network. 2022. *D-PAN: Deaf Professional Artist Network.* Retrieved June 23, 2022 from https://d-pan.org/

[38] Kimberly A Neuendorf. 2018. Content analysis and thematic analysis. In *Advanced research methods for applied psychology*. Routledge, 211–223.

[39] Association of Adult Musicians with Hearing Loss. 2022. *Welcome! - Association of Adult Musicians with Hearing Loss.* Retrieved June 23, 2022 from https://www.musicianswithhearingloss.org/wp/

[40] World Health Organization. 2021. *World report on hearing: executive summary.* Retrieved June 23, 2022 from https://www.who.int/publications/i/item/world-report-on-hearing

[41] Otter.ai. 2022. *Otter.ai - Voice Meeting Notes & Real-time Transcription.* Retrieved June 23, 2022 from https://otter.ai/

[42] William Christopher Payne, Alex Yixuan Xu, Fabiha Ahmed, Lisa Ye, and Amy Hurst. 2020. How blind and visually impaired composers, producers, and songwriters leverage and adapt music technology. In *The 22nd International ACM SIGACCESS Conference on Computers and Accessibility*. 1–12.

[43] Yi-Hao Peng, Ming-Wei Hsi, Paul Taele, Ting-Yu Lin, Po-En Lai, Leon Hsu, Tzu-chuan Chen, Te-Yen Wu, Yu-An Chen, Hsien-Hui Tang, et al. 2018. Speechbubbles: Enhancing captioning experiences for deaf and hard-of-hearing people in group conversations. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–10.

[44] Abir Saha and Anne Marie Piper. 2020. Understanding audio production practices of people with vision impairments. In *The 22nd International ACM SIGACCESS Conference on Computers and Accessibility*. 1–13.

[45] Ene Alicia Søderberg, Rasmus Emil Odgaard, Sarah Bitsch, Oliver Høeg-Jensen, Nikolaj Schildt Christensen, Søren Dahl Poulsen, and Steven Gelineck. 2016. Music Aid: Towards a Collaborative Experience for Deaf and Hearing People in Creating Music. In *New Interfaces for Musical Expression*.

[46] Joseph N Straus. 2011. Prodigious hearing, normal hearing, and disablist hearing. *Extraordinary Measures: Disability in Music* (2011), 150–181.

[47] Sara Louise Wheeler and Andrew Glyn Hopwood. 2015. Tinnitus: a deafhearing phenomenon. *Qualitative Inquiry* 21, 2 (2015), 173–174.

[48] Paul Whittaker. 2008. MatD - Music and the Deaf. In *Hearing, Feeling, Playing: Music and Movement with Hard-of-hearing and Deaf Children*, Shirley Salmon (Ed.). Reichert, 29–40.

[49] Zoom. 2022. *Video Conferencing, Cloud Phone, Webinars, Chat, Virtual Events | Zoom.* Retrieved June 23, 2022 from https://zoom.us/