Tonal Cognition in Sonification: Exploring the Needs of Practitioners in Sonic Interaction Design

Minsik Choi*
minsik.choi@anu.edu.au
School of Computing, The Australian
National University
Canberra, ACT, Australia

Josh Andres†
josh.andres@anu.edu.au
School of Cybernetics, The Australian
National University
Canberra, ACT, Australia

Charles Patrick Martin*
charles.martin@anu.edu.au
School of Computing, The Australian
National University
Canberra, ACT, Australia

Figure 1: How can tonal music principles and the needs of practitioners be incorporated in sonic interaction design tools?

ABSTRACT

Research into tonal music examines the structural relationships among sounds and how they align with our auditory perception. The exploration of integrating tonal cognition into sonic interaction design, particularly for practitioners lacking extensive musical knowledge, and developing an accessible software tool, remains limited. We report on a study of designers to understand the sound creation practices of industry experts and explore how infusing tonal music principles into a sound design tool can better support their craft and enhance the sonic experiences they create. Our study collected qualitative data through semi-structured individual and focus group interviews with six participants. We developed a low-fidelity prototype sound design tool that involves practical methods of functional harmony and interaction design discussed in focus groups. We identified four themes through reflexive thematic analysis: decision-making, domain knowledge and terminology, collaboration, and contexts in sound creation. Finally, we discussed design considerations for an accessible sonic interaction design tool that aligns auditory experience more closely with tonal cognition.

CCS CONCEPTS

• **Human-centered computing** → User studies; **Systems and tools for interaction design**.

KEYWORDS

sonic interaction design, auditory display, creativity support tools, user-centered design, embodied music cognition, tonal cognition

1 INTRODUCTION

The study of tonal music explores the underlying structural relationships among sounds [8]. It has evolved into a systematic framework for hierarchically organizing individual sounds within a continuous perspective [11]. Insights from cognitive science, such as musical expectancy and affordance, which evoke sonic tension and release and impact subsequent actions, have further emphasized the cognitive flow that listeners experience from tonal music as structured sound [2, 22, 23]. For instance, akin to how humans grasp the harmonic relationships in simple melodies, applying tonal cognition offers listener-centered avenues for crafting auditory displays of everyday products [4, 32, 37].

Interest in tonal cognition arose along with music cognitive applications in interactive sonification [19, 24]. Gaver [17, 18] introduced the concept of auditory icon, drawing upon everyday auditory cognition, and Norman [31] briefly explored sound signals as an alternative to visual displays in a similar context. Blattner et al. [3] categorized communicative sounds known as earcons by musical elements like rhythm and pitch, and Brewster explored in depth across studies such as [5–7]. Furthermore, Serafin et al. [37]

expanded the discourse by highlighting the significance of auditory interaction within musical structures [15], and Vickers [41] addressed the intricate relationship between music and sonification [35], mentioning tonal functions and embodied cognition. Research on its application accordingly explored movement sonification between embodied music cognition and task sequence such as Newbold et al. [28, 30]. These confirm user's auditory experience based on musical principles, leading to the discussion on tonal cognition and its employment in interactive sonification.

The application of tonal cognition to sonic interaction, however, remains limited [10]. There is a scarcity of auditory interface design research for designers lacking extensive musical knowledge, and few instances of software solutions aimed at enhancing accessibility of tonal music principles. Interdisciplinary practitioners in auditory interface design process can further complicate the context. Research in interactive sonification has typically focused on end-users for design planning and evaluation [4, 27], and particularly within the applications of tonal cognition, there has been a lack of pragmatic solutions proposed, along with modest attention to methods in use and accessible platforms for practitioners. Although Newbold et al. [29] presented a design model for movement altering sonification, hands-on methods of tonal music and interaction design can be incorporated through a software solution to enhance accessibility for practitioners. Better understanding of designers and their practices could facilitate the development of software that assists them in harnessing tonal cognition through sensible methods for interactive sonification.

This user research, therefore, aims to study sound design practitioners to understand their work practices, language usage, and functional needs to build a design tool deploying tonal cognition. Our method involved individual and focus group interviews followed by reflexive thematic analysis and task flow analysis. We produced a low-fidelity prototype of a software tool that would allow designers to access of tonal principles with interaction design—harmonic functions and user tasks—discussed by the focus groups. We identified four themes from overall qualitative data that foreground decision-making, domain knowledge and terminology, collaboration, and design contexts in sound creation. We discuss further designer-centered software solution development directions based on the results. This research is intended with further stages involving creating high-fidelity prototypes and conducting usability evaluations. Our contributions involve unpacking current sound design practices and potential needs for a sonic interaction tool with tonal cognition, and accordingly providing recommendations for the future development of an accessible tool for practitioners in sonic interaction design.

2 BACKGROUND

Functionality in tonal music frames chordal relationships through three pillars, tonic, dominant and subdominant, where the behavior of chords is in hierarchical relation to the tonic [1]. Tonal cognition within these hierarchical relations enables humans to perceive and appreciate tension and release as musical expectancy [22]. Korsakova-Kreyn [23] proposed two distinct levels of embodied cognition in music: corporeal articulation at a surface level and

tonal cognition at a deep level, and Vickers [41] discussed structured tonal musical frameworks in relation to embodied music cognition and sonification. Newbold et al. [29] ultimately suggested a design method using concepts of tonal cognition such as musical expectancy for movement sonification and explored this concept through user studies [28, 30].

Meanwhile, user-centered design in software development [26] has been applied across domains, including interactive sonification [19, 42]. End-users have been the primary focus of user studies, including experimental testing for usability attributes [34], while studies specifically targeting designers have been relatively rare. Some studies have examined designers' perspectives assisting practitioners in design practices [9, 13]. Selfridge and Pauletto [36] compared initial design ideas among sound designers to find out common points, and Kameth et al. [21] studied designers using sound design support tools and discussed human-AI design considerations; however, few or no studies have specifically explored designer-centered approaches in sonification methods related to tonal cognition. The interdisciplinary nature of sonification in interaction design [20, 33] suggests that designer-centered research addressing this gap might have a wide impact on a diverse range of practitioners.

Efforts to refine design theories through practical methods [25, 39] imply the potential benefits of hand-on application of tonal cognition in sonification. Tonal cognition is rooted in the hierarchical harmonic functions perceived by audience [2], and interaction design where the concept is applied begins with user understanding with scenarios and subdivided task analysis, resulting in sonic interaction design with tonal cognition [19, 33]. The methods in both perspectives share hierarchical structures and emphasize cognitive aspects among individual notes and tasks within continuing contexts [12, 33]. Harmonic functions are codified using Roman numeral notation [16], and user scenarios with task analysis enable practitioners to assign appropriate subtasks for sonic interface design [33]. Aligning these methods in an application could allow designers pragmatic access to tonal cognition concepts in sonic interaction design. In this paper, we intend to explore this alignment, described in Figure 2, by studying a low-fidelity prototype sound design tool with design practitioners. This new approach has the potential to facilitate interconnected progressive displays and explainable design plans within the context of accessibility [10].

3 METHOD

Our study included semi-structured individual interviews with three sound designers, each lasting 30 minutes, along with one hour-focus group sessions with three sound designers and three UX designers, as outlined in Figure 3. The individual interviews aimed to gain an extensive understanding of sound designers, encompassing but not limited to musical approaches. Two focus group sessions, individually with sound and UX designers, focused on hands-on experience with a low-fidelity prototype described in Figure 4 and Appendix A.2. The low-fidelity prototype demonstrated a software tool reflecting the suggested design logic with the methods of functional harmony and interaction design elaborated in section 2. Both individual and focus group interviews were conducted using predetermined open questions (see Appendix A.1) within

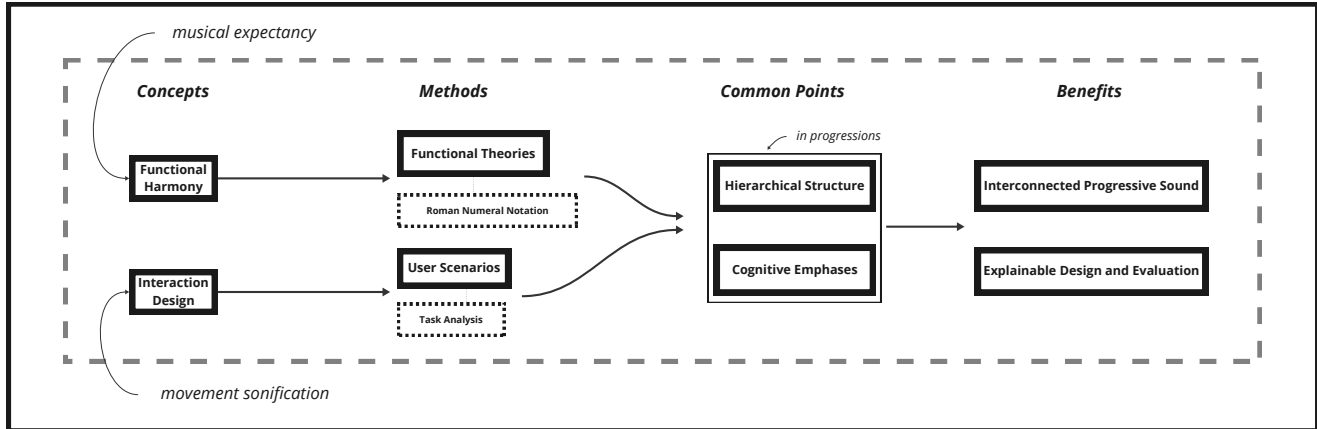**Accessible Design Tool for Practitioners; what do they require?**

Figure 2: Background overview including fundamental concepts, corresponding methods, common ground, and following benefits; musical expectancy and movement sonification are the main points from Newbold et al. [29], and the bigger frame represents the potential software development for designers reflecting this sonification strategy.

the recording environment depicted in Figure 5. Sound designers were asked about their work practices, dynamics, and common language usage related to sound creation, including musical approaches, in individual interviews. Focus groups involved written and oral inquiries about the prototype experience, alongside design discussions beyond sonification that embraced broader opinions from UX designers.

3.1 Prototype

We developed a low-fidelity prototype of a sonic interaction design tool incorporating tonal cognition with harmonic functions and user tasks. The prototype illustrates the design procedure in three phases: ideation, logic structure, and sound production, with plain language for accessibility, as detailed in Figure 4. The ideation phase involves creating parallel user scenarios organized in vertical structures, similar to hierarchical task analysis [38]. Specific purposes and adjectives are assigned to target tasks to guide interface character and effects decisions. The logic structure phase is mainly cognitive arrangement, linking to tonal functions such as start, prolongation, rising, peak, semi-end, and end. Each sound can be tuned by tonal factors for variations in each function. For instance, chord decision includes note arrangement within each combination and acoustic tuning for each note. The sound production phase is for file extraction in audio and visual formats. This phase was designed to allow for open exploration, encouraging sensible ideas. Basic frame was suggested such as file format, sample rate, channel, and bit depth for sonification, and musical and physical—score and spectrogram—are the options for visualization. This prototype was developed using Figma, shown in Appendix A.2, with a focus on the logical flow and structure of the interface, rather than emphasizing specific visual interface elements.

3.2 Participants

To gain a broad understanding of sonic interaction design practices in this initial user research, we recruited three sound designers and three UX designers for our study as described in Table 1. All six participants were employed at large engineering companies in South Korea. Only the three sound designers participated in the individual interviews to explore common sound design contexts, beyond the prototype related to musical approaches. Despite belonging to the same company, the sound designers held varied positions with different responsibilities providing diverse insights within the sound design field. The UX designers also contributed overall interface design perspectives as they came from different industries and companies. The participants educational backgrounds were diverse yet primarily focused on sound, user experience and related engineering fields. Their musical backgrounds also varied but balanced with formal music education, music as ongoing hobby, and brief experiences in musical instruments.

3.3 Procedure

Individual interviews were conducted in a conversational manner, with questions prompting relevant discussions. The focus group interviews included four steps: exploring the prototype, responding to provided questions via Microsoft Forms with individual laptops based on the prototype, exchanging ideas about the prototype experience through group discussion, and collaboratively redesigning the prototype using paper-based samples and pens captured in Figure 5. They provided feedback on the prototype experience in written, verbal, and visual formats during the focus group sessions. The study commenced with a participant briefing and participants provided written informed consent as well as demographic information. Participants did not receive any incentives for their participation. Ethical approval was obtained from ANON Institutional Review Board.
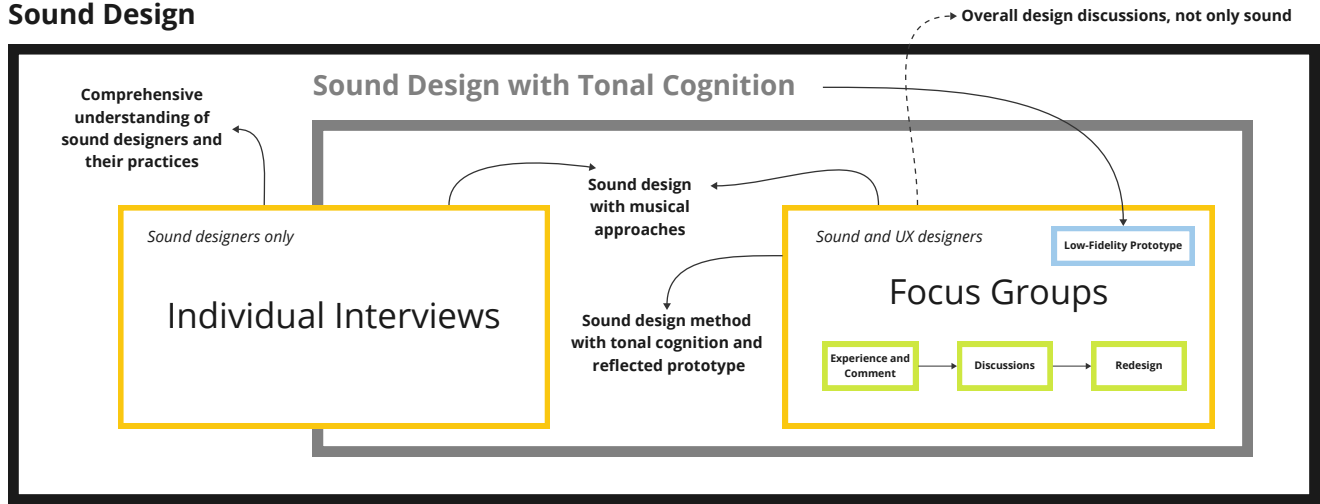
Sound Design

Figure 3: Method overview illustrating conceptual relationships, research scope of each method, and procedure for focus groups. The black frame represents overall sound design, while the gray frame specifically denotes sound design with tonal cognition. The two yellow boxes illustrate what each method encompasses: individual interviews cover both general sound design and sound design with tonal cognition, while focus groups concentrated exclusively on aspects of sound design with tonal cognition using a low-fidelity prototype framed by a blue box. The green boxes outline the procedure of the focus groups.
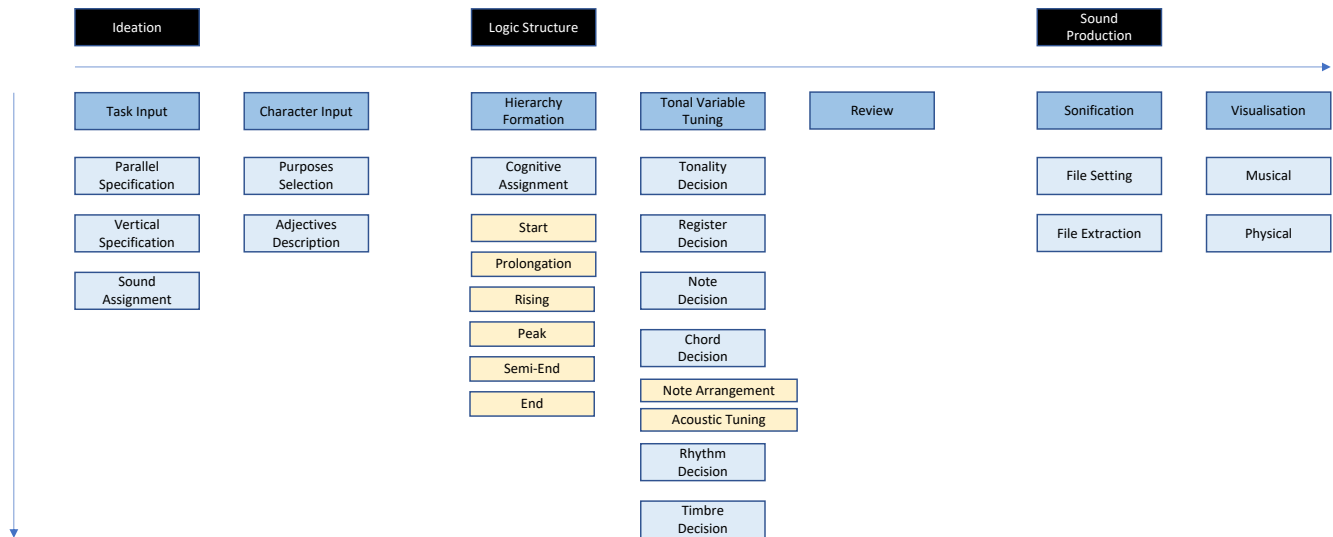

Figure 4: Prototype design logic with user scenario formation, cognitive tonal functions arrangement to target tasks, tonal variable tuning, and file extraction within three main phases.

3.4 Analysis

Qualitative data from individual and focus group interviews were analyzed, resulting in the identification of reflexive themes through thematic analysis [40]. We employed a bottom-up approach, familiarizing ourselves with the collected qualitative data: interview transcripts, prototype experience responses, and redesign sketches and verbal descriptions. Gathered data was semantically coded with quotes pertaining to design practices and functional needs for the prototype, considering participants' educational and musical backgrounds. This process led us to organize reflexive themes as semantic clusters that overlapped with each other as illustrated in Figure 6. We also applied task flow analysis to the work processes of the three sound designers to reveal common tendencies in the way of achieving their goals [14]. The individual interview data with sound designers was specifically used for task flow analysis, and the outcome is presented in section 4.1.

Table 1: Participant information for three UX designers (UX) and three sound designers (SD); HF: human factors, eng.: engineering, and FGI: focus group interview.

	P1 (UX)	P2 (UX)	P3 (UX)	P4 (SD)	P5 (SD)	P6 (SD)
Industry	Mobile phone	Home appliance	Automotive	Audio, automotive	Audio, automotive	Audio, automotive
Position	Senior researcher	Senior researcher	UX researcher	Senior manager	Senior engineer	Technician
Role	User research on mobile experience	Home appliance UX Planning	Vehicle UX design and eng. solution	Car audio system layout design	Virtual sound and noise tuning	Warning sound tuning and EQ validation
Education	Psychology, cognitive science, HF	Communication design, HF	Architecture, HF	Electrical eng., composition, HF	Electrical eng.	Automotive eng.
Music Experience	Brief experience in guitar	Brief experience in flute	Brief experience in violin and bass	Majored and choir as ongoing hobby	Guitar and recording as ongoing hobby	Brief experience in piano
Participation	FGI	FGI	FGI	Interview, FGI	Interview, FGI	Interview, FGI

Figure 5: Focus group description; a: interview environment with individual laptops and recording device, b: individual examination of prototype in Figma via Microsoft Forms, c: redesigning activity with paper-based prototype and pens.

4 RESULTS

In this section, we discuss the themes that were defined by applying our process of reflexive thematic analysis to the qualitative data described in section 3.4 above. We defined four themes which are shown as overlapping ovals in Figure 6. *Framing subjectivity within objective requirements* concerns the procedural characteristics of sound design practices, moving from concrete criteria to intuitive approaches. The sound designers ultimately create sound intuitively based on conceptual keywords, grounded in a concrete and physical foundation. *Variable domain knowledge and terminology* encompasses the language aspects commonly used, primarily domain-specific yet also incorporating universal elements with boundaryless backgrounds and varying levels of music knowledge. *Explaining sound in collaboration* focuses on the need for communicability in interdisciplinary collaboration. Individuals from various backgrounds and musical experience converge for a common purpose, collaborating and eventually reaching a consensus with understandable explanations. *Design context of sonic interaction* describes the contextual aspects involved in designing sound as a whole. These qualitative aspects encompass the entire work process from ideation to generating sound, aiding in the conceptual design direction and sound optimization across diverse situations.

4.1 Framing Subjectivity within Objective Requirements

Our sound designers begin a project by physical configuration, although the final sound is shaped by subjective intuition. They establish a design foundation through hardware decisions, primarily focusing on speakers, along with numerical specifications, aligning them with target products. After the environmental setting, they proceed to refine the sound based on conceptual imagery, including brand keywords, user contexts and emotions, and their own intuitions. As shown in Figure 7, while specific tasks vary depending on roles, their broader framework is characterized by a flow from objective to subjective approaches as the essence of their practices.

P4 described his work process, starting with hardware configuration followed by software tuning. He uses objective information initially and then transitions to more abstract concepts like brand keywords. With a background in music, he emphasized the advantage of his listening skills acquired through music education, particularly for the final tuning stage. P5 primarily engages in framed tuning based on foundational methods, such as order analysis and noise control by RPM. At the final evaluation stage, however, he relies subjectively on his ears and felt experience of the sound. Similarly, P6 begins with basic hardware checks and adjustments as a technician, such as setting the volume level for warning sounds, but he relies on intuition-based figures and abstract concepts by
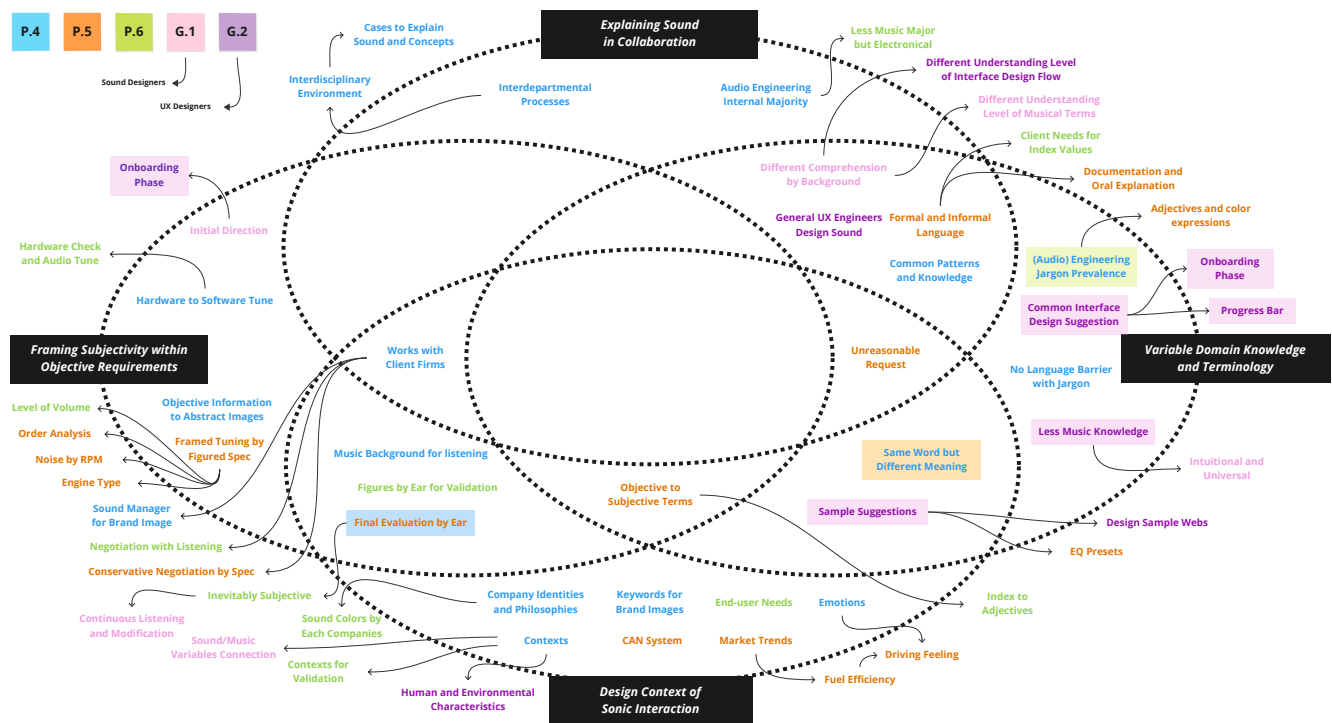
Figure 6: Four discovered reflexive themes comprising individual codes classified by thematic analysis; the colors indicate the source of each code, such as which participant or focus group it originated from, and when a code is mentioned by more than one participant or focus group, two colors are used with additional highlighting.

engineers for the broader audio tuning and validation. In both focus groups, the participants recommended incorporating an onboarding phase in the prototype to establish a clear design direction. This aspect is also mentioned by the UX designers and so could be considered universal; however, it is still reasonable to align it with the practices involved in designing sound within this theme.

4.2 Variable Domain Knowledge and Terminology

The sound designers utilize jargon specific to the audio engineering field for internal communication. For instance, as P4 highlighted, when communicating with designers from different language backgrounds, there are almost no issues since everyone tends to use similar terminology. In contrast, certain words may hold different connotations within sound design. For example, while loudness may commonly denote the physical strength of sound, it refers specifically to the human-centered perspective of volume. P5 also noted the internal usage of adjectives relating to timbre, such as nasal, as well as color-related analogies for sound such as, bright, dark or neutral gray.

The sound designers, however, basically collaborate, and individual understanding of related domains, such as musical or physical expertise, may vary depending on each background. The UX designers are also occasionally engaged in designing sound, indicating that sound design may not be exclusive to sound designer as a profession. During the focus group with sound designers, there was

a discussion about naming music variables, and opinions varied: P4 - "*Tonality could be referred to as harmonics, which is a more understandable engineering term.*", P5 - "*I think both terms are still difficult to understand; perhaps tonality could simply mean a tone?*". While P4, with musical backgrounds, may have a better grasp of tonality and suggested considering the field's subtle nature, P5, who understood fewer musical terms, provided a simpler suggestion that may not correlate with uses within music or sound. Similarly, during the focus group with UX designers, the participants had a stronger understanding of the ideation phase with task flow input in the prototype compared to the sound designers, possibly due to their design-related backgrounds. P2, a home appliance UX designer, shared her experience in auditory interface design, conceptualizing sound with adjectives to guide the development of ring signals. P1 and P3 mentioned parallel experiences in mobile and automotive projects.

The participants had less familiarity with musical terms than expected. They generally preferred intuitive media as alternatives to musical knowledge and universal interface during the prototype experience. These included UI elements such as emojis, control bars, onboarding phase, and progress bars depicted in Figure 8. There was a shared idea for the sample recommendation feature to facilitate intuitive designs within guided frames, associated by their experiences, such as EQ presets and design recommendation websites. P5 suggested that the current flow could be monotonous,
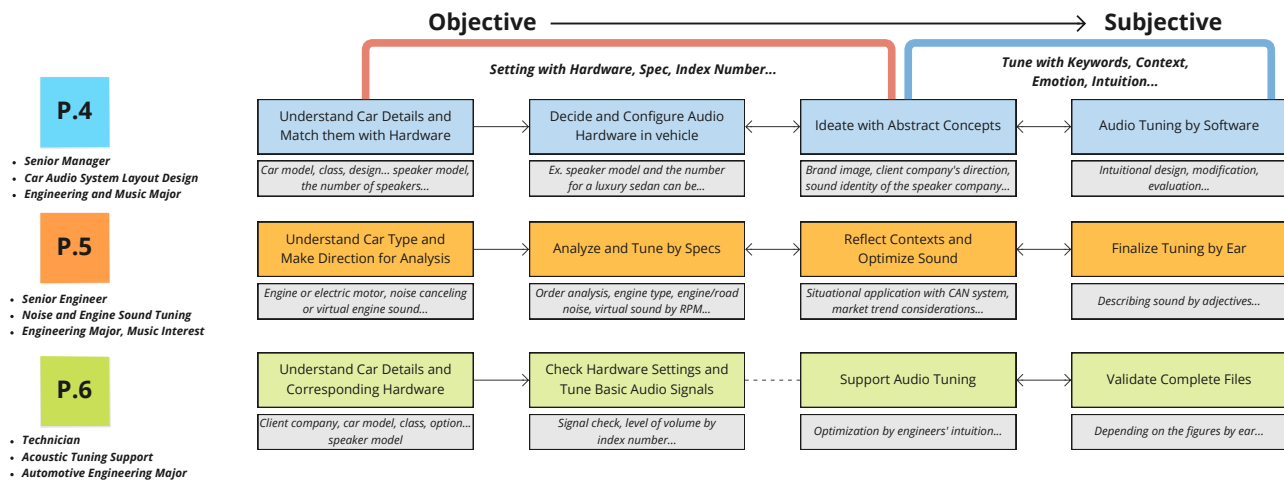
Figure 7: Task flow analysis illustrating the broader framework of designing sound from objectivity to subjectivity; the boxes, color-coded based on each sound designer, show the detailed phases of the sound design process according to their positions and roles.

so customizing samples like EQ presets could enhance the experience. P2 also mentioned the samples in certain design websites, which provides users with confirmation on the right direction.

4.3 Explaining Sound in Collaboration

The sound designers in our study predominantly had backgrounds in electrical engineering, but their work often requires collaboration with other departments, leading to an interdisciplinary environment. This dynamic involves explaining design concepts and allowing stakeholders to experience sonic outputs, resulting in variations of comprehension due to diverse backgrounds. This is not only unique within their company but also occurs with client firms. The sound designers explain and persuade clients to accept designed sounds through negotiations. P4 mentioned communicating with sound managers in client companies during the initial phase to discuss branding image and understanding common patterns within an interdisciplinary environment. P6 also highlighted negotiations with client companies through continuous listening and intuitive explanations. Similarly, both P5 and P6 noted using domain-specific formal language, such as variables and indexes, for documentation but employing informal descriptive language for immediate communication. These flexible linguistic conventions enable adept explainability in the interdisciplinary environment. The nature of work dynamics in designing sound entails the explanation for diverse collaboration while striving towards a common goal.

4.4 Design Context of Sonic Interaction

While sound design begins with a framed direction, it encounters various situations that require sophisticated optimization. P4 emphasized his company identities and design philosophies as an audio electronics firm, and there is even a potential for an additional layer of mutual consideration with client companies. P6 highlighted the

sound color differences among client companies and addressing end user needs. Additionally, P1 underscored considering human and environmental characteristics as contextual variables, which was further mentioned by P4 and P5. P5 elaborated on the controller area network (CAN) as the systematic foundation for contextual possibilities. Similarly, during the focus group with sound designers, the necessity for contextual connections with sound and music variables was addressed. Lastly, P5 mentioned considering market trends along with end user needs. He provided an example of fuel efficiency in car weight reduction, where the subsequent question pertains to driving feeling, aligning with the emotional aspects mentioned by P4.

5 CONCLUSION AND FUTURE WORK

Our study shows that although the sound design process is initially structured around relatively concrete foundations, ultimately, it must accommodate subjective and intuitive nuances. The final phase of sound design is characterized by qualitative factors and involves multiple layers of sound optimization. While audio engineering has its own domain knowledge, this can be adapted to the interdisciplinary dynamic of sound design. The sound designers we studied primarily communicate internally but also collaborate with other departments and external stakeholders. We found that a broader range of individuals than expected are involved in designing sound, indicating that it is not solely the domain of sound design specialists. These thematic frames overlap and influence one another, highlighting the mutual interactions taking place.

Our findings lead to the following recommendations for future development of an accessible tool that supports sound designers in the sonification with tonal cognition. Potential users for sound design software tool must include UX designers, not just sound design specialists, and could potentially extend to other design and engineering roles. The interface should be intuitive, but still involve
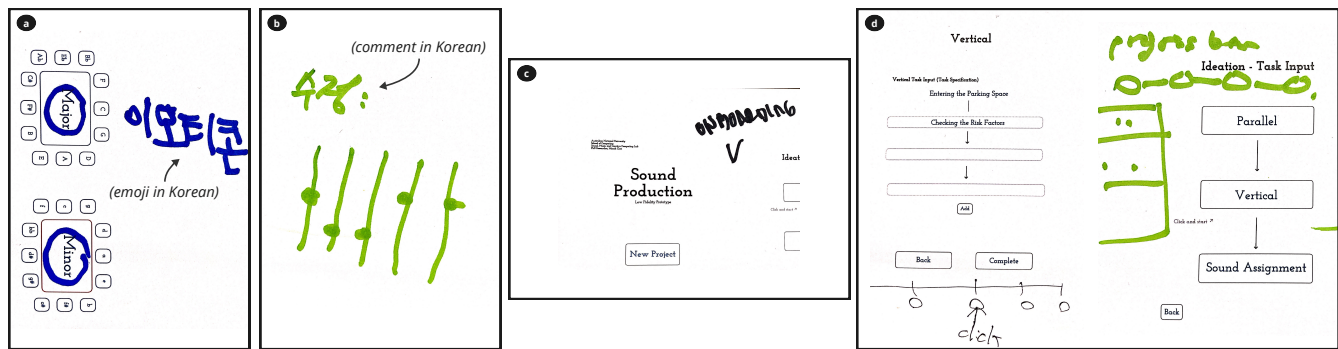
Figure 8: UI element recommendations from the redesigning activity; a: emojis usage for tonality description, b: intuitive control bars, c: onboarding phase, d: progress bars.

domain-specific elements such as adding advanced options to the general task flow to suit both beginners and professionals. To ensure that the design direction aligns with the foundational settings, an onboarding phase is necessary, akin to the initial step of current sound design tasks. Similarly, sample suggestions would benefit designers as a guided framework. Lastly, musical knowledge could be described in engineering or common terminology for accessibility. Musical terms could be distilled into universally understood UI elements, such as major and minor tonal differences depicted by emojis and intuitive variable controllers like equalizers. The final outputs could be represented in a formal format for documentation, even though the interface language may be more intuitive and plain, resembling everyday communications observed in our study.

Future work could explore further details of the sound design software tool leveraging the suggested sonification method based on the findings by the current study. As part of this ongoing research, we will develop a high-fidelity prototype incorporating the discussed design directions. This development process will involve desk methods such as referencing similar software solutions, but the next phase will mainly entail usability evaluation of the refined prototype, possibly in a controlled experiment setting, and the data will be analyzed through both quantitative and qualitative analyses. The research and resultant sonic interaction design tool with tonal cognition will enable practitioners beyond exclusively sound specialists to create sound intuitively but logically with practical methods, infusing insights from the science of music and interaction design.

REFERENCES

[1] David Bernstein. 2002. *Nineteenth-century harmonic theory: the Austro-German legacy.* Cambridge University Press, 778–811.
[2] Emmanuel Bigand and Bénédicte Poulin-Charronnat. 2016. Tonal cognition. *The Oxford handbook of music psychology* (2016), 95–111.
[3] Meera M. Blattner, Denise A. Sumikawa, and Robert M. Greenberg. 1989. Earcons and Icons: Their Structure and Common Design Principles. *Human–Computer Interaction* 4, 1 (1989), 11–44. https://doi.org/10.1207/s15327051hci0401_1
[4] Jorge Boehringer, Marcin Pietruszewski, John Bowers, Bennett Hogg, Joseph Newbold, Gerriet Sharma, Tim Shaw, and Paul Vickers. 2022. Listener-centred Sonification Practice as Transdisciplinary Experimental Artistic Engagement. (2022).
[5] Stephen A Brewster. 1998. Using nonspeech sounds to provide navigation cues. *ACM Transactions on Computer-Human Interaction (TOCHI)* 5, 3 (1998), 224–259.
[6] Stephen A Brewster, Peter C Wright, and Alastair DN Edwards. 1994. A detailed investigation into the effectiveness of earcons. In *SANTA FE INSTITUTE STUDIES IN THE SCIENCES OF COMPLEXITY-PROCEEDINGS VOLUME-*, Vol. 18. Addison-Wesley Publishing CO, 471–471.
[7] Stephen A Brewster, Peter C Wright, and Alistair DN Edwards. 1995. Experimentally derived guidelines for the creation of earcons. In *Adjunct Proceedings of HCI*, Vol. 95. 155–159.
[8] J Peter Burkholder, Donald Jay Grout, and Claude V Palisca. 2019. *A history of western music.* WW Norton & Company.
[9] Edward Burnell, Michael Stern, Ana Flooks, and Maria C Yang. 2017. Integrating design and optimization tools: a designer centered study. In *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, Vol. 58219. American Society of Mechanical Engineers, V007T06A029.
[10] Minsik Choi. 2023. Music theoretical approach to auditory interface design: progressive, explainable, and accessible. In *Proceedings of the 15th Conference on Creativity and Cognition*. 39–42.
[11] Thomas Christensen. 2006. *The Cambridge history of Western music theory.* Cambridge University Press.
[12] Brent Clement. 2023. *Rock Tonality Amplified: A Theory of Modality, Harmonic Function, and Tonal Hierarchy.* Routledge. https://doi.org/10.4324/9781003300236
[13] Jaap Daalhuizen, Petra Badke-Schaub, and Stephen Batill. 2009. *Dealing with uncertainty in design practice: issues for designer-centered methodology.* Vol. 9. Design Society, 147–158. http://www.designsociety.org/iced09_17th_international_conference_on_engineering_design.event.62.2009-08-24.htm 17th International Conference on Engineering Design, ICED09 ; Conference date: 24-08-2009 Through 27-08-2009.
[14] Dan Diaper and Neville Stanton. 2003. *The handbook of task analysis for human-computer interaction.* CRC Press.
[15] Karmen Franinovic and Stefania Serafin. 2013. *Sonic interaction design.* Mit Press.
[16] Robert Gauldin. 2004. *Harmonic Practice in Tonal Music* (2nd ed.). W.W. Norton.
[17] William W. Gaver. 1986. Auditory Icons: Using Sound in Computer Interfaces. *Hum.-Comput. Interact.* 2, 2 (jun 1986), 167–177. https://doi.org/10.1207/s15327051hci0202_3
[18] William W Gaver. 1989. The SonicFinder: An interface that uses auditory icons. *Human–Computer Interaction* 4, 1 (1989), 67–94.
[19] Thomas Hermann, Andy Hunt, John G Neuhoff, et al. 2011. *The sonification handbook.* Vol. 1. Logos Verlag Berlin.
[20] Myounghoon Jeon, Areti Andreopoulou, and Brian FG Katz. 2020. Auditory displays and auditory user interfaces: art, design, science, and research. *Journal on Multimodal User Interfaces* 14 (2020), 139–141.
[21] Purnima Kamath, Fabio Morreale, Priambudi Lintang Bagaskara, Yize Wei, and Suranga Nanayakkara. 2024. Sound Designer-Generative AI Interactions: Towards Designing Creative Support Tools for Professional Sound Designers. In *Proceedings of the CHI Conference on Human Factors in Computing Systems* (, Honolulu, HI, USA,) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 730, 17 pages. https://doi.org/10.1145/3613904.3642040
[22] Stefan Koelsch. 2013. *Brain and Music.* John Wiley & Sons.
[23] Marina Korsakova-Kreyn. 2018. Two-level model of embodied cognition in music. *Psychomusicology: Music, Mind, and Brain* 28, 4 (2018), 240.
[24] Marc Leman. 2008. *Embodied music cognition and mediation technology.* MIT press.
[25] Ronnie Lipton. 2011. *The practical guide to information design.* John Wiley & Sons.
[26] Indrani Medhi. 2007. User-centered design for development. *interactions* 14, 4 (2007), 12–14.
[27] Frederik Moesgaard, Lasse Hulgaard, and Mads Bødker. 2020. Involving Users in Sound Design. In *Design, User Experience, and Usability. Interaction Design: 9th*

International Conference, DUXU 2020, Held as Part of the 22nd HCI International Conference, HCII 2020, Copenhagen, Denmark, July 19–24, 2020, Proceedings, Part I 22. Springer, 405–425.

[28] J Newbold, N Gold, and NL Bianchi-Berthouze. 2017. Musical expectancy in squat sonification for people who struggle with physical activity. In *ICAD'17*, Vol. 23. ICAD'17, 65–72.

[29] Joseph Newbold, Nicolas E Gold, and Nadia Bianchi-Berthouze. 2020. Movement sonification expectancy model: Leveraging musical expectancy theory to create movement-altering sonifications. *Journal on Multimodal User Interfaces* 14 (2020), 153–166.

[30] Joseph W. Newbold, Nadia Bianchi-Berthouze, Nicolas E. Gold, Ana Tajadura-Jiménez, and Amanda CdC Williams. 2016. Musically Informed Sonification for Chronic Pain Rehabilitation: Facilitating Progress & Avoiding Over-Doing. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16).* Association for Computing Machinery, New York, NY, USA, 5698–5703. https://doi.org/10.1145/2858036.2858302

[31] Don Norman. 2013. *The design of everyday things: Revised and expanded edition.* Basic books.

[32] Stephen Roddy and Brian Bridges. 2020. Mapping for meaning: the embodied sonification listening model and its implications for the mapping problem in sonic information design. *Journal on Multimodal User Interfaces* 14, 2 (2020), 143–151.

[33] Yvonne Rogers, Helen Sharp, and Jenny Preece. 2011. *Interaction Design: Beyond Human-Computer Interaction* (3rd ed.). John Wiley & Sons.

[34] Kalpna Sagar and Anju Saha. 2017. A systematic review of software usability studies. *International Journal of Information Technology* (2017), 1–24.

[35] Carla Scaletti. 2018. Sonification ≠ Music. In *The Oxford Handbook of Algorithmic Music*, Roger T. Dean and Alex McLean (Eds.). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780190226992.013.9 Online edition, Oxford Academic, 5 Feb. 2018.

[36] Rod Selfridge and Sandra Pauletto. 2022. Sound design ideation: comparing four sound designers' approaches. In *19th Sound and Music Computing Conference, June 5-12th, 2022, Saint-Étienne (France).*

[37] Stefania Serafin, Bill Buxton, Bill Gaver, and Sara Bly. 2022. *Auditory Interfaces.* Focal Press.

[38] Neville A Stanton. 2006. Hierarchical task analysis: Developments, applications, and extensions. *Applied ergonomics* 37, 1 (2006), 55–79.

[39] Neville A Stanton, Paul M Salmon, Laura A Rafferty, Guy H Walker, Chris Baber, and Daniel P Jenkins. 2017. *Human factors methods: a practical guide for engineering and design.* CRC Press.

[40] Gareth Terry and Nikki Hayfield. 2021. *Essentials of thematic analysis.* American Psychological Association.

[41] Paul Vickers. 2016. Sonification and music, music and sonification. In *The Routledge Companion to Sounding Art.* Routledge, 135–144.

[42] Daniel Wallach and Sebastian C. Scholz. 2012. User-Centered Design: Why and How to Put Users First in Software Development. In *Software for People*, Alexander Maedche, Andreas Botzenhardt, and Lars Neer (Eds.). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-31371-4_2

A APPENDIX: SUPPLEMENTARY MATERIALS

A.1 Semi-structured Interview Questions

These are the questions for individual and focus group interviews. The interviews comprehensively covered the categories below, but not every single question was necessarily asked of all participants or focus groups.

A.1.1 Individual Interview.

- How do they plan the design process?
  - Can you outline the overall sound design process?
  - Can you detail the ideation phase?
  - Can you detail the prototyping phase?
  - What considerations should be reflected when planning the design process?
- Which design phases and tasks are significant?
  - What are the particularly significant processes and tasks in ideation?
  - What are the particularly significant processes and tasks in prototyping?
  - Why do you think the processes and tasks are important?

- Looking at the end-to-end process, where would you say are the critical decisions?
- How do they imagine and decide design ideas?
  - How do you come up with design ideas?
  - How do you prioritize ideas and make final decisions?
- What are the significant design factors?
  - What are the key sound design factors?
  - Why are the factors important?
- How do they connect ideas with design factors?
  - Can you detail the factor mapping process?
  - What are the differences and similarities between design ideas and factors?
  - What are the difficulties in connecting design ideas and factors?
- How do they prototype the sound?
  - How do you fine-tune the sound output?
  - From which perspective are the produced sounds refined?
  - What are the heuristics, are there rules of thumb you use to create sounds?
  - How do you know the sound is suitable?
  - Do musical foundations play a role in your process?
  - What software do you use?
  - Why do you use the software?
  - What are the main features of the software you use?
  - Do they limit what you do, how so?
  - Do the digital tools you use provide music theoretical ideas to tune or modify the sounds?
- How do they verbalize design ideas, factors, process, and sound outputs?
  - What is the typical language used when brainstorming design ideas?
  - What is the common language or manner in which design factors are expressed?
  - What is the common language or manner in which sound outputs are described?
  - Are there instances where languages with distinct characteristics create challenges?
  - Do you use different language with different collaborators?
  - How did you acquire this language?
- Overall opinions about the interdisciplinary work setting and current software
  - What are the characteristics of sound design with people from diverse backgrounds?
  - Do you work with others? Can you say what skills they contribute and how you work with them?
  - If they have a different background, how do you describe the sounds, what language do you use?
  - Are there distinctive aspects resulting from the diverse backgrounds of sound engineers?
  - Do you believe current software incorporates a wide range of sound design perspectives?
  - Do you think current software presents challenges depending on the designer's background?
  - What are the strong points and downsides of the software you use?

A.1.2 Focus Group.

- Examination of the low fidelity prototype in written and oral formats
  - Are there any more design steps or tasks that were not considered?
  - Are there design phases or tasks that could be further connected back and forth?
  - What tasks can be further subdivided?
  - Are there any interface design points that would be good to consider?
  - Do you think it encompasses different design perspectives?
  - Do you think the applied language can be understood without advanced knowledge?
  - Do you think it connects intuitive design ideas with professional music knowledge?
  - Do you think it is an interface that people from various backgrounds can use?
- Overall discussion including broader design perspectives
  - What do you think are the most essential design steps?
  - What characteristics of tasks do you think are key at the critical steps?
  - Why do you think connectivity between design phases is important?

- What are the characteristics of words commonly used for design?
- How do you develop your intuitive design ideas?
- How do you connect the design ideas with physical attributes?
- What do you consider for prototyping?
- What is one feature you wish the software tool you use had?
- How do you think practical, artistic or aesthetic, and physical perspectives are combined in design?
- What are the pros and cons of having designers from different backgrounds working together?
- Do you think current prototyping software reflects intuitive design ideas well?
- What are the pros and cons of using current design and prototyping software in general?

A.2 Low-Fidelity Prototype

Figure 9 shows the low-fidelity prototype created in Figma. Different colors represent distinct design phases along with brief explanations. Some phases were simplified, such as only reviewing one sound rather than all the designed sounds.

Figure 9: Low-fidelity prototype in Figma showing the overall prototype structure and the experience steps in focus group.