From Movement to Sound and Back: A Workshop on Movement-Based and Sonification Design Approaches

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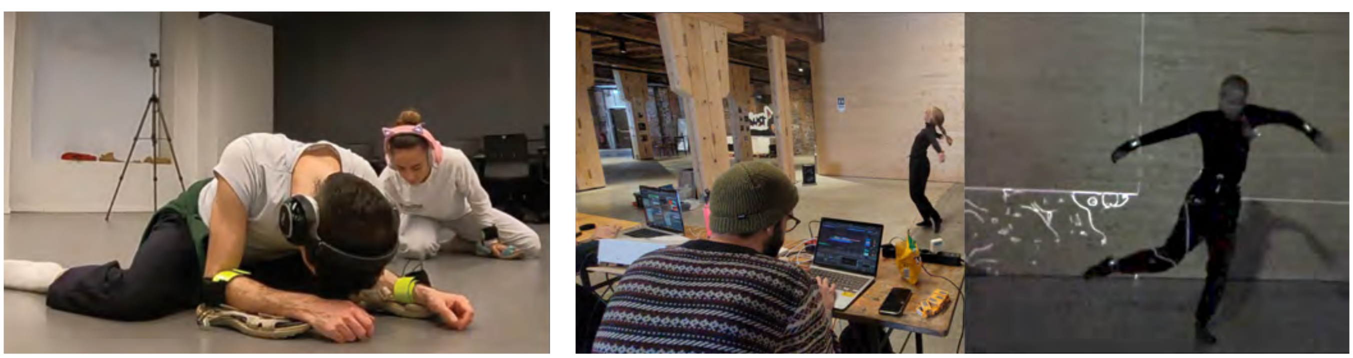

Figure 1: From Movement to Sound and Back: movement sonification in artistic expression during workshop (left, [37, 64] and performance (right) Middle: using the Movement-Sonification toolkit as basis for the performance [45, 76]

ABSTRACT

Movement and sound are intrinsically connected; movement makes sound and sound makes movement. In this playful workshop we aim to unite sonification researchers, music enthusiasts, sound engineers, with movement experts such as SportsHCI researchers, and beyond to engage in a hands-on exchange. The aim of the workshop is to understand how sound can guide movement, and how movement in turn can guide sound design. We will use movement-based design approaches to reflect on the sound design, and use

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sonification approaches to further understand movement. We will use a novel movement sonification tool aiding non-sound experts to easily generate and explore movement sonifications.

KEYWORDS

Sonification, Movement-Based Design, Auditory Display, Movement, Sports

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1 INTRODUCTION

The effects of sound on movement entrainment has been extensively researched [61]. Humans have the tendency to follow auditory rhythms with their bodily movements [8, 18]. Sound has the potential to integrate with locomotion in a subtle and non-distracting way. As such, the usage of sound related to movement is widely explored, as shown in literature reviews [36, 49, 68, 70].

Sonification — the non-verbal representation of data through sound [26] — is a widely adopted approach within Human-Computer Interaction (HCI). The application of sonification demonstrates significant potential for improving physical performance in sports and other movement-oriented practices. Studies indicate that auditory feedback can foster bodily awareness [17, 64, 67], assist with pacing [21, 72], encourage motivation [37, 38, 47, 57], and contribute to the refinement of technique [16, 40]. Typically, movement data is converted to sound through parameter mapping [20], a technique exemplified by e.g. Hermann et al. [27], Schaffert et al. [53], Ceserani et al. [9], Dubus et al., [10]. Within sports and movement contexts, such mappings have been applied toward different goals, such as using sound to correct movement, as demonstrated by Yang et al. [81] and Godbout et al. [19], or instruct movement, as exemplified by works by Van Rheden et al. [72–74], or Hug et al. [31, 32]. Other works showcased how sound can have a spontaneous or persuasive effect on movement, e.g. [60, 66, 69].

Movement-based design methods (MBDM) motivate designers to draw upon the body as a creative asset, using movement as both a medium and a tool in the design process [29, 34]. They emphasize attentiveness to the subtle, transient, and immediate qualities of movement experiences [1, 6, 39]. MBDM have become increasingly recognized across multiple fields for their distinctive capacity to reveal embodied perspectives of stakeholders participating in the design process [54, 80]. These approaches are applied throughout various stages of design work, including sensitization, idea generation, prototyping, evaluation, and the documentation of movement-related insights [62].

In this workshop, we will explore how sonification can provide insights into design for movement, and vice versa. Different from previous workshops on sonification, e.g. Hermann et al. organized a workshop on sonification for sonic interaction design [28] which focused on mobile interaction. In 2016, Höök et al. organized a workshop on movement, emotion, and somaeasthetics [30]. In 2024, Van Rheden et al. conducted a workshop on movement-based design, introducing a first iteration of their movement sonification toolkit [76].

Differently from these prior workshops, we aim to explore *how sonification can contribute to movement-based design* and *how movement-based design can inform and shape movement sonification.* As such, we will explore how these methodologies can enhance, accelerate, and amplify each other. The novelty of this workshop lies in treating movement-based design and movement sonification as mutually informing design approaches.

2 BACKGROUND

2.1 Sonification

Sonification has been employed both for real-time exploration [5] and support [70] of movement and for the post-hoc analysis of recorded datasets [12]. Beyond its role as an immediate feedback modality during interaction, sonification provides an alternative analytic lens that differs fundamentally from conventional visual methods, such as interpreting data through graphs or plots [12]. By mapping movement data onto auditory parameters, sonification can reveal temporal structures, dynamic qualities, and subtle variations in the data that may remain obscured in visual representations [11, 26, 58]. As such, sonification extends the analytic repertoire available to researchers and designers, enabling embodied and multisensory engagement with movement data.

Movement sonification is the process of mapping physical movement parameters (such as position, speed, or acceleration) to auditory signals, allowing users to "hear" their own or others' movements in real time. However, sonification goes beyond conveying information. Its use in dance, performance, and interactive installations has shown that it allows for communicating movement qualities difficult to put into words and evokes emotional responses [37, 38, 64, 67].

Sonification has been applied to various sports and movement contexts as a form of biofeedback for motor learning, rehabilitation, and training [13, 25, 56]. This ranges from functional goals, like conveying biomechanical parameters, to more expressive and experiential qualities of sonification, such as motivation, engagement, and aesthetics [24, 59]. This broad spectrum corresponds to broader HCI directions: whereas first-wave HCI foregrounded usability and task completion, subsequent waves emphasized meaning, engagement, and experience [7, 23].

Stienstra's Augmented Speed-skate Experience study showcases how sports and movement sonification can be understood across three layers of parameter mapping: (1) data acquisition (what to measure, e.g. foot pressure, acceleration), (2) data interpretation (deriving and scaling variables), and (3) sound design (mapping to auditory dimensions such as loudness, pitch, timbre) [59]. This layered view shows how functional mappings provide the structural foundation, whereas aesthetic and motivational concerns influence whether the sounds remain informative and engaging. Examples from rowing [11] and skating [59] demonstrate how athletes benefit both from precise technical cues and from engaging auditory experiences that sustain training.

Figure 2: Movement sonification in sports. A visual impression of movement sonification in the sports contexts of the author's works, showing a broad range of sonification types and approaches. Previous works of the authors included swimming sonification [15, 33, 48, 55] (left), rowing sonification [50–52] (middle), and running sonification [21, 22, 32, 71–74](right). Image by Van Rheden et al. [76]

In the movement sonification design process, movement influences sound, and sound influences movement. This highlights the relation between sound and movement, and the potential to express both functional and expressive and aesthetic qualities both entail. This perspective underpins the goals of our proposed workshop: to explore how movement-based design methods can support the integration of functional mappings and aesthetic qualities in sonification. As such, we propose movement-based design as a potential catalyst within movement sonification design, enabling richer, more creative, and user-centred interactive experiences, as we will show in the next section.

2.2 Movement-based design

Across multiple fields, movement-based design methods have become increasingly valued for their capacity to include embodied experiences within the design process [42, 54, 80]. They serve important functions throughout diverse stages of design projects, including activities of sensitization, idea generation, prototyping, evaluation, and the systematic documentation of movement-related insights [62]. Within both design for movement and design of movement, practitioners are encouraged to engage the body as a generative resource, employing movement as a medium or tool through which design can take shape [29, 34, 42]. This requires sensitivity to the subtle, ephemeral, and immediate qualities of movement experience [1, 6, 39]. Common practices in MBD include bodystorming, embodied sketching, and experience prototyping, among others [4, 41, 42, 44, 46, 63, 67]. We consider all these methods worth exploring when designing for sonification design and within this workshop we will identify their advantages and disadvantages to inform the design of such systems. In turn, we expect sonification of movements will enhance and catalize the movement-based design process.

3 MOVEMENT SONIFICATION TOOLKIT

To explore the relation between movement and sonification during the workshop, we will bring a movement sonification toolkit [45] aimed to enable intuitive, flexible, and expressive interaction with movement data, allowing exploration of diverse sound strategies. We developed this toolkit through workshops with sound experts [76], and movement specialists creating a live performance at a multidisciplinary art exhibition, see Figure 2 right.

The toolkit is a modular, sensor-agnostic system developed in Max/MSP, aimed specifically at enabling non-experts to explore movement data through sound. It provides a graphical user interface (see Figure 3) with which users can connect movement signals, either from recorded data or real-time sensors, to different sound parameters through a matrix-style mapping system. This allows many-to-many relationships (e.g., linking steps to volume while breathing intensity controls pitch), with immediate auditory feedback.

The toolkit currently includes four built-in sound design modules:

- **Test-Module**, which generates a simple sine tone and is ideal for quick functional testing or calibration.
- **Abstract-Module**, an additive synthesizer that allows for expressive and information-rich sonifications through control over pitch, harmonicity, and timbre, making it suitable for highlighting nuanced changes in data.
- **Musical-Module**, which plays segments of familiar melodies (e.g., Für Elise or Bach's Prelude in C) on a synthesized string instrument.
- **Ambient-Module**, which creates immersive naturalistic soundscapes using birds, wind, rain, and thunder elements, offering a low-distraction background suitable for mindful contexts.

Users can quickly compare modules or introduce custom designs to fit specific scenarios.

The toolkit integrates with wireless sensors such as IMUs, pressure sensors, and flex sensors, with low-latency data handling to ensure responsive feedback. Users can record movement-data on the fly and use playback and inspection features enable researchers to test mappings and evaluate designs across sessions. These features make the toolkit a practical environment for the workshop.

4 GOALS OF THE WORKSHOP

The workshop goals are as follows:

- Providing an interdisciplinary forum for researchers, practitioners and designers to explore how sonification design

Figure 3: The Movement Sonification Toolkit GUI. Shown here is the data playback interface with two data streams loaded (breathing and steps of a runner). The Ambient sound design module is active and the mapping matrix illustrates the connections between sensor data and sound parameters.

approaches and movement-based design approaches can enhance, accelerate, and amplify each other

- Getting hands-on experience designing novel sonification experiences through the interactive Sonification Toolkit
- Understanding opportunities and define next steps of movement in sonification design and vice versa.

5 TOPICS OF INTEREST

The topics of interest for the workshop include theories, technologies, and applications related to the use of sound and sonification in movement contexts. Relevant topics include, but are not limited to:

- Sonification design approaches and movement-based design approaches can enhance, accelerate, and amplify each other
- Methodologies and techniques to explore, design, and understand sonifications
- Sonification applications in dance, sportsHCI [14] and rehabilitation
- Individual and group movement sonification and audience involvement [2]
- Accessibility and inclusivity in and through movement sonification, including how sound could support diverse movement abilities.
- Sonification in other embodied and movement-rich contexts, e.g. mobility, gastronomy [79], and play.

6 PRE-WORKSHOP PLANS

We plan to recruit up to 30 participants for the workshop. To achieve this objective, we will issue a call for participation (CFP, see Section 7) on the workshop website and disseminate it broadly within relevant communities and networks. Applications are welcome from both academic researchers and industry practitioners. The CFP will additionally be promoted via HCI-focused mailing lists (e.g., CHI-Announcements) and shared across social media platforms such as LinkedIn, BlueSky, and Instagram. Prospective participants will be invited to submit a position paper including the following information:

- Background: Describing the participant's experience with movement/sonification projects.
- Describe a sonification system that they developed, participated, or experienced.
- Write a reflection including 3 key challenges and 3 key insights when designing movement/sonification systems.

To promote inclusivity and accessibility, we will consult with participants to identify and accommodate any specific needs.

7 CALL FOR PARTICIPATION

Movement and sound are inherently interwoven: movement generates sound, sound motivates movement. This workshop explores how sonification design approaches and movement-based design approaches can enhance, accelerate, and amplify each other. How can movement inform sonification design? And how can sonifications help movement-based design approaches? In this hands-on workshop participants will be introduced to a movement-sonification toolkit and explore designing for sound through movement and designing for movement through sound. We invite HCI researchers that work within the scope of designing interactive systems with emphasis on sound and or movement. For more information, visit https://hci.plus/sites/movement-sonification/ and please fill out the following google form to apply: https://forms.gle/KrFQ3UhzP2eRfvit6

8 WORKSHOP STRUCTURE

The workshop will take place over a single afternoon, consisting of two 90-minute sessions. Planned activities include a keynote presentation by Sarah Fdili Alaoui, short demos or video presentations from participants. Then, the sonification toolkit will be introduced and participants split up into groups in order to explore movement and sonification approaches with specific movement design or sonification design focus. Next, groups discussions and reflect on their design processes and challenges they faced. The activities will be organized according to the following timeline:

- **25 mins: Workshop introduction and keynote**
- **30 mins: Activity 1: Participant introductions** will showcase their movement/sonification examples and discuss challenges and key insights related to movement sonification design. These contributions will be organized collectively on a shared post-it wall.
- 5 mins: Break
- **30 mins: Activity 2: Movement Sonification toolkit introduction** in which participants will try out the toolkit and explore its possibilities. Participants will connect sample movement data to sound parameters and experiment with simple mappings to understand the toolkit's interaction logic.
- Main Break
- **45 mins: Activity 3: Hands-on Exploring of Movement and Sonification** in which participants will go through a design iteration of a movement or sonification design — using either movement as input for sonification or vice versa. Each group will select a movement scenario, choose relevant data streams and create a mapping using the toolkit. They will produce a simple sonification sketch or movement concept that can be shown and discussed in Activity 4.
- 5 mins: Break
- **25 mins: Activity 4: Participant Presentations and Reflections** in which participants will share the outcomes of activity 3 and reflect on the methodology used. The outcomes will be collected to identify common strategies and challenges across groups.
- **15 mins: Closing:** Next steps and future collaboration.

9 POST-WORKSHOP PLANS & OUTCOMES

The workshop results will be communicated to a larger audience through the workshop website. Participant's position papers will be published through arXiv and will be shared on the organizers' website. Movement sonifications designed during the workshop will be shared as videos on the organization website. The anticipated workshops outcomes are as follows:

- Shared understanding of current approaches, challenges, and opportunities in movement sonification.
- Hands-on experience with the Movement Sonification Toolkit for prototyping and exploring mappings between movement data and sound.
- Identification of future directions and research questions for applying sonification in movement-related domains.
- Strengthening the network among researchers and practitioners interested in sonification and movement interaction.

10 ORGANIZERS

The organizing team includes scholars of different backgrounds with extensive experience in hosting workshops at major HCI venues.

Michael Reichmann is a research fellow at the HCI division of the University of Salzburg. His work centers on cross-modality and sonic interaction design [35]. Currently, he is developing the sonification toolkit for non-experts to design sonifications for athlethes to enhance their sports experience and performance.

Vincent van Rheden is a research fellow at the Human-Computer Interaction division of the University of Salzburg, Austria. His PhD focuses on supporting runners with breathing techniques through interactive sonification systems [71, 74]. He has co-organized various sports and movement-based HCI workshops, e.g. [3, 77].

Maria 'Mafe' Montoya is a PhD student in the Exertion Games Lab at Monash University in Melbourne, Australia. Her research covers the design of SportsHCI and WaterHCI systems as well as soma design practice. She has co-organised a Ubicomp'24 workshop on multimodal feedback in sports [75] and a DIS'25 workshop on water sports [43].

Hongyue Wang is a Ph.D. candidate at the Exertion Games Lab, Monash University (Melbourne, Australia). He investigates how auditory elements can be orchestrated as "ingredients" to enrich culinary practitioners' creative experimentation [78, 79]. Building on this direction, he is currently exploring the intersection of AI music generation and sonification to meaningfully integrate auditory interaction into everyday dining and facilitate mindful eating.

Hakan Yılmazer is an interaction designer and UX researcher, working in sports contexts. He explores the use of sound and music to enhance the sports experiences, using wearable and embedded systems that deliver sonification. He is currently working with boulderers and musicians to find new ways of expressing motion through sound.

Laia Turmo Vidal is a postdoctoral interaction design researcher at KTH Royal Institute of Technology developing body-centric and critical approaches to designing for health and well-being. Her work explores how movement sonification can positively transform body experiences in contexts of physical activity and dance [37, 38, 64, 65, 67].

Daniel Hug is a sound and interaction designer who explores the world of sound through design, theoretical inquiry, teaching, and applied research. He is the co-director of the Sound Design master's program at Zurich University of the Arts, and an international lecturer in Sound Studies and Sound Design. With his practice-based and interdisciplinary research, Hug has had a significant impact on the field of sonic interaction design (SID) and integrated music education (IME). His current interests include sound design for health tech and exercise, sound design methodology and participatory sound design processes.

Nina Schaffert is a Postdoc in Human Movement Science and she received her PhD from the University of Hamburg. Her research areas include Movement Sonification; Measuring and Feedback Technologies; Motor Learning and Control; and Movement Analysis. She applies this expertise to research developing applications for sports practice including auditory displays; investigating methods of improving user's performance; and investigating how sonification designs need to be applied for use in sport and rehabilitation in cooperation with industrial partners.

Prof. Alexander Meschtscherjakov is a full professor at the HCI division of Salzburg University. His research focus on new forms of user interface design, user experience with mobility systems, and persuasion to foster new forms of behaviour. He co-organized conferences such as AutomotiveUI'11 or Persuasive'15 and was co-organizer of more than 25 workshops (e.g., CHI'15-'21).

Prof. Florian 'Floyd' Mueller is Professor of Future Interfaces at Monash University in Melbourne, Australia, directing the Exertion Games Lab. Floyd was general co-chair for CHI PLAY'18 and was selected to co-chair CHI'20 and CHI'24. Floyd has co-organized over 6 workshops and Dagstuhl seminars around SportsHCI.

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