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

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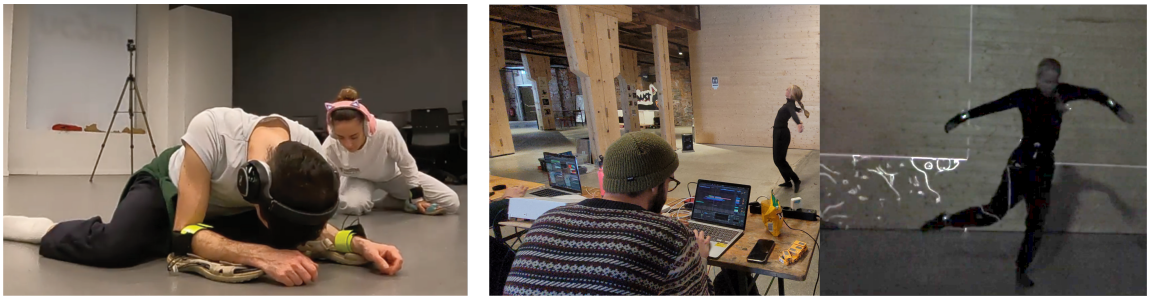

Fig. 1. From Movement to Sound and Back: movement sonification in artistic expression during workshop (left, [35, 59] and performance (right) Middle: using the Movement-Sonification toolkit as basis for the performance [42, 70]

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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 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.

Additional Key Words and Phrases: 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 [56]. Humans have the tendency to follow auditory rhythms with their bodily movements [8, 16]. 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 [34, 45, 62, 64].

Sonification — the non-verbal representation of data through sound [24] — 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 [59, 61**?**], assist with pacing [**? ?**], encourage motivation [35**? ?** , 36], and contribute to the refinement of technique [**? ?**]. Typically, movement data is converted to sound through parameter mapping [18], a technique exemplified by e.g. Hermann et. al [25], Schaffert et. al [49], 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 [75] and Godbout et. al. [17], or instruct movement, as exemplified by works by Van Rheden et. al [66–68], or Hug et. al. [29, 30]. Other works showcased how sound can have a spontaneous or persuasive effect on movement, e.g. [55, 63**?**].

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 [27, 32]. They emphasize attentiveness to the subtle, transient, and immediate qualities of movement experiences [1, 6, 37]. MBDM have become increasingly recognized across multiple fields for their distinctive capacity to reveal embodied perspectives of stakeholders participating in the design process [50, 74]. These approaches are applied throughout various stages of design work, including sensitization, idea generation, prototyping, evaluation, and the documentation of movement-related insights [57].

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 [26] which focused on mobile interaction. In 2016, Höök et. al organized a workshop on movement, emotion, and somaeasthetics [28]. In 2024, Van Rheden et. al conducted a workshop on movement-based design, introducing a first iteration of their movement sonification toolkit [70].

Differently from these prior workshops, we aim to explore *how sonification can contribute to movement-based design* and *how movement-based design can contribute to movement-based design.* As such we will explore how these methodologies can enhance, accelerate, and amplify each other.

Fig. 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, 31, 44, 51] (left), rowing sonification [46–48] (middle), and running sonification [19, 20, 30, 65–68](right)

2 BACKGROUND

2.1 Sonification

Sonification has been employed both for real-time exploration [5] and support [64] 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, 24, 53]. 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 [35, 36, 59, 61].

Sonification has been applied to various sports and movement contexts as a form of biofeedback for motor learning, rehabilitation, and training [13, 23, 52]. This ranges from functional goals, like conveying biomechanical parameters, to more expressive and experiential qualities of sonification, such as motivation, engagement, and aesthetics [22, 54]. 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, 21].

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) [54]. 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 [54] demonstrate how athletes benefit both from precise technical cues and from engaging auditory experiences that sustain training.

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 [39, 50, 74]. 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 [57]. 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 [27, 32, 39]. This requires sensitivity to the subtle, ephemeral, and immediate qualities of movement experience [1, 6, 37]. Common practices in MBD include bodystorming, embodied sketching, and experience prototyping, among others [4, 38, 39, 41, 43, 58, 61]. 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 [42] 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 [70], 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

Fig. 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.

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 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
- Sonification in other embodied and movement-rich contexts, e.g. mobility, gastronomy [73], 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. To apply please fill out the following google form: 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 an Sarah Fdili Alaoui (to be confirmed), 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
- 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.
- 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.

- **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 [33]. 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 [65, 68]. He has co-organized various sports and movement-based HCI workshops, e.g. [3, 71].

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 [69] and a DIS'25 workshop on water sports [40].

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 [72, 73]. 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 [35, 36, 59–61].

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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REFERENCES

[1] Sarah Fdili Alaoui, Baptiste Caramiaux, Marcos Serrano, and Frédéric Bevilacqua. 2012. Movement qualities as interaction modality. In *Proceedings of the Designing Interactive Systems Conference* (Newcastle Upon Tyne, United Kingdom) *(DIS '12)*. Association for Computing Machinery, New York, NY, USA, 761–769. https://doi.org/10.1145/2317956.2318071

[2] Sarah Fdili Alaoui and Jean-Marc Matos. 2021. RCO: Investigating social and technological constraints through interactive dance. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–13.

[3] Josh Andres, Vincent van Rheden, Maria Fernanda Montoya, Michelle Adiwangsa, Thomas Biedermann, and Chris Danta. 2024. More-than-Human Moments via Movement-based Design and Cultural Insights. In *Proceedings of the 36th Australasian Conference on Human-Computer Interaction*. 877–882.

[4] Jon Back, Laia Turmo Vidal, Annika Waern, Susan Paget, and Eva-Lotta Sallnäs Pysander. 2018. Playing Close to Home: Interaction and Emerging Play in Outdoor Play Installations. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–11. https://doi.org/10.1145/3173574.3173730

[5] Tove Grimstad Bang, Sarah Fdili Alaoui, and Elisabeth Schwartz. 2023. Designing in Conversation With Dance Practice. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 684, 16 pages. https://doi.org/10.1145/3544548.3581543

[6] Genevieve Bell, Mark Blythe, and Phoebe Sengers. 2005. Making by making strange: Defamiliarization and the design of domestic technologies. *ACM Trans. Comput.-Hum. Interact.* 12, 2 (jun 2005), 149–173. https://doi.org/10.1145/1067860.1067862

[7] Susanne Bødker. 2006. When second wave HCI meets third wave challenges. In *Proceedings of the 4th Nordic conference on Human-computer interaction: changing roles*. 1–8.

[8] Winston D Byblow, Richard G Carson, and David Goodman. 1994. Expressions of asymmetries and anchoring in bimanual coordination. *Human Movement Science* 13, 1 (1994), 3–28.

[9] Daniel Cesarini, Nina Schaffert, Carlo Manganiello, Klaus Mattes, and Marco Avvenuti. 2013. A smartphone based sonification and telemetry platform for on-water rowing training. Georgia Institute of Technology.

[10] Gaël Dubus. 2012. Evaluation of four models for the sonification of elite rowing. *Journal on Multimodal User Interfaces* 5, 3 (2012), 143–156.

[11] Gaël Dubus and Roberto Bresin. 2013. A systematic review of mapping strategies for the sonification of physical quantities. *PloS one* 8, 12 (2013), e82491.

[12] Alfred Effenberg, Joachim Melzer, Andreas Weber, and Arno Zinke. 2005. Motionlab sonify: A framework for the sonification of human motion data. In *Ninth International Conference on Information Visualisation (IV'05)*. IEEE, 17–23.

[13] Alfred O Effenberg. 2005. Movement sonification: Effects on perception and action. *IEEE multimedia* 12, 2 (2005), 53–59.

[14] Don Samitha Elvitigala, Armağan Karahanoğlu, Andrii Matviienko, Laia Turmo Vidal, Dees Postma, Michael D Jones, Maria F Montoya, Daniel Harrison, Lars Elbæk, Florian Daiber, et al. 2024. Grand Challenges in SportsHCI. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems*. 1–20.

[15] André Engel, Nina Schaffert, Roy Ploigt, and Klaus Mattes. 2022. Intra-cyclic analysis of the front crawl swimming technique with an inertial measurement unit. (2022).

[16] Philip W Fink, Patrick Foo, Viktor K Jirsa, and JA Scott Kelso. 2000. Local and global stabilization of coordination by sensory information. *Experimental Brain Research* 134, 1 (2000), 9–20.

[17] Andrew Godbout and Jeffrey Edwin Boyd. 2012. Rhythmic sonic feedback for speed skating by real-time movement synchronization. *International Journal of Computer Science in Sport* 11, 3 (2012), 37–51.

[18] Florian Grond and Jonathan Berger. 2011. Parameter mapping sonification. In *The sonification handbook*.

[19] Eric Harbour, Vincent van Rheden, Hermann Schwameder, and Thomas Finkenzeller. 2023. Step-adaptive sound guidance enhances locomotor-respiratory coupling in novice female runners: A proof-of-concept study. *Frontiers in Sports and Active Living* 5 (2023), 1112663.

[20] Eric Harbour, Vincent van Rheden, Harald Rieser, Ulf Jensen, and Hermann Schwameder. 2024. Custom Smartphone Application to Guide Locomotor-Respiratory Coupling in the Field Using Step-Adaptive Breathing Sounds. *Journal of Visualized Experiments (JoVE)* 211 (2024), e66733.

[21] Steve Harrison, Deborah Tatar, and Phoebe Sengers. 2007. The three paradigms of HCI. In *Alt. Chi. Session at the SIGCHI Conference on human factors in computing systems San Jose, California, USA*. 1–18.

[22] Christoph Henkelmann. 2007. Improving the aesthetic quality of realtime motion data sonification. *Computer Graphics Technical Report CG-2007-4. University of Bonn* (2007).

[23] Thomas Hermann, Oliver Höner, and Helge Ritter. 2005. AcouMotion–an interactive sonification system for acoustic motion control. In *International Gesture Workshop*. Springer, 312–323.

[24] Thomas Hermann, Andy Hunt, and John G Neuhoff. 2011. *The sonification handbook*. Logos Verlag Berlin.

[25] Thomas Hermann, Bodo Ungerechts, Huub Toussaint, and Marius Grote. 2012. Sonification of pressure changes in swimming for analysis and optimization.

[26] Thomas Hermann, John Williamson, Roderick Murray-Smith, Yon Visell, and Eoin Brazil. 2008. Sonification for sonic interaction design. In *Proc. of the CHI 2008 workshop on sonic interaction design (SID), Florence. CHI.*

[27] Kristina Höök. 2018. *Designing with the body: Somaesthetic interaction design*. MIT Press.

[28] Kristina Höök, Martin Jonsson, Anna Ståhl, Jakob Tholander, Toni Robertson, Patrizia Marti, Dag Svanaes, Marianne Graves Petersen, Jodi Forlizzi, Thecla Schiphorst, et al. 2016. Move to be Moved. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. 3301–3308.

[29] Daniel Hug, Michelle Haas, Jasmin Meier, and Eveline Graf. 2025. Sonic Skater Jump: Exploring the Sound Design of Complex Auditory Movement Guidance for Physical Therapy.

[30] Daniel Hug and Sascha Ketelhut. 2024. Sonic Shuttle Run: Leveraging Sound Design to Improve Affective Response and Performance in Maximal Exercise Tests. In *Proceedings of the 19th International Audio Mostly Conference: Explorations in Sonic Cultures* (Milan, Italy) *(AM '24)*. Association for Computing Machinery, New York, NY, USA, 162–173. https://doi.org/10.1145/3678299.3678315

[31] Daniel Hug, Gabriela Seibert, and Markus Cslovjecsek. 2015. Towards an Enactive Swimming Sonification: Exploring Multisensory Design and Musical Interpretation. (2015).

[32] Caroline Hummels, Kees CJ Overbeeke, and Sietske Klooster. 2007. Move to get moved: a search for methods, tools and knowledge to design for expressive and rich movement-based interaction. *Personal and Ubiquitous Computing* 11 (2007), 677–690.

[33] Michael Iber, Bernhard Dumphart, Victor-Adriel de Jesus Oliveira, Stefan Ferstl, Joschua M. Reis, Djordje Slijepčević, Mario Heller, Anna-Maria Raberger, and Brian Horsak. 2021. *Mind the Steps: Towards Auditory Feedback in Tele-Rehabilitation Based on Automated Gait Classification*. Association for Computing Machinery, New York, NY, USA, 139–146. https://doi.org/10.1145/3478384.3478398

[34] Costas I Karageorghis and David-Lee Priest. 2012. Music in the exercise domain: a review and synthesis (Part I). *International review of sport and exercise psychology* 5, 1 (2012), 44–66.

[35] Judith Ley-Flores, Laia Turmo Vidal, Nadia Berthouze, Aneesha Singh, Frédéric Bevilacqua, and Ana Tajadura-Jiménez. 2021. SoniBand: Understanding the Effects of Metaphorical Movement Sonifications on Body Perception and Physical Activity. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21)*. Association for Computing Machinery, New York, NY, USA, 1–16. https://doi.org/10.1145/3411764.3445558

[36] Judith Ley-Flores, Laia Turmo Vidal, Elena Márquez Segura, Aneesha Singh, Frédéric Bevilacqua, Francisco Cuadrado, Joaquín Roberto Díaz Durán, Omar Valdiviezo-Hernández, Milagrosa Sánchez-Martin, and Ana Tajadura-Jiménez. 2024. Co-Designing Sensory Feedback for Wearables to Support Physical Activity through Body Sensations. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 8, 1 (March 2024), 1–31. https://doi.org/10.1145/3643499 Publisher: ACM.

[37] Lian Loke and Toni Robertson. 2013. Moving and making strange: An embodied approach to movement-based interaction design. *ACM Trans. Comput.-Hum. Interact.* 20, 1, Article 7 (apr 2013), 25 pages. https://doi.org/10.1145/2442106.2442113

[38] Elena Márquez Segura, Laia Turmo Vidal, and Asreen Rostami. 2016. Bodystorming for movement-based interaction design. *Human Technology* 12 (2016).

[39] Elena Márquez Segura, Laia Turmo Vidal, Asreen Rostami, and Annika Waern. 2016. Embodied Sketching. 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, 6014–6027. https://doi.org/10.1145/2858036.2858486

[40] Maria F Montoya, Vincent van Rheden, Josh Andres, Ian Smith, Don Samitha Elvitigala, Andrii Matviienko, Laia Turmo Vidal, Alexander Meschtscherjakov, and Fabio Zambetta. 2025. Surfing the Opportunities for Water Sustainability when Designing Outdoor Water Sports Experiences. In *Companion Publication of the 2025 ACM Designing Interactive Systems Conference*. 68–71.

[41] Florian Mueller, Martin R. Gibbs, Frank Vetere, and Darren Edge. 2014. Supporting the creative game design process with exertion cards. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Toronto, Ontario, Canada) *(CHI '14)*. Association for Computing Machinery, New York, NY, USA, 2211–2220. https://doi.org/10.1145/2556288.2557272

[42] Michael Reichmann, Vincent van Rheden, Antoni Rayzhekov, Thomas Grah, Oliver Jung, and Alexander Meschtscherjakov. 2025. Movement Sonification Toolkit: Enabling Non-Sound Experts to Create Movement Data Sonifications. In *Proceedings of the Annual Conference on Human-Computer Interaction and Sports (SportsHCI 2025)* (Enschede, Netherlands). Association for Computing Machinery, New York, NY, USA, 1–6. https://doi.org/10.1145/3749385.3749410

[43] Juan Restrepo-Villamizar, Steven Vos, Evert Verhagen, and Carine Lallemand. 2021. Crafting On-Skin Interfaces: An Embodied Prototyping Journey. In *Proceedings of the 2021 ACM Designing Interactive Systems Conference* (Virtual Event, USA) *(DIS '21)*. Association for Computing Machinery, New York, NY, USA, 1129–1142. https://doi.org/10.1145/3461778.3462055

[44] Nina Schaffert, André Engel, Sebastian Schlüter, and Klaus Mattes. 2019. The sound of the underwater dolphin-kick: developing real-time audio feedback in swimming. *Displays* 59 (2019), 53–62.

[45] Nina Schaffert, Thenille Braun Janzen, Klaus Mattes, and Michael H. Thaut. 2019. A Review on the Relationship Between Sound and Movement in Sports and Rehabilitation. *Frontiers in Psychology* 10 (2019), 244. https://doi.org/10.3389/fpsyg.2019.00244

[46] Nina Schaffert and Klaus Mattes. 2015. Interactive sonification in rowing: an application of acoustic feedback for on-water training. *IEEE MultiMedia* (2015).

[47] Nina Schaffert, Klaus Mattes, and Alfred O Effenberg. 2010. Listen to the boat motion: acoustic information for elite rowers. In *Human interaction with auditory displays–proceedings of the interactive sonification workshop*. 31–38.

[48] Nina Schaffert, Klaus Mattes, and Alfred O Effenberg. 2011. An investigation of online acoustic information for elite rowers in on-water training conditions. *Journal of human sport and exercise* 6, 2 (2011), 392–405.

[49] Nina Schaffert, Klaus Mattes, and Alfred O Effenberg. 2011. The sound of rowing stroke cycles as acoustic feedback. International Community for Auditory Display.

[50] Dennis Schleicher, Peter Jones, and Oksana Kachur. 2010. Bodystorming as embodied designing. *Interactions* 17, 6 (nov 2010), 47–51. https://doi.org/10.1145/1865245.1865256

[51] Gabriela Seibert, Daniel Hug, and Markus Cslovjecsek. 2015. Towards an enactive swimming sonification: exploring multisensory design and musical interpretation. In *Proceedings of the Audio Mostly 2015 on Interaction With Sound*. 1–8.

[52] Charles H Shea, Gabriele Wulf, Jin-Hoon Park, and Briana Gaunt. 2001. Effects of an auditory model on the learning of relative and absolute timing. *Journal of motor behavior* 33, 2 (2001), 127–138.

[53] Jelle Stienstra, Kees Overbeeke, and Stephan Wensveen. 2011. Embodying complexity through movement sonification: case study on empowering the speed-skater. In *Proceedings of the 9th ACM SIGCHI Italian chapter international conference on computer-human interaction: facing complexity*. 39–44.

[54] Jelle Stienstra, Kees Overbeeke, and Stephan Wensveen. 2011. Embodying complexity through movement sonification: case study on empowering the speed-skater. In *Proceedings of the 9th ACM SIGCHI Italian chapter international conference on computer-human interaction: facing complexity*. 39–44.

[55] Frederik Styns, Leon van Noorden, Dirk Moelants, and Marc Leman. 2007. Walking on music. *Human Movement Science* 26, 5 (2007), 769–785. https://doi.org/10.1016/j.humov.2007.07.007 Music, Movement, Sound and Time.

[56] Michael H. Thaut. 2013. Entrainment and the Motor System. *Music Therapy Perspectives* 31, 1 (05 2013), 31–34. https://doi.org/10.1093/mtp/31.1.31 arXiv:https://academic.oup.com/mtp/article-pdf/31/1/31/6931079/31-1-31.pdf

[57] Laia Turmo Vidal, Elena Márquez Segura, Laia Turmo Vidal, and Elena Márquez Segura. 2018. Documenting the Elusive and Ephemeral in Embodied Design Ideation Activities. *Multimodal Technologies and Interaction* 2, 3 (June 2018), 35. https://doi.org/10.3390/mti2030035

[58] Laia Turmo Vidal, Elena Márquez Segura, and Annika Waern. 2018. Sensory bodystorming for collocated physical training design. In *Proceedings of the 10th Nordic Conference on Human-Computer Interaction* (Oslo, Norway) *(NordiCHI '18)*. Association for Computing Machinery, New York, NY, USA, 247–259. https://doi.org/10.1145/3240167.3240224

[59] Laia Turmo Vidal, Ana Tajadura-Jiménez, and Judith Ley-Flores. 2025. Temporal Trajectories: Characterizing Somatic Experiences that Unfold Over Time. In *Proceedings of the 2025 ACM Designing Interactive Systems Conference (DIS '25)*. Association for Computing Machinery, New York, NY, USA, 2931–2949. https://doi.org/10.1145/3715336.3735777

[60] Laia Turmo Vidal, Ana Tajadura-Jiménez, José Manuel Vega-Cebrián, Judith Ley-Flores, Joaquin R. Díaz-Durán, and Elena Márquez Segura. 2024. Body Transformation: An Experiential Quality of Sensory Feedback Wearables for Altering Body Perception. In *Proceedings of the Eighteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '24)*. Association for Computing Machinery, New York, NY, USA, 1–19. https://doi.org/10.1145/3623509.3633373

[61] Laia Turmo Vidal, José Manuel Vega-Cebrián, María Concepción Valdez Gastelum, Elena Márquez Segura, Judith Ley-Flores, Joaquin R. Diaz Duran, and Ana Tajadura-Jiménez. 2024. Body Sensations as Design Material: An Approach to Design Sensory Technology for Altering Body Perception. In *Proceedings of the 2024 ACM Designing Interactive Systems Conference (DIS '24)*. Association for Computing Machinery, New York, NY, USA, 2545–2561. https://doi.org/10.1145/3643834.3660701

[62] Laia Turmo Vidal, Hui Zhu, Annika Waern, and Elena Márquez Segura. 2021. The Design Space of Wearables for Sports and Fitness Practices. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3411764.3445700

[63] Edith Van Dyck, Jeska Buhmann, and Valerio Lorenzoni. 2021. Instructed versus spontaneous entrainment of running cadence to music tempo. *Annals of the New York Academy of Sciences* 1489, 1 (2021), 91.

[64] Vincent van Rheden, Thomas Grah, and Alexander Meschtscherjakov. 2020. Sonification Approaches in Sports in the Past Decade: A Literature Review. In *Proceedings of the 15th International Conference on Audio Mostly* (Graz, Austria) *(AM '20)*. Association for Computing Machinery, New York, NY, USA, 199–205. https://doi.org/10.1145/3411109.3411126

[65] Vincent van Rheden, Thomas Grah, Alexander Meschtscherjakov, Rakesh Patibanda, Wanyu Liu, Florian Daiber, Elise van den Hoven, and Florian 'Floyd' Mueller. 2021. Out of Your Mind!? Embodied Interaction in Sports. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI EA '21)*. Association for Computing Machinery, New York, NY, USA, Article 79, 5 pages. https://doi.org/10.1145/3411763.3441329

[66] Vincent van Rheden, Eric Harbour, Thomas Finkenzeller, Lisa Anneke Burr, Alexander Meschtscherjakov, and Manfred Tscheligi. 2021. Run, beep, breathe: exploring the effects on adherence and user experience of 5 breathing instruction sounds while running. In *Proceedings of the 16th International Audio Mostly Conference*. 16–23.

[67] Vincent van Rheden, Eric Harbour, Thomas Finkenzeller, and Alexander Meschtscherjakov. 2023. Breath Tools: Exploring the Effects on Adherence and User Experience of 4 Sounds Assisting Runners with Coupling Breath to Steps. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI EA '23)*. Association for Computing Machinery, New York, NY, USA, Article 57, 7 pages. https://doi.org/10.1145/3544549.3585736

[68] Vincent van Rheden, Eric Harbour, Thomas Finkenzeller, and Alexander Meschtscherjakov. 2024. Into the Rhythm: Evaluating Breathing Instruction Sound Experiences on the Run with Novice Female Runners. *Multimodal Technologies and Interaction* 8, 4 (2024). https://doi.org/10.3390/mti8040025

[69] Vincent van Rheden, Maria F Montoya, Don Samitha Elvitigala, Alexander Meschtscherjakov, and Florian'Floyd' Mueller. 2024. Multimodal Sports Interaction: Wearables and HCI in Motion. In *Companion of the 2024 on ACM International Joint Conference on Pervasive and Ubiquitous Computing*. 952–955.

[70] Vincent van Rheden, Michael Reichmann, Alexander Meschtscherjakov, Antoni Rayzhekov, Sascha Ketelhut, Daniel Hug, and Nina Schaffert. 2025. LET'S MOVE TOGETHER: A WORKSHOP ON MOVEMENT DATA SONIFICATION FOR SPORTS AND REHABILITATION *(AM '25 - pre-press)*.

[71] Vincent van Rheden, Dennis Reidsma, Lars Elbæk, Carine Lallemand, Laia Turmo Vidal, Andrii Matviienko, Don Samitha Elvitigala, Florian Daiber, Fabio Zambetta, and Florian 'Floyd' Mueller. 2024. Why Movement-Based Design!? Exploring Methods and Experiences in MBD. In *Companion Publication of the 2024 ACM Designing Interactive Systems Conference* (IT University of Copenhagen, Denmark) *(DIS '24 Companion)*. Association for Computing Machinery, New York, NY, USA, 453–457. https://doi.org/10.1145/3656156.3658399

[72] Hongyue Wang, Jialin Deng, Linjia He, Nathalie Overdevest, Ryan Wee, Yan Wang, Phoebe O Toups Dugas, Don Samitha Elvitigala, and Florian Floyd Mueller. 2025. Towards Understanding Interactive Sonic Gastronomy with Chefs and Diners. *Proceedings of the 2025 CHI conference on human factors in computing systems* (2025), 1–19. https://doi.org/10.1145/3706598.3714237

[73] Hongyue Wang, Jialin Deng, Dehui Kong, Ziqi Fang, Hong Luo, Nandini Pasumarthy, Rakesh Patibanda, Sasindu Abewickrema, Xiao Zoe Fang, Don Samitha Elvitigala, and Florian 'Floyd' Mueller. 2025. GastroConcerto: Towards Designing Auditory Dining System to Enrich Chefs' Culinary Practices. In *Proceedings of the Extended Abstracts of the CHI Conference on Human Factors in Computing Systems (CHI EA '25)*. Association for Computing Machinery, New York, NY, USA, Article 298, 8 pages. https://doi.org/10.1145/3706599.3719700

[74] Danielle Wilde, Anna Vallgårda, and Oscar Tomico. 2017. Embodied Design Ideation Methods: Analysing the Power of Estrangement. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 5158–5170. https://doi.org/10.1145/3025453.3025873

[75] Jiajun Yang and Andy Hunt. 2015. Real-time sonification of biceps curl exercise using muscular activity and kinematics. Georgia Institute of Technology.