

Drawing Space with Rain: The Umbrella as a Flow Interface

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Figure 1: This interactive umbrella transforms falling raindrops into dynamic sonic cues, enabling you to perceive—and even shape—the boundary between yourself and the environment with every tilt or sway.

Abstract

This study explores new possibilities for transforming perceived space by using an umbrella as a dynamic spatial auditory interface. While spatial audio technologies have been widely applied across various domains, there are few opportunities in daily life to consciously perceive the boundary between personal and external space. Due to its physical structure and everyday usage, the umbrella has a unique ability to render such boundaries perceptible.

Focusing on the “flow” of raindrops across the umbrella’s surface, the system detects continuous rain movement in real time rather than merely capturing impact sounds. Spatial auditory feedback encourages users to actively perceive dynamic spatial boundaries, as the rain draws auditory contours through interaction with the umbrella.

To this end, the umbrella is conceptualized as an interactive interface that senses raindrop movement and applies spatial audio processing. In addition, users can dynamically alter the virtual size of the umbrella, enabling perceptual shifts in spatial scale.

Rather than treating the umbrella as a mere protective object, this system reimagines it as a medium for perceiving environmental change through sound. By integrating natural phenomena

with spatial audio, this approach suggests new directions for embodied perception and expression.

Keywords

Umbrella, Rain, Sensing flow, Spatial Audio, Augmented Spatial Perception

1 Introduction

Spatial acoustics technology has advanced across various fields, including virtual reality (VR), gaming, and architectural acoustic design. These technologies primarily focus on the accurate reproduction of sound fields to enhance listener immersion. However, sound is not merely a medium that fills a space; it dynamically interacts with its surroundings, changing in response to environmental factors. The arrangement of walls and objects, as well as the manner in which sound reflects, allows humans to unconsciously perceive the extent and shape of a given space. Despite its importance, research focusing on spatial perception through sound still has space to be explored.

Humans constantly perceive and navigate their surrounding space in everyday life. However, the explicit recognition of spatial boundaries is rare. For instance, walls provide a visual boundary in enclosed spaces, while tactile sensations such as water pressure on the skin help define bodily contours when submerged. However, there are few instances where spatial boundaries are dynamically perceived through sound.



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Within this context, an umbrella serves as a unique medium for spatial perception. It functions as a physical boundary, demarcating the "outside," where rain falls, from the "inside," which remains dry. Moreover, as raindrops collide with and flow along the umbrella's surface, this boundary is not only auditorily perceived but also dynamically rendered through sound. The movement of raindrops along the umbrella outlines the boundary, creating a perceptual representation of space. This act of "drawing" with sound transforms the flow of rain into an active agent of spatial perception, rather than a mere physical phenomenon.

Raindrops initially impact the umbrella as discrete points, generating transient impact sounds. These sounds provide acoustic feedback, reinforcing the perception of the boundary's presence. However, the raindrops do not remain static; they merge and move along the surface, forming continuous lines. This movement transforms the boundary from a static plane into a dynamically evolving framework. The unpredictable trajectories of raindrops create shifting contours, akin to a brush gliding across a canvas, continuously redrawing the boundary in real time. This dynamic process does not merely result in an accumulation of impact sounds but rather constitutes an evolving spatial representation over time.

This movement can be likened to the trails of meteors across the night sky. Just as meteors momentarily trace luminous lines before vanishing into darkness, raindrops inscribe fleeting auditory lines upon the umbrella's surface, continuously reshaping the perception of space. In this study, we incorporate meteor soundscapes to integrate different scales of fluid motion, aiming to create a novel auditory experience.

This research proposes a system that detects the real-time movement of raindrops along the surface of an umbrella and applies spatial audio processing to enhance the perception of rain as a boundary-defining phenomenon. This study introduces a new interactive auditory interface that enables real-time perception of environmental changes through a familiar everyday object—the umbrella.

The contributions of this study are threefold:

- (1) Introducing a novel application of the umbrella as an auditory interface.
- (2) Moving beyond static spatial acoustics to explore the creation of dynamic sound fields that adapt to environmental changes.
- (3) Designing a new spatial auditory experience that integrates natural phenomena.

By enabling individuals to perceive the process of "rain drawing space," this research explores the potential for sound-mediated transformations of personal spatial awareness.

2 Related Works

2.1 Spatial Audio and Immersive Environments

Spatial or immersive audio has received considerable attention for its ability to influence users' sense of direction, distance, and presence. Early conceptual frameworks, such as the acousmonium introduced by Bayle [4], involved multi-loudspeaker layouts designed to distribute sound across speaker arrays of various sizes and orientations. More recently, Smith and Anderson [25] proposed ArraYnger, a toolset that simplifies the management of complex loudspeaker topologies, thereby lowering barriers to deploying immersive audio experiences. On the headphone side,

Blauert [6] and Begault [5] established foundational principles for human sound localization and 3D audio in virtual reality (VR). Building on these developments, studies by Larsson, Västfjäll, and Kleiner [17] and by Kern and Ellermeier [16] demonstrated that embedding naturalistic or ambient soundscapes in VR can enhance users' sense of presence. Following these developments, [17] and [16] showed that embedding naturalistic or ambient soundscapes in VR increases users' perceived presence. Furthermore, Shayman et al. [24] and Gerritse et al. [11] demonstrated that spatial audio cues can enhance navigational accuracy and tolerance for redirected-walking manipulations, indicating that subtle audio information can help align users' perception of virtual and physical environments. Additional studies by Proffitt, and Williams [19], Wenzel [26], and Hendrix and Barfield [13] emphasize how 360-degree auditory cues complement vision and shape spatial cognition.

2.2 Rain Sound as a Spatial Cue

Rain is commonly treated as ambient noise, yet it can provide distinctive clues for distance and direction. For instance, Cheng, Lin, and Lee [8] presented a scene-aware rain sound model that adapts raindrop timbre and volume according to the materials they strike, enhancing realism and spatial awareness in VR. Related work by Proverbio et al. [21] found that diffuse, rain-like noise can boost alertness, indirectly improving a listener's sensitivity to spatial details. From an audio synthesis perspective, Zheng et al. [27] and Dong et al. [10] explored physically-based or statistical approaches to rain sound generation, revealing how the distribution of raindrops across different surfaces can yield rich environmental information about space and texture. These findings suggest that rain offers more than mere background sound; instead, it can serve as a nuanced cue that helps define a listener's sense of the surrounding environment.

2.3 Interactive Interfaces in NIME

Research in the realm of New Interfaces for Musical Expression (NIME) often focuses on tangible or gestural control of sound in a three-dimensional field. Sardana et al. [22] developed Locus, a glove-based interface for 128-channel playback, allowing users to position and move audio sources in real time. Smith and Anderson [25] introduced ArraYnger to streamline interactive 360 spatial sound design, making it easier to conduct user studies and performances. Further innovations described by Bukvic, Sardana, and Joo [7] and by the Monet team [2] employed multi-touch or motion-based strategies that treat space as a key compositional parameter, while Pérez-López [20] proposed the 3Dj framework to manage complex spatialization tasks in SuperCollider. Novel hardware systems, such as the tensegrity-based iOSCahedron iOSCahedron [12] or ultrasonic arrays for holographic audio [15], have also expanded the design space for spatial instruments, shifting the focus from static "soundfields" to user-driven manipulation of immersive audio.

2.4 Umbrella-Based Interactions

Beyond purely technical audio solutions, umbrellas have featured in a number of artistic and design-oriented projects exploring new modes of sonic interaction. Kamiyama and Okuno [14] implemented Oto-Shigure, a musical interface that uses an umbrella canopy to generate and control rain-like sounds, enabling various timbral or spatial effects. Nagai et al. [18] introduced Funbrella, which attaches vibration actuators to an umbrella handle so that

users can record and replay various raindrop behaviors, thus transforming everyday rain into an interactive experience. Further examples include Re-rain by Kyouei Design [9] and Comfortable rain-para-soul by Sato and Aoki [23], both of which couple umbrella surfaces with speakers or sensing hardware to create novel audio feedback. While these designs emphasize real-world raindrop contact or acoustic resonance, work such as KokoKasa project from Kyoto Institute of Technology [1] shifts attention to personal boundaries, using light to visualize interpersonal distance. These umbrella-based explorations collectively highlight the potential for everyday objects to serve as sonic interfaces that reshape how users perceive and negotiate space.

2.5 Positioning Our Approach

Much of the above research has focused on discrete raindrop impacts or static reproduction of soundfields. Although immersive audio systems are often designed to accurately localize or spatialize sounds, the continuous real-time motion of raindrops flowing across an umbrella’s surface remains underexplored. Several works by Kamiyama and Okuno [14], Nagai et al. [18], Kyouei Design [9], and Sato and Aoki [23] by Kamiyama and Okuno [9, 14, 18, 23] employed umbrellas to engage users with rain, yet their emphasis lay primarily on collision sounds or vibration feedback rather than tracking the evolving pattern of water movement. By concentrating on the dynamic “flow” of rain and rendering it through spatial audio, our study aims to transform the umbrella into a *dynamic spatial auditory interface* that reveals a shifting boundary between personal and external space. Instead of recreating a predetermined soundfield, we propose an environment in constant flux: the user experiences an audible contour that changes in real time as raindrops move over the canopy. This approach builds upon immersive audio research by Bayle [4], Larsson, Västfjäll, and Kleiner [17], and Kern and Ellermeier [16], [4, 16, 17] but diverges from conventional speaker arrays by integrating a natural phenomenon into an interactive system. In so doing, we seek to encourage users’ conscious perception of how raindrops physically and sonically delineate their immediate surroundings.

3 System Design

This system explores the concept of perceiving spatial boundaries through an acoustic interface using a virtual umbrella. The umbrella is positioned at the boundary between personal and external space, possessing a unique characteristic of making this boundary perceptible through sounds such as raindrops. This makes it an effective object for studying spatial perception.

3.1 Motivation and Concept

Visual perception is constrained by the field of view, whereas auditory perception enables 360-degree spatial awareness. While vision excels in high-resolution and long-distance recognition, these characteristics are less crucial for perceiving sounds emitted from the relatively close surface of an umbrella. This system investigates the interaction of sound, spatial perception, and the physical boundary provided by the umbrella within the enclosed umbrella space. The core of the system’s design lies in this combination of the umbrella, sound, and spatial perception.

3.2 System Overview

3.2.1 Sensor Implementation. To capture the movement of water flow on the umbrella surface, we embedded capacitive sensors on

the surface. A total of 76 sensors were evenly distributed to detect dynamic changes in the flow. All parts are completely waterproof except for the sensor part, and a resistor is incorporated in the sensor circuit to prevent short circuit.

Since we aimed to sense the vertical movement of rainwater, the sensors were aligned in the vertical direction. The umbrella was divided into eight sections, allowing for localized detection of water flow patterns.

The electrode size was determined to effectively detect the vertical flow of water. Since water droplets do not move in a perfectly straight line but rather shift slightly laterally as they flow down the umbrella surface, we set the electrode width to 3 cm to accommodate this behavior.

3.2.2 Sound Design. To create an interface that allows users to perceive the flow of water through sound, we selected auditory stimuli that effectively convey a sense of motion. Since the phenomenon of water flow inherently involves spatial movement, we employed spatial audio techniques to represent it.

Reflections of sound by the outer ear play an important role in how humans perceive the location of sound sources [3]. We determined that over-ear headphones would be the most suitable choice. This allows for a clear and immersive auditory experience, ensuring that users can accurately perceive the movement of water flow on the umbrella’s surface.

3.3 Adaptive Spatial Perception Through Sound

Our system is based on the hypothesis that the movement of water on the umbrella’s surface influences spatial perception. Traditional sound design approaches focus on constructing sound within a predefined spatial environment. However, we explore the possibility of dynamically altering the perceived spatial environment by changing the virtual size of the umbrella in Unity. By allowing users to adjust the umbrella’s size dynamically, we enable a novel form of sound-space interaction, providing an experience where spatial perception evolves in real time.

4 Implementation

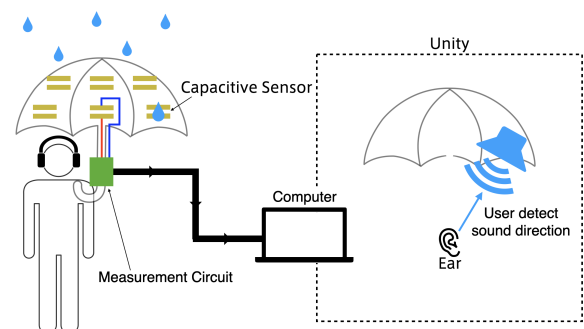


Figure 2: System architecture. Raindrop contact is sensed by capacitive electrodes, processed by an Arduino, and transmitted to Unity for 3D audio rendering.

This system is designed to sense raindrops falling onto the surface of an umbrella and to generate spatial audio based on the acquired data. It consists of three main components as shown in Figure 2: (1) fabrication of electrodes, (2) sensing hardware for detecting water-droplet contact, and (3) software that integrates

the sensed data and performs audio processing. When a raindrop contacts the umbrella surface, the resulting change in capacitance is measured by an Arduino Nano Every and transmitted via serial communication to a 3D software environment (Unity). In Unity, the system uses electrode information mapped onto a virtual umbrella model to render spatial audio that corresponds to the position of each raindrop.

4.1 Umbrella Panels and Electrode Fabrication

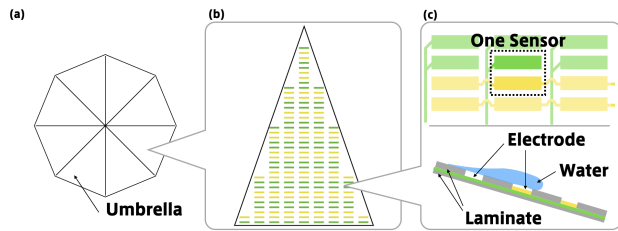


Figure 3: Umbrella design and electrode structure. (a) Eight panels, each with 122 electrodes. (b) Arrangement of electrodes in a single panel. (c) Cross-section illustrating how droplets bridge the row and column foils.

The umbrella consists of eight panels in Figure 3(a), each incorporating 122 independent electrodes in Figure 3(b). Each electrode is formed from two layers of copper foil: one layer is exposed, while the other is insulated in Figure 3(c). The lower layer uses unprocessed laminate, whereas the upper layer is a laser-cut laminate with 5×30 mm rectangular openings arranged in rows and columns at 10 mm intervals. Between these two layers, x-mm-wide copper strips are placed in crossing rows and columns following a repeating pattern of two consecutive strips, followed by two gaps, and then two strips again. This layout ensures that electrical conduction between row and column foils occurs only when a water droplet physically bridges them.

4.2 Sensing Hardware for Each Panel

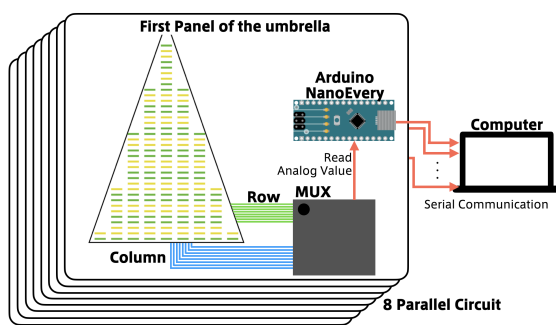


Figure 4: Circuit diagram and hardware configuration. Each umbrella panel is read by an 8×8 multiplexer and an Arduino Nano Every, then transmitted to a PC for real-time processing.

Figure 4 shows the implemented circuit diagram and its connection to the computer. Each panel is assigned a dedicated Arduino Nano Every, to which the electrodes are connected via an 8×8 multiplexer. The multiplexer switches channels approximately every $5 \mu s$, enabling all electrodes on a single panel (8×8

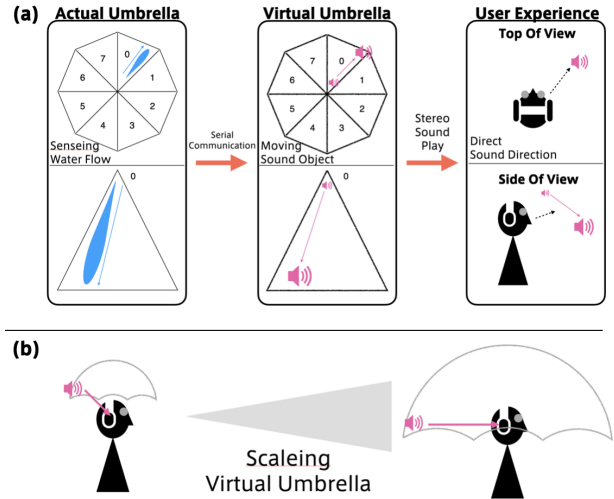


Figure 5: Virtual umbrella in Unity with eight panels and 122 audio objects each. Raindrop-triggered sound is rendered in 3D, and rescaling shifts perceived distance and direction.

channels) to be scanned in about $320 \mu s$. The Arduino Nano Every acquires the sensor values using its 10-bit internal ADC and transmits them at 115,600 bps to the Unity environment on a PC via serial communication.

4.3 Data Integration and Communication

Eight Arduino Nano Every boards operate in parallel, each one assigned to a different umbrella panel. The sensor readings for each panel are transmitted to the PC through separate serial ports. A Unity application on the PC receives these eight data streams in real time and updates the virtual umbrella object accordingly, enabling spatial audio rendering based on raindrop contacts.

4.4 Virtual Umbrella Model and Spatial Audio Rendering.

Figure 5(a) shows the behavior of a virtual umbrella in Unity when rain falls on the umbrella. It also shows the user experience. A virtual umbrella composed of eight planar segments is implemented in Unity, corresponding to the eight physical panels. Each segment includes 122 audio objects, mirroring the real-world distribution of electrodes. When a sensor reading on a particular electrode exceeds a threshold, the associated audio object is triggered, and 3D sound is rendered at the panel’s coordinates. By wearing headphones, users perceive the rain sound arriving from the direction matching each raindrop’s contact point on the umbrella. Additionally, the virtual umbrella can be rescaled, causing the perceived sound to shift slightly in both distance and direction in Figure 5 (b).

5 Pilot Study

5.1 Environment

The system was operated in a quiet indoor environment. Measures were taken to minimize background noise to ensure that participants could focus on the performance experience.

The setup of the umbrella-shaped interface and the participants during its use is shown in Figure 6.

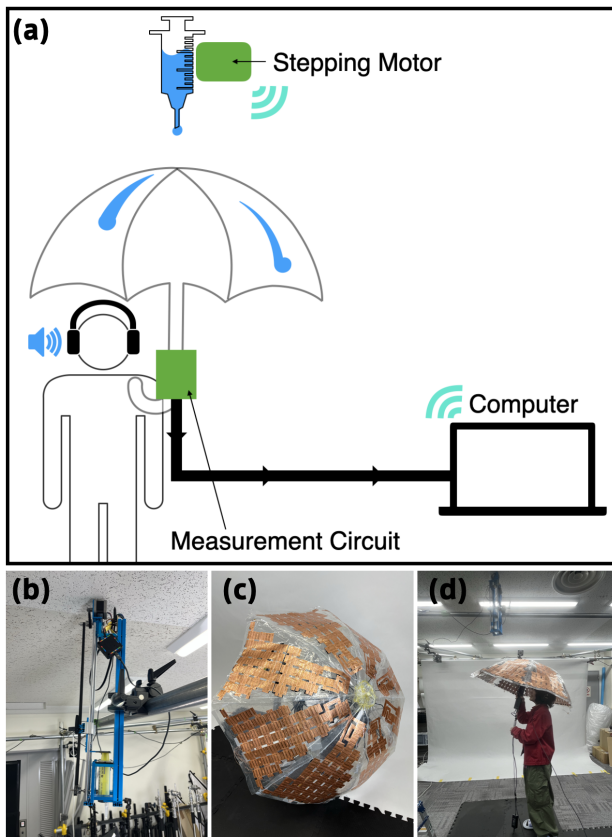


Figure 6: Virtual umbrella in Unity with eight panels and 122 audio objects each. Raindrop-triggered sound is rendered in 3D, and rescaling shifts perceived distance and direction.

5.2 Objective

The objective of this pilot study is to examine how replacing the shape of an electronic musical instrument with an umbrella affects the user's performance behavior and experience.

This study focuses on the spatial characteristics of the umbrella. An umbrella functions as a boundary that separates the internal space where the user is located from the external space where rain falls. In this pilot trial, we utilize this characteristic to investigate how changing the size of the surrounding space (i.e., the umbrella) influences performance behavior and the perception of sound.

To examine this, we establish the following two experimental conditions and analyze their differences:

- (1) Performance using a fixed-size umbrella: The size of the umbrella remains constant, and the participant performs freely.
- (2) Performance with random changes in virtual umbrella size: The virtual umbrella size varies randomly, requiring the participant to perform under different spatial conditions.

5.3 Experimental Procedure

In this experiment, participants performed using the developed umbrella-based interface. The experimental procedure is as follows:

- (1) Preliminary Explanation

- Explanation of how to use the umbrella-based interface.
- Explanation of how water droplets flowing on the umbrella surface generate sound.

- (2) Performance Experiment

- Performance with a fixed-size umbrella (10 minutes).
- Performance with random changes in virtual umbrella size (10 minutes).

Each performance condition lasted for 10 minutes, totaling 20 minutes of performance.

For systematic droplet generation, the system employs a dripping device using a stepping motor. This device releases water droplets by pressing a syringe filled with water, where the syringe diameter is 4 mm. Additionally, participants wore headphones to ensure that they could only hear the sound generated by the system (Figure 6).

5.4 Participants

Three male participants were recruited for this experiment. The selection criteria were as follows:

- Experience in playing musical instruments.
- Experience in improvisation or composition.
- Experience in using digital audio equipment or music production software.

The average age of the participants was 24.7 years (standard deviation ± 3 years).

5.5 Experimental Procedure

The experiment was conducted according to the following steps:

- (1) Preliminary Explanation

- Explanation of the experiment's objectives and procedures, obtaining informed consent.
- Explanation of how to use the umbrella-based interface and the system's sound generation mechanism.

- (2) Pre-Experiment Questionnaire

- Collection of participants' basic attributes (age, gender, musical experience, experience with digital audio equipment, etc.).

- (3) System Experience

- Participants performed using the umbrella-based interface under the following two conditions:

- (a) Performance with a fixed-size umbrella (10 minutes).
- (b) Performance with random changes in virtual umbrella size (10 minutes).

- (4) Post-Experiment Questionnaire and Semi-Structured Interview

- A post-experiment questionnaire was conducted to collect participants' evaluations of the performance experience and spatial perception.
- A semi-structured interview was conducted to explore participants' subjective experiences and insights in detail, focusing on the following questions.

5.6 Pre-Experiment Questionnaire

Before the experiment, participants completed a questionnaire to collect demographic information and their prior experience with music and digital audio equipment. This was done to ensure that all participants met the selection criteria and to analyze how their background might influence their perception and interaction with the umbrella-based interface.

Table 1: Pre-Experiment Questionnaire Items

No.	Question
1	Participant ID
2	Gender (Male / Female / Other)
3	Age
4	Dominant Hand (Right / Left / Both)
5	Occupation (If student, specify major)
6	Experience in playing musical instruments (excluding school lessons)
7	If yes, which instruments have you played?
8	Years of experience in playing musical instruments
9	Experience in composition or improvisation (excluding school lessons)
10	Other musical experience
11	If yes, what kind of experience? (e.g., vocal training, etc.)
12	Years of experience in other musical activities
13	Years and details of formal music education
14	Experience in using digital audio equipment (e.g., MIDI controllers, synthesizers, etc.)
15	If yes, years of experience
16	Experience in using music production software (e.g., Ableton Live, MAX/MSP, etc.)
17	If yes, years of experience

5.7 Post-Experiment Questionnaire

After the experiment, participants answered a questionnaire evaluating their experience with the umbrella-based musical interface. This questionnaire measured their perception of spatial awareness, sound interaction, and intuitiveness of the system using a five-point Likert scale. The responses were used to quantitatively assess the effects of the umbrella-based interface on performance and spatial perception.

Table 2: Post-Experiment Questionnaire Items

No.	Question
1	Participant ID
2	Did you find the operation of the umbrella-based electronic musical instrument intuitive? (5-point Likert scale)
3	Did using the umbrella-based electronic musical instrument make you aware of space? (5-point Likert scale)
4	Did using the umbrella-based electronic musical instrument make you aware of spatial boundaries? (5-point Likert scale)
5	Were you satisfied with the changes in sound and its controllability? (5-point Likert scale)

5.8 Semi-Structured Interview

Following the post-experiment questionnaire, a semi-structured interview was conducted to gain deeper insights into the participants' subjective experiences. Participants were asked open-ended questions regarding their perception of space, the boundary of the umbrella, their emotional response, and overall thoughts on the system. The qualitative data obtained from these interviews provided a more comprehensive understanding of how the interface influenced the users' spatial perception and musical interaction.

Table 3: Semi-Structured Interview Questions

No.	Question
1	How did using the umbrella-based electronic musical instrument influence your perception of the surrounding space?
2	Did you become aware of the "boundaries" of space? If so, at what moments did you notice them?
3	What sensations did you experience while performing? (e.g., enjoyable, difficult, immersive)
4	Which part of the umbrella (surface, edge, handle, etc.) were you most conscious of during the performance?
5	What emotions arose while performing?
6	After completing the performance, did you notice any changes in your mood, awareness, or perception?
7	What aspects of this system do you think could be improved?

6 Reflections on Use and Experience

This section presents an analysis of the insights and experiences obtained through preliminary observations of the umbrella-shaped interface in use.

6.1 Participant Behavior

During the experiment, participants experienced the umbrella interface in various ways. Some remained still under the umbrella, attentively listening to the sound and its changes, while others rotated the umbrella or moved around the area where the droplets were falling. These behaviors suggest an attempt to explore the system's overall structure and the relationship between sound and space. The act of rotating the umbrella may have been intended to examine how the sound changed depending on the direction. Additionally, moving around under the dripping water may have been an attempt to confirm the relationship between the point of sound generation and the participant's position. These results indicate that this interface does not merely provide a passive auditory experience but also encourages active exploration.

6.2 Spatial Perception When Using the Umbrella Interface

Participants reported different perceptions of space when using the umbrella interface. Participant A felt that the umbrella created a unique personal space that provided a sense of security. The physical structure of the umbrella enclosed the user, generating an independent space that temporarily separated them from the real environment. Participant B noted that the spacious feeling might have been influenced by the setting, but still reported that using the umbrella made the room feel more open. This perception of expanded space may be influenced by spatial audio elements and the visual effects of the umbrella's transparency. Participant C perceived the inside of the umbrella as a space similar to being inside a futon, experiencing comfort and relaxation. Furthermore, they noted a resemblance to the feeling of "not wanting to leave" a warm futon, suggesting that the presence of the umbrella contributed to psychological comfort.

6.3 Awareness of Spatial Boundaries

Participant A stated that they were more aware of the direction of the sound, or the change in sound imaging, rather than the spatial

transformation itself. They noted that, because the actual sound of the rain could also be heard through the headphones, it was difficult to clearly grasp the relationship between the real rain and the space represented by the system. Participant B focused more on the sense of spatial extent rather than spatial boundaries. This may be because the time delay (lag) between when the water droplets hit the umbrella and when the sound was produced made it difficult to recognize the movement of the droplets across the umbrella's surface. On the other hand, Participant C clearly recognized the inside of the umbrella as a "segregated space" and felt as though they were in an environment distinct from the outside world. In particular, they reported that this sense was stronger when the sound was playing, and despite using a transparent umbrella, they still experienced a feeling of being in their own enclosed space. This suggests that sound may be a key factor in influencing the perception of spatial boundaries.

6.4 Awareness During Performance

During the performance, Participant A was constantly aware of the relationship between the sound and the device. Participants B and C both reported that the weight of the umbrella was noticeable during the performance. Participant B also stated that they became more conscious of the sound of water droplets hitting the umbrella, a sound they would not usually pay attention to. Participant C reported that their awareness was directed toward the surface and membrane of the umbrella. They particularly found the transition from soft to loud sounds to be the most pleasant moment, which led them to explore and actively seek out such sound changes. This suggests that the dynamics of the sound played a role in guiding participants' performance behavior.

6.5 Changes in Sensations and Emotions During Performance

Participant A felt that the umbrella was heavy but still found the performance experience enjoyable and reassuring. Participant B also noticed the weight of the umbrella but at the same time experienced a sense of calmness and a pleasant drowsiness. Participant C described a sensation similar to receiving a shampoo treatment at a hair salon. Additionally, they reported that viewing the outside world through the transparent vinyl umbrella felt like looking through a glass window. They further noted that the umbrella's interior enhanced their sense of security, allowing them to feel less self-conscious and more comfortable engaging in facial expressions or actions that they might otherwise find embarrassing.

6.6 Changes in Mood and Perception After the Performance

Participant A stated that the experience made them more conscious of the umbrella as a space itself. Participant B reported feeling relaxed and drowsy after the performance. Additionally, they became more attentive to the actual sound of raindrops and started paying attention to natural sounds that they would not usually notice. Participant C also felt a sense of calm and relaxation after the performance.

6.7 Areas for Improvement

All participants pointed out that the weight of the umbrella was burdensome. Additionally, Participant B noted that the lag in

sound generation caused discomfort in the performance. Furthermore, all participants felt that a greater variety of sounds in the system would make the experience more engaging. Participant A observed that when sounds were triggered continuously, they occasionally cut off midstream, and suggested that the sensitivity or configuration of the trigger might need adjustment. They also suggested that using a larger umbrella could enhance spatial perception and allow for more dynamic changes in sound. Additionally, they noted that some sensors remained activated due to water droplets that adhered to the umbrella without flowing, indicating that sensor sensitivity adjustments were necessary.

6.8 New Suggestions

Participant B suggested experimenting with a system where different sounds are produced from the upper and lower parts of the umbrella. They also proposed creating different areas with varying intensities of rainfall, allowing the performer to move between them while playing. Furthermore, they speculated that using a raincoat instead of an umbrella as the interface could provide a novel performance experience. They also expressed interest in an interface that focuses on playing music through the rhythm of the rain rather than changes in spatial perception. Participant C noted that the experience of using this interface resembled being inside a tent. They suggested that performing in a location such as an open grassland, rather than in an urban environment, could enhance the interaction with nature and deepen the sense of personal space.

7 Conclusion

This study proposed an interactive umbrella system designed under the concept of "drawing space with rain." By converting the flow of raindrops into spatial audio feedback, the system enables users to perceive spatial boundaries in real time through sound. Reframing rain as both a material and a medium, the umbrella is reconceptualized as a performative interface for sensing and shaping the environment, rather than merely serving as a protective tool.

Utilizing capacitive sensors and spatial audio rendering, the system captures the motion of water across the umbrella surface and generates responsive acoustic feedback. Unlike traditional static sound reproduction, this approach embraces the unpredictability of natural phenomena and transforms it into an interactive auditory interface. This transition encourages users to shift from passive listening to active and improvisational spatial exploration.

Findings from a pilot study suggest that the interior of the umbrella was perceived as a temporally enclosed space, and that changes in umbrella size influenced users' perception of spatial scale. Participants also reported increased awareness of spatial boundaries through sound, as well as emotional and perceptual shifts after the experience, indicating the system's potential to foster new modes of spatial recognition.

At the same time, limitations were identified, such as the physical weight of the umbrella and latency in acoustic response, which occasionally disrupted the performative experience. Addressing these issues will require structural lightening, improved sensor calibration, and enhanced response speed. Additionally, expanding the range of parameters that can be extracted from rain flow may increase the system's expressive capabilities. Wireless implementation is also planned to enable use in actual outdoor rain environments.

Future studies will involve a larger and more diverse participant group to further explore the system's impact across different user backgrounds and perceptual tendencies.

This system contributes a novel interface that stimulates spatial thinking and creativity using everyday materials. It functions not only as a perceptual modulator but also as a platform for expression and improvisation. Potential applications include interactive installations and mixed-reality environments such as AR/VR, where fluid and intuitive spatial interactions are essential.

8 Ethical Standards

This study was approved by the Research Ethics Committee of the Faculty of Library, Information and Media Science at the University of Tsukuba (Approval No. 24-159). All participants provided informed consent prior to participation. Personal data were collected and managed using participant ID numbers to ensure anonymity and prevent identification. No conflicts of interest, financial or non-financial, are declared.

9 Acknowledgments

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