MUSICAL APPLICATIONS IN INTERACTIVE SONIFICATION: A SCOPING REVIEW

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ABSTRACT

Interactive sonification transforms data into sound and mediates sonic experiences, often drawing on musical knowledge to support human engagement. Despite ongoing discussions of the intertwined relationship between sonification and music, efforts to systematically review musical applications in interactive sonification remain limited. To address this gap, we conducted a scoping review of 199 studies, guided by three research questions to identify research themes, analyse how musical knowledge is conceptualised and applied, and reflect on patterns across thematic groups and musical applications. We identified eight thematic groups, with musical applications largely situated between single sounds and horizontally organised structures. These findings are examined in relation to thematic clusters, the role of music in structuring sonic interactions, and the appropriate use of musical knowledge. This study provides a structured overview of musical applications in interactive sonification, guiding future directions through reflection on thematic patterns and the effective use of music.

1. INTRODUCTION

Sonification refers to the transformation of data into sound to convey information [1, 2], allowing auditory means to mediate human interaction [3]. In interactive contexts, it supports communication via the auditory channel and is typically realised through auditory displays or interfaces [4], including representational forms such as auditory icons and earcons [5, 6]. The field now encompasses diverse conceptual discourses and technical approaches [7], from visual substitution and artistic reinterpretation to spatial technologies and algorithmic methods [8]. These applications remain aligned with the core concept of sonification, expanding its role within sonic interaction design [9].

Sonifying data involves mapping input data to acoustic parameters [8, 2], which can further be framed through musical variables in interaction contexts [10]. Designing interactive sonification with musical concepts can extend beyond the physical attributes of sound, drawing on human engagement in musical interaction [11]. Prior work has discussed both the distinctions and overlaps between sonification and music [12, 13], alongside challenges shaped by musical applications and its interdisciplinary nature [14], with musical knowledge and practice remaining influential in how interactive sonification is structured and interpreted. For example, musical expectancy can shape embodied listening through tension and release [15], and a performer-centred perspective can guide collaborative sound interaction and creation [16].

Reflecting the intertwined nature of this relationship, studies at the intersection of interactive sonification and music are dispersed across themes and musical applications [17]. Musical concepts are framed and applied across domains in varied ways, shaped by differences in disciplinary background and depth of musical knowledge and practice. Given the distinct dynamics of sound, music, and interaction in sonification research, a structured mapping of how musical applications are integrated into interactive sonification can clarify research contexts and guide future directions within this evolving landscape. In response to this, we conducted a scoping review at the intersection of interactive sonification and music, addressing three research questions:

1. What research themes can be identified at the intersection of interactive sonification and music?
2. How has musical knowledge been conceptualised and applied in interactive sonification?
3. What indicative patterns can be observed across research themes and musical applications?

We identified 199 papers and classified them into thematic and musical categories and examined patterns across the findings, guided by the framework proposed by Arksey and O'Malley [18]. Eight thematic groups were identified, with musical applications largely situated between single sounds and horizontally organised structures, corresponding to the zero-to-one dimensional range defined in this study. These findings are further interpreted in relation to the research questions. This study offers a structured overview of the literature at the intersection of interactive sonification and music, contributing to refined future research directions through improved understanding of thematic distributions and interconnections and reflection on the role and effective use of music.

2. METHOD

We conducted a scoping review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Scoping Reviews (PRISMA-ScR) guidelines [19]. A scoping review was appropriate as the study aims to map the research landscape by identifying themes and examining musical applications, rather than addressing a narrowly defined evaluative question [20]. Details of the search, screening, and analysis are outlined below.

2.1. Search Strategy and Eligibility Criteria

Records were identified through searches in eleven online libraries using four keywords: sonification, auditory interface, auditory display, and music. These were combined into three keyword pairs: sonification and music, auditory interface and music, and auditory display and music. The records were then screened at the title and abstract level using more specific keyword combinations. Keywords representing sonification included sonification, auditory interface, auditory display, auditory signal, auditory feedback, auditory icon, auditory cue/cueing, auditory alarm, auditory representation, earcon, lyricon, and spearcon. Music-related keywords were limited to music, rhythm, melody, and harmony, restricting the scope of this study to tonal music. At least one keyword from each category was required to appear in the title or abstract for screening. Full-text articles were subsequently assessed, and only sonification studies reflecting interactive contexts were included.

Eleven online databases were used in this study: Zenodo, ACM, Springer, Sage Journals, IEEE Xplore, Taylor & Francis, AIP Publishing, JSTOR, Cambridge Core, Georgia Tech Library, and AES E-Library. The databases were selected based on general publication trends observed using the search keywords in Google Scholar, accessed via Publish or Perish [21]. This process helped identify relevant journals and conferences, and databases were selected based on their coverage of these venues. Databases such as ACM, Springer, Taylor & Francis, and IEEE Xplore were used to ensure broad coverage. Additional databases were included to capture specific journals and conferences, including Journal of the Audio Engineering Society (JAES), New Interfaces for Musical Expression (NIME), International Community for Auditory Display (ICAD), Human Factors and Ergonomics Society (HFES), Human Factors, Ergonomics in Design, The Journal of the Acoustical Society of America (JASA), Organised Sound, Computer Music Journal, Leonardo, and Leonardo Music Journal (LMJ). The search was not restricted by publication date, as ICAD spans only around 30 years and the review aimed to provide a comprehensive overview of the field. Only full papers were included, and the search was conducted in July 2023. Search keywords, databases, and publication venues are listed in Table 1.

Table 1: Overview of the search strategy, including search and screening keywords, databases, and targeted venues.

Keywords	**Search:** ("Sonification" OR "Auditory Interface" OR "Auditory Display") AND "Music" **Screening:** ("Sonification" OR "Auditory Interface" OR "Auditory Display" OR "Auditory Signal" OR "Auditory Representation" OR "Auditory Feedback" OR "Auditory Icon" OR "Auditory Cue/Cueing" OR "Auditory Alarm" OR "Earcon" OR "Lyricon" OR "Spearcon") AND ("Music" OR "Rhythm" OR "Melody" OR "Harmony")
Databases	Zenodo, ACM, Springer, Sage, IEEE Xplore, Taylor & Francis, AIP, JSTOR, Cambridge Core, Georgia Tech Library, AES E-Library
Venues	JAES, NIME, ICAD, HFES, Human Factors, Ergonomics in Design, JASA, Organised Sound, Computer Music Journal, Leonardo, LMJ

2.2. Screening and Selection Process

Records were identified through the eleven selected databases using the predefined keywords, retrieving only full papers through database search functions. For databases targeting specific journals or conferences, searches were restricted to those venues. In total, 3,647 records were identified. Duplicate records (n=14) were removed, while follow-up studies were retained. Title and abstract screening excluded 3,246 records, leaving 387 for full-text assessment. Full-text articles were then assessed with a focus on interactive sonification. Following full-text review, 188 articles were excluded and 199 studies were included in the review. Covidence [22] was used for title and abstract screening and full-text review, while references were managed using Zotero [23]. The selection process is illustrated in Figure 1. The dataset is publicly available through an online repository.[1]

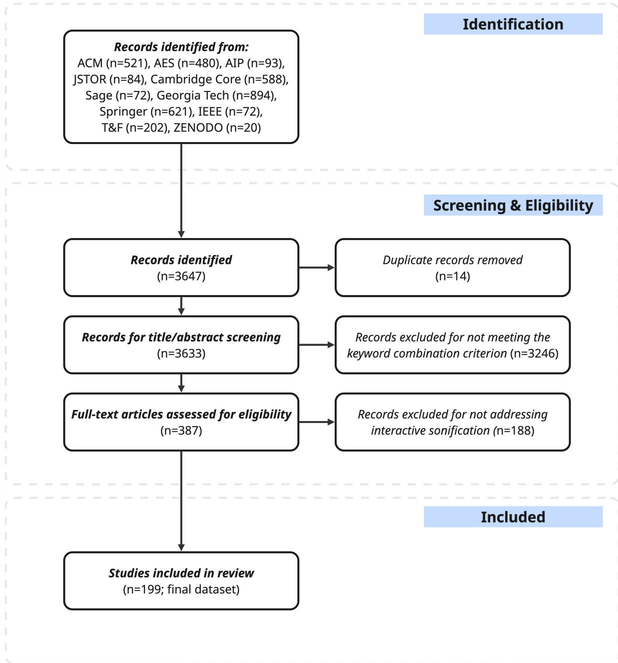

Figure 1: PRISMA flow diagram of the literature search and screening process.

2.3. Data Charting and Analysis

The included studies were interpretively categorised into research themes and musical applications. Descriptive statistics provided a quantitative overview, supplemented by qualitative interpretation of representative cases within each category. Guided by the framework proposed by Arksey and O'Malley [18], the charted data were organised and sorted according to key themes and musical applications, with coding conducted by the first author. Theoretical applications were organised using dimensional concepts devised in this review to accommodate cases not explicitly framed in tonal terminology. The category structure used for analysis is presented in Table 2.

[1] https://github.com/Yorkcla/Scoping-Review-of-Musical-Applications-in-Interactive-Sonification

2.3.1. *Research Theme*

Research themes were grouped into eight categories: *art*, *design*, *emotion*, *medicine*, *movement*, *nature*, *space*, and *vision*. Initial codes such as brain, education, game, security, sport, tactility, and robot were excluded due to limited occurrence or overlap with other categories. The vision theme was refined from a multimodal concept to focus on visual elements, with one tactile exception. Each theme reflects a distinct focus: design addresses sonification methodologies; nature involves data from natural sources such as brainwaves and heartbeats; vision covers studies that supplement or enhance visual information through sound. The remaining themes—art, emotion, medicine, movement, and space—correspond directly to their subject domains. Studies could be assigned to multiple themes to explore interrelations.

2.3.2. *Musical Application*

Musical applications were classified into two categories: theoretical and experiential. Theoretical applications refer to sonification variables interpreted in terms of tonal music elements, including note properties and tonal structures such as melody, chords, and harmony, whereas experiential applications refer to approaches that draw on musical experience through performance and composition. Theoretical applications were further divided into three levels, drawing on tonal concepts but using dimensional categories to accommodate cases beyond explicit tonal terminology. The dimensional levels refer to the structural complexity of relationships between sounds, ranging from single sound units (zero), to one dimensional relationships including horizontal (sequential) and vertical (simultaneous) arrangements, to integrated horizontal and vertical structures (two). Experiential applications were categorised as either from or for musical experience, depending on whether they draw on existing musical expertise or aim to facilitate musical engagement. Listening was not treated as a subcategory, as it was inherent in most studies. Cases were classified as non-specified when sound input was ambiguous, when music or complex, unidentified sounds were used as input, or when multiple applications were not clearly separable. Review articles were excluded from the musical categorisation, and articles spanning multiple groups were assigned to bridging categories.[2]

Table 2: Research themes and musical application categories.

Research Theme	Art, Design, Emotion, Medicine, Movement, Nature, Space, Vision
Musical Application	**Theoretical:** Zero, One(horizontal), One(vertical), Two **Experiential:** from Performance, from Composition, For Performance, For Composition *supplemented with bridging and non-specified categories.

3. RESULTS

3.1. Overview of the Studies

The review included 199 studies from 72 journals or conferences. ICAD held the largest share with 85 studies, followed by Journal of Multimodal User Interfaces with 11, Audio Mostly with 8, and JAES with 6. Regarding research themes, there were 113 instances where only a single theme was pertinent, as shown in Table 3. Design held the most frequent occurrence with 47 instances, followed by vision with 19, movement with 13, and medicine with 9. However, when assessing the concurrent relevance of all themes, the top groups were design with 61, vision with 54, and medicine with 52.[3] In terms of interrelationships, the most pronounced overlaps were between medicine and movement, with 15 instances, and between medicine and vision, with 13 instances, as illustrated in Table 4. There were 9 instances of overlap between medicine and space, 8 between design and vision and between nature and vision, and 7 between art and nature and between art and vision. Overall, medicine and vision emerged as key hubs, structuring thematic interconnections. Additionally, there were 16 reviews, 13 theoretical studies, and 131 studies involving human subjects.

The musical categorisation resulted in 122 theoretical and 16 experiential studies, as shown in Table 5. 11 studies employed both theoretical and experiential applications, 30 studies were non-specified, and 4 studies fell between theoretical and non-specified categories. The theoretical applications included 87 zero dimensional, 19 one dimensional, and 16 two dimensional studies. The experiential applications comprised 5 from and 5 for musical experience, and 6 studies that incorporated both purposes.

Table 3: Number of studies across the eight thematic groups, including single-theme counts, totals with overlaps, reviews, theoretical studies, and studies involving human participants.

	Art	Design	Emotion	Medicine	Movement	Nature	Space	Vision
Single	6	47	7	9	13	7	5	19
Total	24	61	17	52	35	25	31	54
Review	1	11	0	3	1	1	4	0
Theoretical	1	9	1	1	1	0	3	2
Human	15	33	14	39	27	14	16	37

Table 4: Overlaps among the eight thematic groups.

	Art	Design	Emotion	Medicine	Movement	Nature	Space	Vision
Art	-	0	1	3	2	7	5	7
Design	0	-	1	0	0	1	5	8
Emotion	1	1	-	4	2	2	0	3
Medicine	3	0	4	-	15	5	9	13
Movement	2	0	2	15	-	0	3	1
Nature	7	1	2	5	0	-	3	8
Space	5	5	0	9	3	3	-	6
Vision	7	8	3	13	1	8	6	-

3.2. Research Theme

3.2.1. *Art*

6 studies focused solely on the art theme, rising to 24 when overlaps were considered. Overlaps comprised 0 with design, 1 with emotion, 3 with medicine, 2 with movement, 7 with nature, 5 with space, and 7 with vision. 15 involved human subjects, 1 was a review, and 1 was theoretical. The studies included instances of sonifying visual data or providing auditory aids for visualisation, aligned with artistic objectives. They addressed the sonification of

[2]Bridging categories cover boundaries, including intermediate levels such as non-specified to zero, zero to one, and one to two, as well as dual aspects such as horizontal/vertical, from/for, and performance/composition.

[3]Numbers in Table 3 exceed totals due to overlaps.

Table 5: Number of studies by musical application categories (hor = horizontal, ver = vertical, perform = performance, comp = composition, T/E both = both theoretical and experiential, Non-T = between non-specified and theoretical). Review articles (n = 16) were excluded.

	Zero	Zero-One(hor)	Zero-One(ver)	Zero-One(both)	One(par)	One(ver)
Theoretical	17	56	9	5	5	2
	One(both)	One(hor)-Two	One(ver)-Two	One(both)-Two	Two	Sum
	2	5	4	1	16	122
	from Perform	from Comp	from Both	For Perform	For Comp	For Both
Experiential	1	3	1	2	3	0
	Both Perform	Both Comp	Sum			
	4	2	16			
	T/E Both	Non-Specified	Non-T	Sum		**Total**
Others	11	30	4	45		183(16)

biological data, interaction in performance, as well as explorations in algorithmic composition. These topics highlighted connections with natural data visualisation and visual modalities, thus suggesting art as a component of a cluster centred on vision.

[24] introduced a sonification tool designed to translate visual art into auditory form, achieving a trans-artistic purpose termed musical vision. Similarly, [25, 26] proposed guidelines offering design principles for sonifying visual art. In [27], a strategy for comprehending classical Chinese poetry was proposed, involving sonification through a text-to-music framework. This approach mapped musical elements to poem characteristics, employing stochastic algorithms for literary interpretation. [28] pursued predictive modelling for musical sonification using biological data, and [29] explored user experience in collaborative composition by integrating bodily signals. [30] harnessed real-time sonification data from performers to engage with the audience. [31] introduced an algorithmic composition system that integrated geographic and meteorological data. [26] also adopted a machine-learning-based sonification approach to translate visual artworks into music.

3.2.2. Design

47 studies addressed the design theme exclusively, increasing to 61 when overlaps were taken into account. No overlaps were observed with art, medicine, or movement; 1 with emotion, 1 with nature, 5 with space, and 8 with vision. These thematic relationships suggest a cluster centred on vision, supported by methodological studies that frequently used visual data and spatial contexts in sonification. Of these, 33 involved human subjects, 11 were reviews, and 9 were theoretical studies. Consistent with the theme's focus on sonification methodology, many studies adopted theoretical perspectives or proposed future directions. Design encompassed studies on embodied auditory perception, experimental evaluations of variables, domain-specific methodologies, and analyses of musical applications.

[32, 33] approached sonification design through investigations of embodied tonal cognition. Empirical studies across diverse interface types were conducted by [34, 35, 36], typically involving auditory experiments followed by statistical analyses. Context-specific design methodologies were explored in [37, 38, 36]. Musical articulations such as legato were examined by [39], and conceptual distinctions between chord and harmony were clarified in [40]. Specific musical elements were also examined, such as cadence in [41]. Several studies further explored mappings between sonification and visual or spatial elements [42, 43].

3.2.3. Emotion

7 studies were centred solely on the emotion theme, expanding to 17 when overlaps were included. Emotion represented the smallest proportion among the selected themes, yet it intersected with most others, including 1 related to art, 1 to design, 4 to medicine, 2 to movement, 2 to nature, 0 to space, and 3 to vision. 14 involved human subjects, 0 were reviews, and 1 was theoretical. Applications were explored in interdisciplinary contexts such as medicine, where emotions were considered cognitive responses to auditory stimuli. Emotion was framed as a manifestation of cognitive processes, informing sonification design across domains.

In [32], a theoretical approach was adopted for affective interaction through sonification, drawing on embodied music cognition. [44] explored sonification as a medium for both information transmission and emotional expression, evaluating it across three aspects. [45] utilised Twitter data to extract emotional elements and translated them into musical compositions through sonification. [46, 47, 48] investigated interactive sonification applications across domains, including gait-based sonification to access emotional factors and auditory feedback or music listening for relaxation. These studies frequently situated emotion within therapeutic or rehabilitation contexts, emphasising psychological impact.

3.2.4. Medicine

9 studies were situated within the medicine theme alone, increasing to 52 when overlaps were considered, reflecting frequent cross-theme intersections. Overlaps spanned 3 with art, 0 with design, 4 with emotion, 15 with movement, 5 with nature, 9 with space, and 13 with vision. Movement, vision, and space emerged as particularly relevant. 19 involved visually impaired participants, suggesting a bridge between medicine, movement, and vision, with a secondary connection to space. 39 involved human subjects, reflecting the clinical orientation of medical research. 3 were reviews and 1 was theoretical. Applications included auditory feedback for interpreting medical data visualisations or sonifying clinical data, studies engaging visually impaired participants to elicit movement for medical purposes, and cases in sports contexts.

In [49], automatic musical augmentations were implemented within surgical procedures to interpret visualised data. [50] evaluated interactive auditory alarms in clinical multitasking contexts. [51, 52] examined the use of music to support comprehension of medical information and facilitate informed decision-making. Therapeutic applications were investigated in [53, 54, 55], particularly within rehabilitation contexts, employing specialised triggers such as heartbeats to evoke behavioural responses. In sports settings, [56] explored the role of sonification in cycling.

3.2.5. Movement

13 studies concentrated on the movement theme exclusively, rising to 35 when overlaps were taken into account. Overlaps included 2 with art, 0 with design, 2 with emotion, 15 with medicine, 0 with nature, 3 with space, and 1 with vision. 27 involved human subjects, 1 was a review, and 1 was theoretical. The prevalence of user methods reflects movement's close association with human behaviour. Similar to emotion, this theme spans diverse contexts and intersects strongly with medicine, particularly in user validation, and with space due to movement within spatial boundaries. Studies addressed behaviour triggering in virtual environments, auditory representations of performance movements, sports feedback, robot interface design, and movement sonification in gaming.

[57] examined auditory alerts to prevent shoplifting in a virtual retail environment. [58] focused on elbow movements in piano performance for educational purposes. [59] explored sonification of motor skills in golf putting from a human-machine interaction perspective. [60, 61] investigated sonification in robot interfaces to improve user communication. [62, 63] examined gaming contexts, incorporating consonance and dissonance in real-time interaction.

3.2.6. Nature

7 studies focused solely on the nature theme, increasing to 25 when overlaps were considered. Overlaps comprised 7 with art, 1 with design, 2 with emotion, 5 with medicine, 0 with movement, 3 with space, and 8 with vision. Vision, art, and medicine emerged as particularly prominent intersections. 14 involved human subjects, 1 was a review, and 0 were theoretical. The theme focused on the sonification of natural data and its connections to visualisation. Studies frequently addressed biological signals such as brainwaves and heartbeats, while artistic approaches used natural data as material for musical compositions.

[31] introduced sonification techniques based on geographic and meteorological data, and [64] explored pattern recognition through the sonification of fossil morphology. [65] examined planetary properties, proposing sonification as a complementary perspective to visual interpretation in solar system contexts. [66, 67] extended the exploration of brain activity into real-time and 3D environments. [68, 69] investigated the sonification of heartbeats, incorporating musical elements such as rhythm and harmonic tension. [28] developed a modular system for modelling biological data through structured sound and musical processes.

3.2.7. Space

5 studies centred exclusively on the space theme, rising to 31 when overlaps were included. Overlaps extended to 5 with art, 5 with design, 0 with emotion, 9 with medicine, 3 with movement, 3 with nature, and 6 with vision, indicating broad overlap across themes. Medicine and vision were particularly prominent, and space functioned as a connective theme in sonification design. 9 involved visually impaired participants, further reinforcing links between space, medicine, and movement. 16 involved human subjects, 4 were reviews, and 3 were theoretical. The theme was characterised by studies integrating spatial design into sonification, exploring sound and space relationships, and addressing movement within spatial environments, particularly for visually impaired users.

[70] investigated urban environment sonification tailored for architects and designers to generate multimodal outputs. [71] developed an auditory display system for smart city data in Dublin. [72, 73] examined the interplay between sound and space within soundscape contexts, including real-time spatialisation for performers and architects. Studies examining the movement of visually impaired users were identified in [74, 75, 76, 77], often incorporating environmental variables in task-specific contexts such as artwork appreciation, with a focus on spatial accessibility.

3.2.8. Vision

19 studies were centred on the vision theme alone, increasing to 54 when overlaps were considered. Overlaps comprised 7 with art, 8 with design, 3 with emotion, 13 with medicine, 1 with movement, 8 with nature, and 6 with space. Medicine, design, nature, and art emerged as particularly prominent intersections, with 7 studies addressing visual impairment, indicating a cluster centred on vision. 37 involved human subjects, none were reviews, and 2 were theoretical. Research focused on vision addressed the sonification of visual data or its use as an alternative or complement to visual modalities, often through methodological or artistic approaches.

[78] transformed images into chromatic scales based on colour properties. [79] linked sounds to visual elements to enhance user experiences of visual scenes, such as in an aquarium. [24] proposed a sonification approach designed to generate polyphonic musical compositions from visual images. [25] proposed guidelines for sonifying visual artworks, integrating artistic attributes into musical parameters. [80] introduced a multimodal auditory system for algebra notation, using prosody and musical earcons to enhance structural comprehension for visually impaired users.

3.3. Musical Application

3.3.1. Theoretical: Zero Dimension

Zero dimension refers to individual sound units corresponding to single notes. There were 17 instances directly associated with zero dimension, and 70 cases intersected with one dimension, resulting in a total of 87. This constituted a large proportion of both the theoretical categories and the overall pool. Zero-to-one dimension (horizontal), representing an intermediate level between notes and a melodic line, accounted for the largest share with 56 cases. Additionally, zero-to-one (vertical) accounted for 9 cases, and zero-to-one (both) for 5. Studies focusing on single musical variables often employed experimental methods with specified variable mappings. Zero-to-one (horizontal) introduced temporal organisation, such as tempo, rhythm, or timing, at the level of single sound units. Zero-to-one (vertical) emphasised single sound units with limited vertical combinations. Some instances considered both horizontal and vertical aspects while still focusing on single units.

[50] examined individual sounds, exploring simple variables such as alarm type and volume. [35] conducted a usability test of spearcons, focusing on pitch and timbre. Similarly, [81] examined the effectiveness of lyricons, centred on the mapping of single variables. [82] initiated from rhythm and approached melody as an extension, without explicitly addressing harmonic progression despite the harmonic context of the stimuli. [83] sonified visual brightness, moving beyond individual musical parameters to include chordal features. [84] considered individual variables such as pitch and loudness, horizontal attributes such as attack and de-

cay, and harmonic contexts, focusing primarily on chordal qualities rather than broader harmonic progression.

3.3.2. Theoretical: One Dimension

One dimension refers to relationships between sounds through sequential and simultaneous arrangements corresponding to melodic and chordal structures. There were 9 cases aligned with one dimension and 10 overlapping with two dimensions. Horizontal approaches were more common than vertical ones but less prevalent than zero dimensional approaches. This may reflect instances intended as one or two dimensions but classified as the zero-to-one dimension. Some studies referenced harmony but treated horizontal and vertical aspects separately rather than integrating them into a two dimensional structure. Studies focusing on horizontal relationships examined melodic organisation through pitch and temporal structures, while vertical approaches focused on consonance, dissonance, or the timbral features of tonal keys. Some studies incorporated both horizontal and vertical aspects.

[51] investigated melodic elements in relation to users' musical preferences. [85] also emphasised horizontal relationships, examining melodic sonification through pitch and time resolution controls. [63] involved scale concepts but primarily focused on chordal consonance and dissonance. [25] appeared to pursue a two dimensional approach through successive chords, though the progression between sounds remained limited. [86] focused on vertical chromatic relationships within tonal keys for earcon design, while [87] incorporated arpeggios in major scales, involving both vertical and horizontal aspects.

3.3.3. Theoretical: Two Dimensions

Two dimensions refer to sound structures integrating horizontal and vertical relationships in progressions, corresponding to harmonic structures. There were 16 cases classified as two dimensional. Although fewer in number, these cases represent the most comprehensive tonal theoretical applications, encompassing the preceding categories. Studies within two dimensions often drew on functional aspects of tonal music, integrating computational techniques and mathematical models for optimisation.

[27] extended harmonic progressions beyond rhythm, melody, and chords to align with Chinese classical poetry. [31] linked tonic, subdominant, and dominant chord relationships to a Markov chain model, supporting functional structures in tonal music. [88] explored harmony across notes, chords, and melodies in visual sonification, while [41] emphasised hierarchical musical structures through cadences. [89] emphasised melody while still demonstrating harmonic aspects, reflecting how musical variables may overlap in practice across the reviewed studies.

3.3.4. Experiential Application

Experiential applications comprised two categories: from practice and for practice, considering composition and performance. 5 instances were identified within from practice: 3 in composition, 1 in performance, and 1 spanning both. The for practice category included 5 studies, with 3 in composition and 2 in performance. 6 cases overlapped between from and for. Although few, 11 studies combining experiential and theoretical approaches suggest that experiential elements appear in sonification research. In from practice, studies considered compositional layers beyond theoretical elements or incorporated overall musical background as a variable. Studies in for practice used natural data as compositional sources or explored behavioural and spatial aspects in performance. Cases spanning both categories reflected approaches based on practice aimed at enhancing musical experience.

[90] used sound stimuli created by a composer and analysed the composing process in distinct phases. [91] highlighted the role of compositional experience in shaping aesthetics in auditory display design. [92] examined how musical background influences the comprehension of auditory displays. [93] introduced a platform for composing computer music using climate data. [30] proposed a system enabling audiences to interactively control the sonification of performers' real-time movement data during live performances. [94] presented a playable 3D virtual model of a historical clavichord controlled through a MIDI keyboard.

3.3.5. Other Cases

This section covers cases that are both theoretical and experiential, non-specified instances, and studies between non-specified and theoretical approaches, capturing those that do not fit neatly within the primary categories. 11 cases combined theoretical and experiential applications, integrating musical knowledge for artistic practice. 30 instances were classified as non-specified, where the input could not be confined to a specific category. 4 studies fell between non-specified and theoretical, applying variables at a near non-specified level despite a zero dimensional scope.

[24] used chord sequences to sonify visual data for compositional purposes. [26] mapped visual art styles and genres to musical parameters for the sonification of visual artworks. [95] combined theoretical concepts with compositional techniques in music education through audio games. [96] approached sonification through broader perceptual dimensions without specifying theoretical categories, while [97] explored varied perspectives on sonification design through interviews with practitioners. [49, 98, 99] used music as input to explore complex sound elements, reflecting how variables are not always clearly distinguished.

4. DISCUSSION

We begin by addressing the three research questions concerning research themes and musical applications. For RQ1, eight thematic groups were identified across the reviewed studies, with prominent clusters centred on medicine and vision. For RQ2, musical applications were predominantly theoretical (67%), with the largest share falling within the zero-to-one (horizontal) dimension (31%), while only 16 studies (9%) employed two dimensional harmonic structures. Experiential applications were relatively rare (9%). For RQ3, observed patterns are discussed below.

Two thematic clusters centred on medicine and vision emerged, as illustrated in Figure 2. Medicine and vision were closely related, and medicine also connected to movement through topics such as rehabilitation and to space, which provides the context for movement. Vision was linked with medicine through research on visual impairment and the sonification of medical data such as brainwaves and heartbeats. Auditory feedback complementing visual medical signals also remained relevant to medicine. Research on visual impairment illustrates the connections between medicine, vision, movement, and space within this narrative. A similar connection around vision emerged through the artistic sonification of visualised natural data. Sonification of visual data across domains also linked vision to the design theme, reflecting the prevalence of visual materials in sonification methodologies.

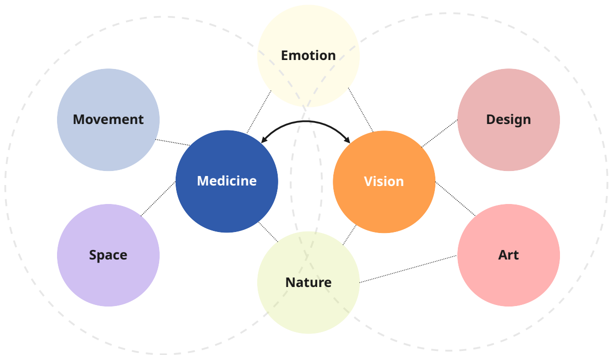

Figure 2: Clusters centred on medicine and vision and their connections to other thematic groups.

Interpreting the role of music within these thematic connections remains challenging. Although this review focused on sonification research related to music, musical elements did not necessarily shape the clusters themselves. The clusters instead appear to reflect broader trends in interactive sonification research. The taxonomy of sonification outlined in [8] already encompasses most of the contexts represented within these clusters, including research on visual impairment. From this perspective, music in interactive sonification research is less a distinct element and more a means of structuring parameters underlying sonic interactions. As outlined in [17], the boundary between sonification and music exists but is blurred within an evolving relationship, with musical knowledge often forming the basis for such configurations.

The majority of the studies relied on theoretical applications. The largest portion fell within the bridging category zero-to-one (horizontal), corresponding to the range from single notes to melodies. A few studies explored one and two dimensional aspects, though they remain limited in number and scope. The use of experiential knowledge derived from musical practice also appears relatively rare. Moreover, some studies were difficult to attribute to specific musical parameters, suggesting that musical applications were not always explicitly articulated in the studies reviewed. Music in interactive sonification research is often approached through simplified musical concepts and is sometimes treated as an abstract reference that can be difficult to define.

Complex musical concepts, however, do not necessarily lead to effective sonification [97]. The key lies in applying musical knowledge in ways that align with each study's objectives. During the review, instances of imprecise musical terminology were observed. The terms chord and harmony were sometimes used interchangeably, making it unclear whether studies referred to simultaneous sound complexes or relationships between chord progressions. Harmony was often used broadly, with only a few studies explicitly examining relationships between chords. Similarly, although some studies focused on melody, harmonic influences were also present in the stimuli. Conversely, studies using simple zero dimensional variables in auditory displays often provided clearer descriptions of the variables and their purposes, facilitating rigorous interpretation of the findings. Detailed musical expertise can support sonification, but its effectiveness depends on how appropriately it is applied to each study's aims, suggesting that future research would benefit from clearly articulated musical concepts when creating sonic interactions aligned with those aims.

5. LIMITATIONS

We acknowledge two main limitations. First, our definition of music centres on tonal music. Although dimensional concepts were used to accommodate a broader range of studies, music cannot be confined to a single definition. Tonal music, however, remains prevalent, particularly among non-musicians who design or use auditory displays [100], supporting tonal music as the analytical focus. Second, the review is limited to literature within a defined timeframe. While recent studies may reveal emerging trends, this review focuses on providing an overview of the research landscape to date through a consistent framework applied across a broad dataset and grounded in existing musical concepts. Future work may extend this scoping review through systematic literature reviews with more refined research questions.

6. CONCLUSION

This paper presents a scoping review of how musical knowledge is applied in interactive sonification research. Across the 199 studies reviewed, eight thematic groups were identified, with musical applications largely structured around single theoretical variables with limited temporal organisation. The thematic interconnections observed across two clusters suggest that music functions less as a distinct element and more as a means of structuring parameters that underpin sonic interactions. Studies predominantly relied on simple theoretical variables, but effective sonification appears to depend less on increasing musical complexity than on aligning clearly defined musical concepts with research objectives. This review highlights the importance of appropriately conceptualising musical knowledge, whether theoretical or experiential, and applying it in ways aligned with research objectives to create sonic interactions grounded in musically shaped sonic experiences.

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A. APPENDIX: FINAL DATASET

This appendix presents the included studies categorised by musical applications. Further detailed analyses are available in the online repository.

Table 6: Included Studies by Musical Application Categories (n = 199)

Theoretical	[101] [27] [102] [103] [104] [105] [106] [82] [107] [108] [109] [83] [110] [111] [112] [59] [113] [114] [32] [115] [116] [74] [117] [118] [45] [33] [60] [119] [50] [120] [31] [61] [87] [70] [46] [121] [122] [123] [124] [125] [126] [44] [127] [128] [75] [129] [130] [131] [132] [133] [134] [88] [135] [51] [77] [47] [136] [34] [35] [137] [138] [139] [42] [25] [64] [84] [36] [80] [39] [140] [141] [142] [143] [144] [145] [146] [78] [147] [81] [148] [62] [149] [150] [71] [54] [29] [151] [152] [40] [153] [63] [154] [155] [156] [157] [55] [158] [69] [159] [160] [161] [162] [85] [163] [41] [86] [164] [165] [68] [166] [167] [168] [169] [170] [65] [171] [172] [173] [174] [175] [89] [176]
Experiential	[177] [178] [179] [58] [180] [30] [181] [182] [92] [90] [183] [91] [67] [79] [94] [93]
T/E Both	[24] [56] [184] [185] [186] [95] [187] [188] [52] [189] [26]
Non-Specified	[190] [191] [53] [49] [192] [98] [76] [193] [194] [195] [66] [196] [197] [38] [198] [48] [199] [200] [96] [28] [99] [201] [202] [203] [204] [205] [206] [57] [97] [207]
Non-T	[208] [209] [210] [73]
Review	[211] [212] [213] [37] [214] [215] [216] [43] [217] [218] [219] [220] [221] [72] [222] [223]