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Spatiality in Sound – a phenomenological exploration

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Abstract

This research explores how spatiality in sound can be created through the impact of movement onto sound. We make use of the kinetic sound sculpture Sounding Influencer, which employs pendulums with loudspeakers attached to their lower ends and a body moving in it. By detaching loudspeakers from the sound sculpture, we can expand their mobility and explore additional movement possibilities and the specific spatial impact onto sound. The loudspeakers emit sine tones at varying frequencies and are manually set in motion by a performer. The study investigates how different types of movement— both, of the pendulums, the independent loudspeakers, and the performer —affect acoustic phenomena. Their spatial layout and changes in amplitude and frequency are being perceived, and result in a dynamic soundfield. The research aims to understand sound perception, highlighting the complex relationship between interacting body, movement, space and sound. This paper presents the findings of an exploratory study focusing on these dynamics. By demonstrating the increasing complexity of these interactions, we hope to stimulate discussions on the potential of kinetic sound art and its impact on auditory perception.

1 Introduction

The reproduction of sound through loudspeakers has traditionally been a static experience. However, since the late 1950s, the integration of motion into loudspeaker systems has opened new dimensions in auditory perception. Kinetic loudspeakers have emerged both as technical apparatuses and as artistic media.

Kinetic Loudspeakers as Apparatuses

The foundations of kinetic sound reproduction were laid by pioneering technical developments. The Leslie speaker, invented in 1940 by Donald Leslie [1], had a lasting impact on pop culture and remained influential until the 1980s. In 1959 Karlheinz Stockhausen's *rotating loudspeaker* table for his composition *Kontakte* (1959) introduced the possibility of targeted spatial sound movement, using four microphones placed around a rotating speaker [2]. Independently, Hermann Scherchen's *Zero Radiator* - a spherical loudspeaker system with 32 speakers - was developed to achieve naturalistic spatial dispersion and activate the room acoustics in a new way [3].

Since the mid-1960s, moving loudspeakers have become a design element. Movement freed them from their usual role as passive emitters and established them as sonic and visible actors. In the following decades, new devices expanded the range of possible movements. Peter Bosch and Simone Simons' *Electric Swaying Orchestra* (1992) introduced parametrically driven pendulums carrying microphones and speakers, whose movements generated unpredictable sonic interactions [4]. More recently, large-scale kinetic systems such as Ray Lee's *Ring Out* (2017) deploy swinging loudspeaker arms in public spaces, enabling immersive outdoor performances [5]. These apparatuses do not merely serve to distribute sound differently—they function as performative objects with their own mechanical and aesthetic logic.

Space and Sound: Space as a Designable Dimension

Since the 1950s, the musical use of space has evolved from fixed loudspeaker configurations to highly flexible, interactive and immersive systems. Early pioneering works – such as Pierre Schaeffer's *pupître d'espace* (1951) [6], Stockhausen's *Gesang der Jünglinge* (1956) [7] and Boulez's space-related concepts [8]– laid the foundation for space as a compositional dimension. In the 1960s and 1970s, musical theatre productions (Zimmermann [9], Nono [10]) and immersive environments (*Vortex Concerts*, *Dream House*, *HPSCHD*, *Rainforest*) expanded the spectrum. At the same time, loudspeaker orchestras such as the Acousmonium and the first mobile loudspeaker systems (Les Antonymes [11]) emerged.
In the 1970s, technical developments such as the Halaphon led to more precise control of sound movements. International exhibitions, in particular the 1970 World Expo in Osaka, featured elaborate audio architectures such as the Spherical Auditorium [12], the Steel Pavilion [13], the Pepsi Pavilion (E.A.T.) [14] and the Swiss Pavilion which presented space and sound as an inseparable unity. These large-scale experiments remained mostly temporary and institutionally bound.

Artistic Works and Compositional Practices

Technical innovation in kinetic loudspeakers has continually intersected with compositional experimentation. Stockhausen's *Kontakte* (1958–60) integrated loudspeaker motion as an expressive spatial parameter. Edgard Varèse's *Poème électronique* (1957), composed for the Philips Pavilion at the 1958 Brussels World's Fair, pioneered spatialized electronic sound in an architectural context [15]. In the 1980s and 1990s, artists like Gordon Monahan revisited rotation movement. His *Speakers Swinging* (1982) used manually swung speakers to produce Doppler shifts from sine tones [16], a principle taken further by Lara Stanic in *Swing* [17] or Etsuro Masuda in *Doppler Waves*. In Jesse Austin-Stewart's *Four Swinging Speakers* the audience initiates motion, directly engaging with spatialized sound dynamics [18].

A recent continuation of this trajectory is Sounding Influencer (2019), a kinetic sound sculpture by Annkathrin Poepel and Peter Faerber. Pendulums with attached loudspeakers create complex acoustic interactions via amplitude modulation, Doppler shifts, and changing spatial reflection patterns. Depending on the version, between two and twelve pendulums form a system that links motion, sound, and spatial perception in real time.

Research Context

Recent studies in spatial audio, psychoacoustics, and embodied music interaction [19, 20] highlight the importance of motion not only as a generator of physical sound variation, but as a core component of auditory experience. This study contributes to that discourse by examining how both the movement of sound sources and the motion of human bodies within the sound field affect auditory perception.

As an explorative and phenomenological investigation, it draws from real-time performance settings and examines how motion and spatial configuration serve as compositional parameters. Motion is per se already a spatial matter. The findings aim to expand the vocabulary of spatial sound practice by demonstrating how perceptual phenomena—such as shifting amplitude envelopes, spatial masking, or interference patterns—can be deliberately shaped through motion. Thus, motion and space are not treated as separate conditions, but as active, expressive agents in the sonic experience.

2 Background

Previous Works on the Kinetic Sound Sculpture Sounding Influencer

The Sounding Influencer project investigates the artistic potential of moving and oscillating loudspeakers. Initiated in 2019, it has evolved through several iterations that combine the kinetic sound sculpture, composition, and performative interaction. All versions exclusively employ sine tones as a means of isolating and examining specific acoustic phenomena.

The first version was constructed with twelve pendulums, each equipped with a loudspeaker at its end. Once a pendulum comes to rest, a motor can draw it into a horizontal position to release it, allowing it to swing freely. The initial composition *Decelerating Floatation* (2020) explored both acoustic and visual effects resulting from various pendulum constellations. The swinging movement of the speakers emitting sine tones created spatially modulated sound structures through changes in amplitude, frequency, and spatial interference, turning the entire system into a performative instrument [21].

Metamorphosis I (2021) introduced a performer into the setup of six pendulums, who carried two loudspeakers in her hands and used her arms in pendulum-like movements. This addition expanded the degrees of freedom beyond mechanical motion and opened the performative space to new directions of bodily interaction. The performer navigated behind and between the pendulums, responding to and mimicking their motion. In *Metamorphosis II* (2021), a mobile frame for four pendulums was developed, enabling the sculpture to be presented outside of the lab. Instead of carrying loudspeakers, the performer wore a motion sensor on her thigh, which controlled the pitch of the sine tones. Her choreographic language interacted dynamically with the pendulums in front of and beside her. *Metamorphosis III* (2022) further expanded the spatial setup by using two four-pendulum frames placed to the left and right of the performance area. The performer, now equipped with motion sensors on both wrists, controlled the pitch of each pendulum group. For the first time, she physically intervened in the sculpture by manually stopping the pendulums, intensifying the feedback loop between body and sound. In *Metamorphosis IV* (2022) three four-pendulum frames were used with altogether 12 pendulums, which oscillated linearly and unidirectionally. In contrast, the performer responded to the pendulums with free, multidimensional movements in space. This reversed the conventional paradigm of dance - in which music guides movement - by allowing the dancer's movement to actively shape the sound. The modified sound was then transmitted back to the loudspeakers of the kinetic sound sculpture, creating a reciprocal interplay between human and machine. In the works *Metamorphosis I–IV*, the sonic material was composed solely of sine waves. These works were performed at the Zurich University of the Arts (ZHdK) and at various national and international venues [22].

For *RKK (RaumKlangKörper*, 2023) the kinetic sound sculpture was reduced back to two pendulums emitting sine tones to play with specific differences in the interaction patterns between pendulums and performer. The performer moved along, between and around these. She played with static sound, moving sound, static body and moving body, and the interaction between sound and body. In addition, the pitch of the sounds was being modulated to interact with the movements of the performer. Movement changed sound and the sounds influenced the movements, making the performer become a co-composer.

In *Liquid Sunshine II* (2024) a sound installation was developed with nine pendulums in three frames. The speakers emitted underwater recordings from the Caribbean (Lesser Antilles). The pendulum movement imitated a water wave. Visually, the sounds were complemented by videos of underwater and above-water recordings from the Caribbean creating a visual acoustic unity.

Planet Mantra (2024) was developed as a performance combining nine pendulums, a performer, and synchronized planetary light projections. The sound material consisted of monochord tones and vocal recordings of the Indian Mantra *Brahmaa Muraaris*, which were spatially modulated through pendular motion and real-time sensor data from the performer. The work explored the interplay of body, sound, and light as a contemporary ritual that links ancient sonic tradition with kinetic spatial composition.

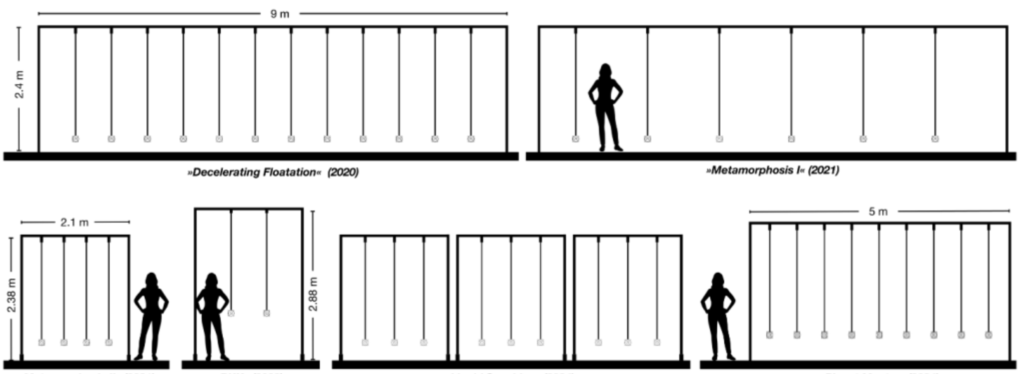

Fig. 1. Different configurations of the kinetic sound sculpture Sounding Influencer. Graphic: P. Faerber.

Since 2022, the dedicated research group who developed *RKK* has continuously been working together. Our work focuses on a phenomenological exploration of the acoustic effects of moving sound and the subjective perception of sonic change when sounds are being influenced by various movement patterns and spatial acoustics. We examine the interplay between the performer's movements and the sound field, demonstrating influences of expanded motion possibilities onto sound, and revealing the intricate interplay between human and mechanical movements.

At ICMC 2024 in Seoul, Corea, we presented our findings on a comparison of subjective auditory perception and measurable acoustic phenomena in swinging loudspeakers and moving body in the due of the development of the performance *RKK* [23]. These findings are based on the perceptions of us, the three members of the research group, and recordings having been made during explorations and performances.

2024 we also conducted a series of five listening experiments in rooms with different acoustic characteristics. Each session involved 14 to 18 participants. Out of 48 auditory examples, 40 were presented blind to test the influence of visual cues on spatial hearing and the perception of motion in sound. The evaluation process is still going on. Initial results indicate that auditory spatial impressions vary significantly depending on whether the movements of the pendulums and the performer are visible or not.

Recent Advancements

Since 2025 we have been expanding the focus of our research towards the spatiality of the change of sound through the impact of movement. We have been extending the spatial directions of the loudspeaker movement beyond the pendulum mechanism by integrating mobile loudspeakers. In the evolving performance *Oblique Sounds* the kinetic sound sculpture with two pendulums was combined with three loudspeakers hanging on springs from the ceiling and three handheld speakers set in motion by two performers.

The exploration centers around how the spatial configuration of pendulums, free-moving speakers, and the human body and various types of movement amongst them affect acoustic phenomena such as amplitude and frequency shifts. The goal is to gain a deeper understanding of spatiality in the auditory perception in interactive environments and to explore the relationship between space, sound and (bodily) motion in performative contexts. Throughout, the project applies a phenomenological approach: it does not seek technological optimization but rather investigates how shifts in spatiality, movement, kinetic systems and room conditions transform our auditory experience and inform new forms of artistic expression. Sounding Influencer thus contributes to the growing field of kinetic sound art and opens up further discussions on perception, spatiality, and corporeality in sound-based artistic research.

Fig. 2. Performer A. Stoecklin with mobile speakers. Foto: A. Poepel.

Research Questions

Extending the spatial directions of the loudspeaker movements beyond their coupling to the sound sculpture adds to exploring changes of sound. The handheld loudspeakers can be directly coupled to the movement of the human body, significantly increasing the complexity of the interaction between the body and the sound source. The performer's movements are no longer solely tied to the pendulum motion, can now be independent and much freer in space and thus influence the sound field in more varied ways.

The core research questions guiding this study are:

a) What influence does the spatial positioning of the loudspeakers and the arrangement of the various movement options have on the sound experience?

b) How do different combinations of moving speakers and movements of the performer affect the spatial perception of sound?

c) What are the specific acoustic phenomena observed when moving speakers and performers interact within a sound field?

d) How does the introduction of independent speaker mobility, coupled to human movement, enhance the complexity of sound interaction?
e) What specific movements does this set up demand from the performer to serve the sound installation and the modulation of the sounds?

3 Methodology and procedure

This exploratory approach allows for subsequent observation and interpretation of complex interactions between movement, sound and space. The methodology was intentionally designed to be open-ended, enabling the researchers to adapt to emerging patterns and phenomena throughout the study. The iterative process includes the testing of different movement scenarios, with each scenario providing insights into the dynamic relationship between loudspeakers, their spatiality and movement, and the performer. The exploratory nature of the study also emphasizes the collection of subjective auditory impressions from observers, which add valuable qualitative data to complement the quantitative measurements with video and audio recording of each.

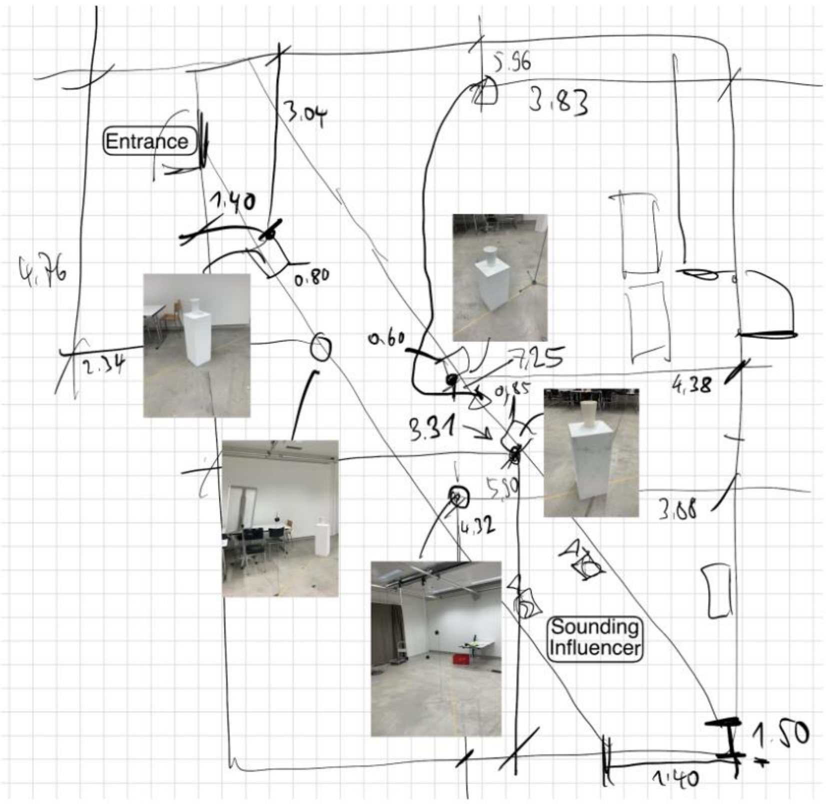

Fig. 3. build-up sketch, P.Faerber.

We play with different spatial layouts and combinations between loudspeakers and body, moving or static and with different movements of mobile loudspeakers.

a) Spring-Suspended Loudspeakers: The loudspeakers are suspended from the ceiling using elastic springs, allowing both vertical oscillation and pendular movement. When set in motion, they produce dynamic Doppler shifts, harmonic tremolo effects, and subtle phase modulations—similar to the acoustic behavior of swinging pendulums. The spring resistance introduces a dampened, resonant quality, while gravity ensures a natural decay of movement.
b) Spring Resonance: The system's natural frequency (dependent on spring stiffness and speaker mass) influences oscillation speed. Combined Motions: Vertical bouncing + pendulum swings create complex Lissajous-like interference patterns in sound propagation.
c) Performers Carrying Mobile Loudspeakers: two performers move through space with handheld loudspeakers, making the spatial shifting of the sound sources perceivable to a static listener. When the performers move towards or away from each other (or in synchronized patterns), the interaction generates:

- Doppler shifts (provided that the speed of movement is fast enough, pitch modulation due to relative motion)
- comb filtering (phase cancellations from delayed wave interactions)
- spatial smearing (diffuse, ambient sound clouds due to overlapping trajectories)

This results in atmospheric almost ambient sound clouds.

d) Combined Movements: Handheld and Suspended Speakers: Moving the handheld loudspeakers alongside the spring-suspended ones creates layered interactions:

- Beat frequencies (when slight pitch differences arise from Doppler shifts)
- Transient reflections (quick movements produce sharp, flutter-like echoes)
- Resonant feedback (if speakers pick up and re-amplify each other's output)

The combinations of their changes in sounds make complex sound interactions possible.

e) Additional Resonating Spaces: for the performance *Oblique Sounds* we added three conical earthen pots as small resonating spaces. When moving the handheld speakers in and out of these the volume of the sounds could be increased drastically. When moving the opening of the pots around the speakers, this rotation became acoustically perceivable. Moving two pots with their openings quickly away from the same speaker in different directions a whining sound was generated.

f) The Performer's Challenge: Movement as Sound Design: Moving the mobile speakers freely is a challenging task for the performer. The movement wants to serve the sound modulation and the composition and not become an independent act. It balances around the tight border between artistic expression and functionality. Controlled acoustics (predictable Doppler/phasing) and artistic expression (improvisatory, fluid trajectories) want to support one another.

g) Space-Specific Resonance and Movement as Spectral Modulation: The acoustic profile of the performance space is measured through a controlled frequency sweep, revealing distinct resonant modes (Raumklang). While most sonic material originated from the composer's pitch series, selected tones are deliberately being aligned with the room's modal structure to enhance spatial and spectral transformation.

h) Visibility: In 2024 we started to explore the influence of sight and visibility onto the auditive perception. In our hearing experiments we covered the kinetic sound sculpture in which a body was moving with non-transparent veils, so as to find out what movement the listeners would extract. The perception often differs strongly from what is actually happening, and the perceived movement and spatiality is mostly much more vivid than the actual one. For the performance „Oblique Sounds" we are integrating this concept by inviting audience to close their eyes for parts of the performance and are dimming the light to invite a focused auditive experience of the performance. The evaluation of the data collected in the hearing experiments still needs to be finalized.

This approach transforms the spatial setup into a live acoustic instrument during the performance, where movement, resonance, and interference become core compositional elements—an interplay between spatial acoustics and performative intuition.

Fig. 3. Video still from *Oblique Sounds*, performers A.Poepel, A.Stoecklin.

4 Room Acoustics of 5.K10 at ZHdK

For *Oblique Sounds* we used the room-specific resonances of the performance space where we premiered at ZHDK, Zurich, Switzerland 9.5.2025, measured with REW V5.31.3.

The principal resonances were identified at 201, 261, 339, 450, 585 Hz, with additional peaks at 432, 501, 801 Hz (see figure 2). Performance activity focused primarily on the frequency range between approximately 200 and 900 Hz, where modal response was most pronounced.

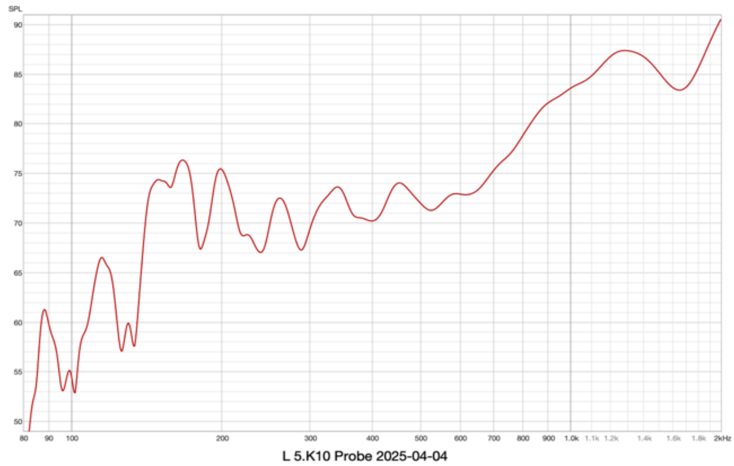

Fig. 4. Frequency sweep measurement of the performance space at ZHdK, showing the main resonant modes used in the performance.

The small handheld loudspeakers were tuned to 339 Hz, reinforcing a dominant mode, and to 450 Hz, introducing a detuned, shifting layer.
Spring-suspended loudspeakers triggered the peaks at 432, 501 and 585 Hz. Pendulum loudspeakers triggered the lower room modes (201, 261 Hz) producing deep, breathing undertones.
Handheld units (450, 339 Hz), were being moved dynamically through space, their trajectories generating Doppler shifts and phase cancellations that interacted with the mid-frequency modes of the spring-suspended loudspeakers (432, 501 and 585 Hz) producing shimmering, metallic textures and subtle beating phenomena—rhythmic pulsations merging temporal and spatial perception. The 801 Hz resonance appeared only intermittently from a pendulum loudspeaker as a high, spectral overtone, triggered when the pendulum moved through intersecting nodal points of the room.

5 Results

a) Acoustic Phenomena: The exploration reveals the afore mentioned distinct acoustic phenomena that arise from the interplay of movement and sound:
   - Doppler Effect: Observed as a frequency shift caused by the relative motion of the pendulums to the listener. This effect is most prominent when pendulums move at their peak velocities. For example, as a pendulum swings toward the listener, the frequency of the perceived sine tone increases. Conversely, as it moves away, the perceived frequency decreases.
   - Amplitude Modulation: Changes in loudness are being caused by the varying distances between the pendulums and the listener. When combined with early reflections, these fluctuations create complex patterns, particularly when pendulums swing near reflective surfaces.

   Volume changes occur in the pots with their resonance behaviour.
   - Standing Waves: Sound waves within the installation space interact to create areas of constructive and destructive interference. These standing waves significantly alter auditory perception, depending on the listener's position within the space.

b) Interaction Between Motion Sources: When both the pendulums and the performer are in motion, their combined effects create intricate auditory patterns, with overlapping Doppler shifts and amplitude modulations masking individual phenomena. The more complex the movement and their relative shifts to one another are, the less distinct are the auditive shifts. Sometimes they even each other out.

c) Enhanced Mobility and Interaction: The decoupling of loudspeakers from the pendulum structure introduces new possibilities for interaction. By attaching loudspeakers directly to the performer's body, the performer through her widened range of movement gains more possibilities of influencing the sound. This allows to explore spatial acoustics in more nuanced ways, integrating movement and sound modulation. This development adds layers of complexity to the relationship between body, movement, space, and sound, enabling nuanced play in the sound field. In performance spatial composing goes hand in hand with the auditive outcome, adding visual components. However, when this is being perceived only through listening, the spatial acoustics gain a much wider range.

6 Discussion and Conclusion

This exploratory study underscores the significant impact of movement on sound and acoustic space perception. The Sounding Influencer exemplifies the intricate relationship between movement and sound in kinetic art. Influencing factors are the speed and direction of motion. The integration of mobile loudspeakers and the decoupling of movement constraints advances the understanding of interactive sound perception and its spatiality. The dynamic interplay of movement and sound, resulting in complex auditory experiences, offers an expansion of interactive sound art. This study bridges quantitative research with artistic practice, providing a unique lens to explore auditory perception in motion-based environments. The study also highlights the potential of kinetic sound art to engage audiences by transforming static auditory environments into interactive soundscapes. Future research will deepen the investigation of the role of room acoustics and different spatial configurations in shaping sound perception.

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