Role-Separated Live Movement Sonification: Toolkits as Mediators of Distributed Agency in Performance

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Abstract

Real-time movement sonification in dance is typically framed as a problem of gesture–to–sound mapping. However, when mappings are reconfigured during live performance, sonification systems do more than translate motion data. They reorganize participation, timing and agency within the performance ecology. This paper examines a role-separated live configuration in which a dancer (mover) performed while an operator (mapper) adjusted movement–to–sound relationships in real–time using a sonification toolkit implemented in Max. The case was developed during a ten-day workshop and presented in two public performances. Adopting a Research-through-Design (RtD) methodology, the enacted configuration is treated as a research artifact. We introduce a conceptual interaction model describing sonification toolkits as mediators of distributed agency across mover, mapper and coupling environment. A reflective case analysis compares first-person accounts from both roles to articulate recurring interactional structures across the performance. The contribution lies in reframing live sonification toolkits as collaborative performance interfaces. The findings demonstrate how real-time mapping reconfiguration structures mutual engagement and redistributes control, offering design considerations for movement–to–sound coupling environments in artistic contexts.

Keywords

Movement Sonification, Live Performance Interaction, Role-Based Interfaces, Distributed Agency, Sonification Toolkits

1 Introduction: Live Movement Sonification as a Design Problem

There are numerous examples of movement sonification projects situated in artistic and performance contexts [16, 27, 28]. In many of these works, movement–to–sound relationships are designed in advance and are commonly framed as gesture-to-sound mappings, whether in experimental, compositional or performance-oriented contexts [18, 30, 43]. Within such configurations, the mapping structure is typically stabilized prior to performance.

However, in the case presented here, mappings were reconfigured during the performance itself, altering its ecology. During a ten-day artistic workshop, a mapping software environment in the form of a Max-based sonification toolkit was deployed and further expanded to enable flexible adaptation of movement–to–sound relationships in real–time. This configurability introduced a role separation between a mover (dancing) and a mapper (operating the toolkit), reshaping how participation, responsiveness and control were distributed. This paper investigates this role-separated setup in order to understand how real-time mapping reconfiguration reorganizes performance interaction. In this context, a sonification toolkit is not only a mapping tool but participates in timing, agency and negotiation between human roles. It thereby functions as a mediating layer through which roles interact. The central claim of this paper is that live, role-based movement sonification foregrounds sonification toolkits as collaborative performance interfaces whose mediation of agency becomes structurally explicit.

This paper contributes (1) a reflective performance case of role-separated live sonification, (2) a conceptual framing and articulation of sonification toolkits as mediators of distributed agency in performance and (3) interactional design considerations for the development of movement–to–sound coupling environments in artistic contexts.

While role-separated configurations have implicitly existed in prior performance practices, this work does not introduce a fundamentally new structural paradigm. Instead, it contributes a formal articulation that makes these configurations explicit.

These contributions are grounded in a concrete performance configuration where dance becomes a particularly demanding setting for real-time sonification. The immediacy of embodied interaction and the need for coordination between artistic intention and technical mediation leads to requirements that differ from analytical sonification contexts. These include, amongst others, timing, agency distribution and negotiation of constraints. Instead of treating data-to-sound mapping as a fixed design decision, such a system must support continuous negotiation across rehearsal and performance. We present a reflective account of such a situated and role-based coupling as a case of live sonification in practice. Methodologically, this work adopts a Research-through-Design (RtD) orientation, treating the enacted sonification configuration as the primary research artifact. In RtD, artifacts function as "ultimate particulars" that embody design decisions and possibilities [6], operating as material propositions or "physical hypotheses" explored through instantiation and use [24]. The theoretical contribution emerges through articulating and annotating these concrete instantiations [19] and is therefore conceptual rather than empirical. Aligned with practice-based research traditions in the arts [9] and reflective approaches in digital musical instrument research [14, 15, 45, 52], the live configuration and its performance deployment form the core object of inquiry.

2 Related Work

This section situates the work within research on movement sonification and interactive performance, reviewing gesture–to–sound mapping in dance and the structuring of roles, agency and collaboration.

2.1 Dance Movement Sonification

The present work qualifies as sonification because it performs a systematic and reproducible transformation of movement data

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into sound [12]. Sonification has always operated between scientific representation and musical composition and multiple musical works employ procedures consistent with contemporary sonification concepts [44]. The overlap between sonification and music is therefore embedded within the field [22].

Movement sonification in dance is often articulated through parameter-mapping approaches in which bodily features are translated into sound parameters [11, 13, 42, 47].

Within this line of work, Schacher presents a framework that distinguishes motion data, abstract gesture representations and sound control layers, arguing that meaningful mappings require abstraction [43]. Gesture operates here as a meta-layer integrating sensing modalities into musical control structures, foregrounding mapping as a mediating process that organizes expressive interaction.

Similarly, the proposal of movement qualities (MQ) as an interaction modality shifts attention away from spatial trajectories to the dynamics of how movement is performed [1]. MQ-based interaction integrates motion over time and produces a system that is perceived as dialogical rather than mimetic. Model-based and hierarchical mapping approaches demonstrate how real-time gesture-to-sound coupling can be collaboratively developed with performers, covering sensorimotor and expressive evaluation [30]. This emphasis on expressive and collaborative development situates mapping as an aesthetic and interactional design process rather than a technical transformation. In this regard, interactive dance–music systems may technically resemble parameter-mapping sonification, but often differ in their goals: artistic systems prioritize aesthetic dimensions over informational representation [20]. This shift in orientation also affects how movement itself is framed and segmented within computational systems. Alaoui et al. demonstrate how computational tools for choreography often isolate specific movement components or compositional concerns [2].

Other work emphasizes micro- and meso-temporal coupling between bodily dynamics and sound synthesis. Cross-correlation of sensor data from different body parts has been used to modulate parameters such as pitch, amplitude, and spatialization [27]. In this context, movement is treated as dynamically structured material capable of shaping sound across multiple musical time scales.

Alongside, participatory design approaches highlight that movement-to–sound mapping can be seen as a negotiated aesthetic process. Collaborative workshops and interviews with expert dancers reveal preferences for continuous mappings that preserve synchronicity and for systems that prioritize aesthetics over total sonic control [28]. This highlights that sonification design in dance is shaped by multiple stakeholder perspectives. Giomi further frames movement sonification as a somatic practice [20]. Here, sound enhances kinesthetic awareness and reorganizes bodily perception. Experimental studies show that auditory feedback can refine expressive qualities and bodily perception [20, 21]. Sonification thus operates both as an external representation and as a medium for transforming corporeal knowledge.

Furthermore, Vickers and Hogg situate sonifications and musical works within a shared "Æsthetic Perspective Space" [50]. This suggests that expressive dance sonifications may be understood simultaneously as informational displays and as musical or sound-art works, depending on the listening stance.

Despite advances in abstraction, expressiveness and participatory mapping design, most approaches still center on gesture-to-sound mapping, with less attention to how mappings are modified and negotiated during live performance. This shift from mapping structure to interactional mediation grounds the present work.

2.2 Roles and Relationships in Interactive Performance

Established practices often intertwine artistic exploration, performance and instrument-making [35]. Performer, designer and composer roles frequently overlap, and musical agency is redistributed between performer, instrument and system [35].

Building on this redistribution of roles and agency, interaction can be understood as an event-based and embodied process structured by roles and dramaturgy rather than as an isolated task execution [25].

The work of Fdili et al. shows that the integration of technology into dance can generate tensions between aesthetic intent and technical robustness. Sensor systems can constrain performers, while ambiguous or partially hidden mappings can foster immersion and poetic engagement [16]. Interactive dance research further frames such systems as potentially "conversational", functioning as instruments, partners, or environmental elements depending on configuration [26]. Drawing on the development of an interactive dance work and qualitative interviews with collaborators, Johnston shows how real-time systems can be experienced as co-performers requiring listening and responsiveness. When operators adjust parameters in real–time, interaction may become triadic rather than dyadic, introducing a three-way dialogue between performer, system, and operator [26]. More broadly, complex interactive experiences present themselves as continuous trajectories across structures of space, time, roles and interfaces [4]. Collaborative musical interfaces further demonstrate that musical control is structured through constraints, distributed leadership and negotiated participation [5]. Prior research on mutual engagement in creative collaboration defines engagement as joint involvement with both the shared product and collaborators, supported by mutual awareness and mutual modifiability [7]. Mutual modification and attunement can serve as indicators of engaged collaboration [8].

At the level of instrumental configuration, multi-person and role-distributed instruments have precedents within NIME. Two-person instruments such as Tooka demonstrate how direct physical coupling can create balanced shared control, requiring coordinated action for meaningful sound production [17]. Many-person instruments further show how distributing control across symmetric or asymmetric roles reshapes performer communication, interdependence and audience perception. This can sometimes challenge the distinction between ensemble and instrument itself [41]. Likewise, relocating live coding into real-time instrument construction establishes a dual-role model in which an instrument builder modifies the instrument while a separate performer plays it, requiring mechanisms that preserve playability under continuous change [29]. By introducing feedback systems, cross-faded transitions and push–pull control mechanisms, the model demonstrates how dynamic reconfiguration reshapes agency and affordances during performance. These works suggest that splitting instrumental control across roles is not merely logistical but structurally transformative.

Collaborative digital musical instrument development research has shown that participation depth and role definitions are shaped by embodied access to instruments and by how interaction is configured [23]. Restricted embodied access tends to reinforce rigid

Figure 1: Graphical user interface of the Advanced Sonification Toolkit (AST). The interface provides matrix-based routing between sensor input channels and sound modules, alongside parameter controls for filtering, scaling, and interpolation.

role boundaries, while shared, in-person engagement supports role fluidity and joint decision-making [23].

These role dynamics are tied to digital systems that are often experienced as oscillating between instrument, compositional tool, and infrastructure depending on mapping stability, embodiment, and context of use [32].

Unlike acoustic instruments shaped by long-term usage, digital environments overlap with composition and tool-building and their mappings remain alterable throughout practice [32].

Taken together, this body of work suggests that interactive performance systems structure roles, access, and agency, informing our examination of how live mapping reconfiguration reshapes participation in a role-separated sonification setting.

3 System Overview: A Sonification Toolkit as a Live Coupling Environment

This section describes the Advanced Sonification Toolkit (AST) and its technical integration within the presented live performance configuration.

3.1 Toolkit Architecture

The AST is a modular sonification toolkit for real-time movement data in dance and sports contexts, extending the Movement Sonification Toolkit [40] and developed through workshops [39, 48] and sonification projects [33, 49]. The AST belongs to a broader family of modular sonification frameworks that provide graphical routing structures, configurable data-processing (e.g., filtering, thresholding, scaling) and flexible mappings between data streams and sound parameters [3, 34, 38, 51]. Similar architectures exist in web-based environments that lower entry barriers even further [10, 31, 37].

The AST shares the previously described core architectural characteristics with these environments while focusing on real-time movement sonification. In this sense, it is not presented here as architecturally unique. Its specificity lies in its orientation toward real-time movement: it is structured to support rapid mapping reconfiguration and many-to-many routing which make it well suited to be operated under performance conditions.

From a human–computer interaction perspective, software toolkits operate by introducing abstraction layers that manage complexity and negotiate the tension between flexibility and usability. This influences how interaction can be structured and who can meaningfully engage with the system [36].

The relevance of the AST lies in its use within a live performance configuration; we therefore present only the characteristics necessary to understand how it structured role-based interaction.

Developed in Max with a standalone graphical interface, it provides a matrix-based routing structure supporting many-to-many relationships between sensor input channels and auditory parameters, alongside modular sound design modules (see Figure 1).

While comparable configurations can be directly built in environments such as Max, Pure Data, or SuperCollider, the AST introduces abstraction layers that organize sensing, routing, and sound modules into a unified interface, supporting rapid reconfiguration and collaboration without requiring advanced programming expertise.

For the performance configuration, selected modules from the AST were instantiated within Ableton Live using Max for Live, embedding the toolkit within a musical production environment rather than using the standalone system.

The AST functions neither strictly as an instrument nor as a toolkit; its status instead emerges as a configurable coupling environment through practice.

Figure 2: Technical setup during performance. A movement sensor positioned in front of the Ableton Live set, with custom Max for Live devices visible. The setup illustrates the integration of sensor input, live signal processing, and real-time mapping within the AST environment.

3.2 Performance Infrastructure and Data Pipeline

In the enacted configuration, the AST was embedded within a sensor-to-audio pipeline linking wearable motion sensors to sound generation and processing.

An inertial measurement unit (IMU) to Open Sound Control (OSC) to audio pipeline was established. Wearable M5StickC Plus2 IMUs streamed accelerometer and gyroscope data wirelessly via OSC over Wi-Fi. Custom patches were developed in Max and multiple Max for Live devices enabled integration of sensor data directly into Ableton Live.

The system exhibited occasional variability: IMUs intermittently lost Wi-Fi connection, and minor shifts in sensor placement affected signal consistency, leading to fluctuations in responsiveness.

Figure 2 shows the live setup during performance, including one of the movement sensors positioned in front of the Ableton Live set with custom Max for Live devices visible, illustrating the integration of sensor input and real-time mapping within the AST environment.

In addition, a custom glove, validated in a sports context [49], incorporating a stretch sensor connected to an M5Stick, was developed to stream index finger flexion as a continuous control signal.

Multiple sensor locations (e.g., hand, finger, foot) were tested during development and four sensors were used in the final performance configuration: three IMU sensors (on each wrist and on the right ankle) and the glove sensor (see Figure 3). Data processing included direct access to the accelerometer and gyroscope streams, magnitude calculations and algorithmic step detection for event-based triggering. Threshold, low-pass filter and scaling parameters were freely adjustable within the data input signal chain, shaping how the data streams were conditioned and how the mapped sound responded to movement.

In parallel, the signals streamed via Wi-Fi to a visual artist who generated real-time projections in TouchDesigner, resulting in a multimodal configuration combining sound and visuals.

The following sections examine how this coupling environment functioned as a mapping system and as part of the performance ecology itself.

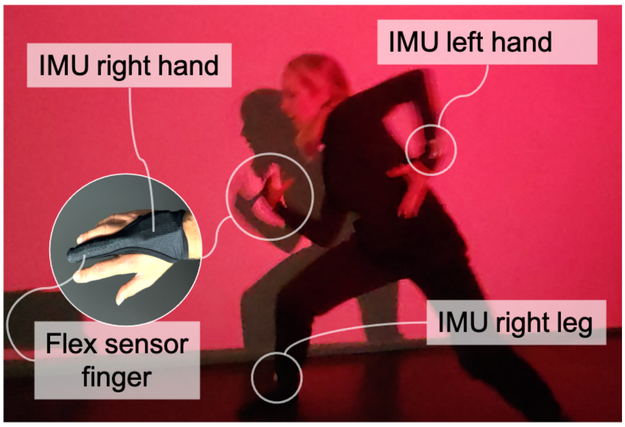

Figure 3: Final configuration of the sensors of the mover. At the right hand a glove with integrated flex sensor and IMU. At the right arm a wrist band with IMU. At the right leg a band with IMU around the ankle.

4 Case Setting: 10-day Artistic Hackathon

The case examined in this paper was developed during an open artistic workshop format bringing together approximately 300 artists across different disciplines. Over a ten-day period, technical prototyping and artistic collaboration were conducted in preparation for a public showcase presentation.

Newly developed and refined modules from the standalone version of the AST were instantiated within Ableton Live via Max for Live devices interfacing directly with a fixed musical score. The workshop format, involving rapid prototyping and public presentation under time constraints, required continuous negotiation of mapping decisions, role distribution and technical stability.

4.1 Rehearsal Process and Mapping Development

Over the ten-day period, three performance scenes were collaboratively developed with the dancer/choreographer. She also composed a fixed musical score within Ableton Live. Within this macro-structure, different modulation strategies were applied to different scenes: in some segments, sensors modulated filters on the main bus; in others, they controlled sound effects, triggered synthesizer notes, or modulated different synthesis parameters.

Mapping strategies evolved iteratively through reassignment of sensor channels, adjustment of scaling ranges and continuous tuning of data-processing parameters to align movement qualities with musical responsiveness. Some mappings were fixed prior to performance, while others remained adjustable. The workshop context enabled informal feedback from other participating artists, supporting parallel technical prototyping and artistic development.

These iterative adjustments were not just technical refinements but structured how responsibilities and responsiveness were distributed between mover and mapper. Mapping development therefore functioned simultaneously as compositional work and as negotiation of interactional roles.

The visual component combined sensor-driven elements with manually modulated projections. In addition to the dancer (mover), visual artist, and sonification operator (mapper), two further collaborators contributed to the technical and conceptual development.

Figure 4 illustrates the rehearsal configuration, including the spatial arrangement between mover and mapper, as well as a performance moment in which sensor-driven visuals and sound modulation are active.

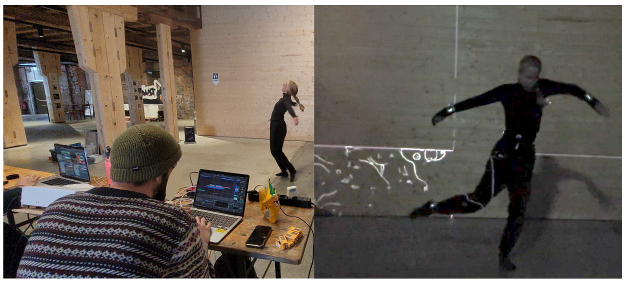

Figure 4: Left: Rehearsal configuration showing the mover (sensor-equipped) and the mapper operating the coupling environment. Right: Public performance moment with sensor-driven visuals and live movement–to–sound modulation.

4.2 Performance Configuration

The final outcome consisted of two public runs of an approximately eight-minute dance piece presented at a showcase presentation. During performance, multiple parameters within the data stream chains were adjusted in real–time in response to the dancer's movement dynamics. In selected moments, sensor-to-parameter mappings were reassigned live, allowing the coupling between specific body parts and sonic processes to shift within the fixed musical score. These moments arose when the sonic outcome no longer aligned with expectations, whether due to movement variation or sensor drift, or through intentional artistic intervention by the mapper.

The resulting configuration combined fixed musical form, iterative mapping design, real-time parameter adjustment and cross-modal collaboration within a public performance setting. While recalibration during rehearsals was often negotiated through verbal or gestural cues, the performance setup shifted this negotiation to being mediated solely through the coupling environment. The overall structure stabilized in the last rehearsal runs and remained largely consistent across both performances. At the same time, mapping ranges, thresholds, filters and scaling parameters were adjusted live.

Scene 1 started with low distorted drone notes that were processed through a comb filter. The magnitude of both hand accelerometers controlled modulation: the right hand adjusted the dry/wet balance of the comb filter, the left hand controlled the delay parameter. Sensor values were normalized (0–1) and rescaled live by the mapper (e.g., mapping dry/wet range to 0–75%). A higher sine-like tone was subsequently added and amplitude-modulated, producing a fluttering texture. The right foot accelerometer magnitude controlled the modulation frequency, while the mapper adjusted the frequency range in relation to the comb filter.

In **Scene 2**, electronic drums entered and the texture intensified. The right hand accelerometer magnitude directly modulated the volume of a continuous filtered noise layer. The mapper changed accelerometer axes (x, y, z), scaling and threshold values to realign the modulation with the expected sonic outcome. The scene intensified with more layers of sound being added. After a preliminary climax, the finger sensor controlled the cutoff frequency of a low-pass filter on the main bus, with progressively closing the fist, gradually lowering the cutoff and producing an increasingly muffled sound. Scaling and threshold values within the data-processing chain, as well as occasional reassignment of that signal to the filtered noise layer, were adjusted live by the mapper.

In **Scene 3**, the sonic elements were gradually removed until only ambient noise remained. Footsteps and kicks triggered random bass notes: the triggering structure was fixed, but the pitch and the threshold determining note activation was adjusted in real–time by the mapper.

Figure 5 visualizes the mover's control in each scene, while Figure 6 illustrates the scene-based configuration, showing how control responsibilities and sonic elements evolved across the performance.

5 Interaction Model: Mover and Mapper

Live movement sonification here is structured by three interdependent roles: the mover, the mapper, and the coupling environment (AST). These roles define how agency, access, and participation are distributed within performance.

We refer to this configuration as a role-separated live sonification interaction model: the mover performs embodied choreography, while the mapper configures and adjusts movement–to–sound relationships in real–time. This separation makes the redistribution of agency explicit.

By externalizing mapping control into a distinct role, the configuration exposes how toolkit interfaces structure participation depth and modifiability during performance.

In the present configuration, the mover has embodied access to movement generation but not to mapping parameters, whereas the mapper has direct access to threshold tuning, data filtering, scaling, routing and coupling adjustments. Participation is therefore asymmetrically distributed. However, this asymmetry does not imply any hierarchical control.

Applied to live sonification, this suggests that meaningful collaboration depends not only on who produces sound, but on whether contributions can be perceived and modified across roles.

This perspective is made explicit in the interaction model proposed here. The present model formalizes this triadic structure: the mover engages the coupling environment through embodied action; the mapper modulates the environment's responsiveness; the environment mediates perception and feedback between them. The coupling environment therefore operates as a mediating layer. It defines which parameters are adjustable, who can adjust them and when adjustments become perceptible. Sonification intent is not pre-contained in the choreography nor fixed in mapping design; it emerges through the ongoing negotiation enabled and constrained by this environment.

Figure 7 visualizes this triadic configuration, highlighting how embodied input and parameter tuning are mediated by the coupling environment rather than directly exchanged between roles.

The contribution of this model lies not in the presence of multiple roles, but in foregrounding the toolkit interface as the structural mediator that enables and constrains role-dependent participation, mutual modification and agency redistribution.

6 Reflective Performance Case

This section presents a reflective analysis of the performance configuration, treating the setup as a situated research artifact, based on first-person reflection from the mapper and a semi-structured interview with the mover.

6.1 Methodology

Consistent with an annotated portfolio logic, the contribution lies in identifying interactional qualities grounded in a specific artifact rather than abstracting explanatory theory [6].

The reflective orientation follows precedents in digital musical instrument research where first-person accounts expose tensions between sensitivity, control and unpredictability that become visible only in performance use [14, 15, 52].

Similar to performer-centered case studies in live system research, this account is descriptive and generative rather than generalizing across populations [46].

The analysis proceeded through iterative comparison of first-person reflections of the mapper and interview material from a 30-minute semi-structured interview with the mover. The interview was transcribed using the Whisper speech recognition model and reviewed for accuracy. The material was examined through the lens of the interaction model to identify recurrent interactional

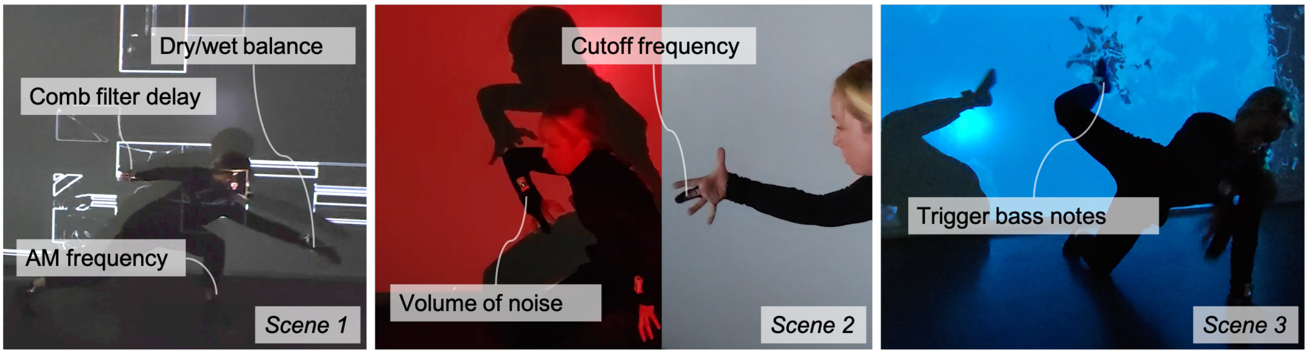

Figure 5: Interactions of the mover in each scene. In scene 1, the mover adjusted comb filter parameters. With the right hand IMU she adjusted dry/wet balance, with the left IMU the delay. In scene 2, the mover adjusted the volume of the noise layer with the right IMU. Then the focus shifted to the flex sensor on the finger to control the cutoff frequency of a low-pass filter on the main bus. In scene 3, quick movement changes with the right foot triggered bass notes.

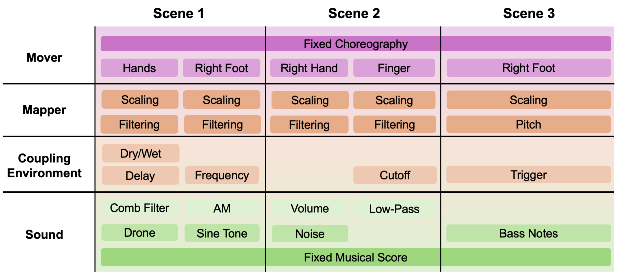

Figure 6: Scene progression and role-dependent control structure. The diagram shows how movement inputs, parameter operations and resulting sonic elements were introduced and reorganized across the three scenes.

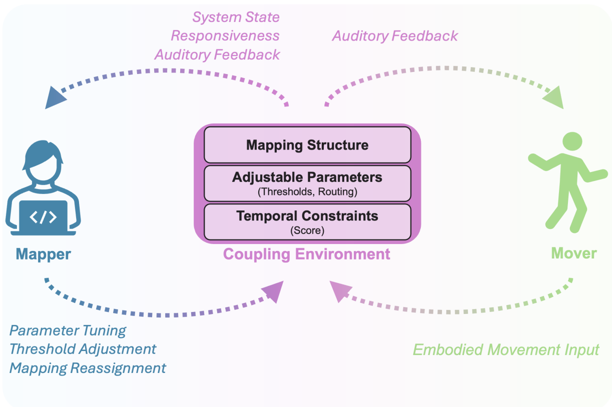

Figure 7: Role-separated live sonification interaction model. The mover provides embodied movement input to the coupling environment, while the mapper performs real-time parameter tuning. The coupling environment (AST) mediates the interaction.

structures across roles, without applying a formal qualitative coding framework.

As the findings are derived from a single case involving one mover and one mapper, they are not intended to be statistically generalizable but function as generative insights grounded in a specific configuration.

6.2 Reflections

The following subsections present recurring interactional patterns identified through iterative comparison of both perspectives, each illustrated through paired accounts and a brief structural observation.

6.2.1 Experienced Anticipation. The performance structured anticipation of system responsiveness differently for mover and mapper, with each role orienting toward distinct aspects of the interaction.

Mapper Perspective: The mapper operated with macro-level knowledge of the choreography and fixed score, enabling anticipatory threshold, filter, and scaling adjustments. At the same time, embodied variation and occasional sensor inconsistencies led to continuously updated anticipation and therefore required constant adaptation. The system's sensitivity to subtle movement variations meant that while larger formal developments could be anticipated by the mapper, their actual sonic realization differed in each run.

Mover Perspective: The mover reported limited anticipation of specific sonic outcomes because the choreography and musical score had been predefined. Moments of failed triggering were experienced as surprising. She described one instance: "*I was expecting a sound that just didn't occur and that was kind of surprising.*" In another case, she reacted to the absence of sound by adapting her movement to respond to the audible output instead: "*And then I just kind of reacted to the sound instead of the sound reacting to me.*" She occasionally noticed the mapper adjusting parameters through changes in sonic feedback rather than through direct visual attention, explaining: "*I think because of the sound feedback… but then it was maybe less an anticipation, but more an observation.*"

Structural Observation: Anticipation operated asymmetrically: the mapper anticipated choreographic structure, while the mover anticipated sonic continuity. The adaptation was uneven, with the mover at times compensating through movement and the mapper at other times recalibrating parameters. The coupling environment thus structured anticipation differently across roles.

6.2.2 Parameter Tuning. The performance incorporated multiple forms of parameter tuning, shaping sonic events such as threshold-based triggering, scaling, and filtering, which were flexibly adjusted within the AST.

Mapper Perspective: Threshold values were adjusted in real–time

in response to movement intensity. Parameter tuning shaped how much force or clarity was required from the mover to trigger certain sonic events. Low-pass filter parameters within the input data stream were also modified depending on movement speed to suppress rapid fluctuations. Parameter manipulation was experienced as an active part of the performance rather than as a technical adjustment. It was difficult to distinguish whether the need for adjustment arose from sensor behavior, movement variation, or anticipatory recalibration on the part of the mapper. However, particularly in the last scene, where steps triggered individual notes, fine-tuning thresholds felt like collaboratively articulating the notes together with the mover.
Mover Perspective: The mover described adjusting her motion on several occasions, e.g., during the last scene of the performance: "*In the very last scene when I did the stepping motion, I had to adjust my movement to really only trigger the bass notes once and not several times. So that the bassline would kind of move slower and not get ahead of the rest.*" In moments when effects did not trigger, she either compensated physically or shifted attention to the existing sound.
Structural Observation: Thresholds mediated effort and responsiveness. Both participants modified behavior in relation to triggering conditions. This aligns conceptually with mutual modification as an indicator of engaged collaboration [7].

6.2.3 Technical Instability as Performative Condition. The sensor-based setup introduced moments of technical instability, resulting in unpredictable triggering and variable responsiveness during performance.
Mapper Perspective: In early rehearsals, unpredictability in the sensor responsiveness was experienced as problematic. Over time, instability was reframed as part of the narrative character of the performance. The system was configured so that certain critical sonic events could also be triggered manually by the mapper to feel more in control. This became necessary during the second performance in Scene 3, when the foot sensor responsible for note triggering lost its wireless connection and the notes were triggered manually instead.
Mover Perspective: Asked about the technical stability of the sensor setup, the mover recalled that she needed: "*some kind of predictability… the feeling that more or less the sound or the effect would be similar each time.*" She further stated: "*The whole Max setup seemed quite stable. And then the sensors: there was always a tiny risk with them.*" She described unpredictability as generative, noting that it increased alertness during performance. At the same time, she emphasized the need for baseline predictability to feel confident. She stated: "*I wouldn't say frustrating. More like… generative… and I would add that it kind of forced me to stay very alert.*" Notably, during the second performance she did not perceive that note triggering had been taken over manually.
Structural Observation: Instability was not uniformly interpreted. For the mapper, it initially threatened control; for the mover, it heightened performative attention, but only against a background of sufficient baseline stability.

6.2.4 Instrumentalization. The performance also revealed role-dependent experiences of the coupling environment, particularly regarding whether it was enacted as an instrument.
Mapper Perspective: During performance, adjusting parameters and reassigning mappings felt comparable to playing a musical instrument. The mapper experienced shaping sonic outcomes in real–time via the AST as playing an instrument together with the mover, each responsible for different aspects of the resulting sound.
Mover Perspective: In contrast to the mapper's instrumental enactment, the mover described the system as a *"sonic universe."* She stated: "*I think it was co-performing more with a system or maybe with a sonic universe or a specific world that I was in.*" She further explained: "*I think in my role as a performer I experienced it as an environment.*" She described that in specific moments, when movement–to–sound mappings were direct and immediately responsive, it felt as if she were playing an "*invisible instrument*".
Structural Observation: The coupling environment did not hold a singular functional status. It was enacted as instrument for the mapper and as environment for the mover.

6.2.5 Agency. The performance configuration made questions of agency explicit, resulting in reflections on how influence, control, and responsibility were experienced across different roles.
Mapper Perspective: The mapper experienced controlling and shaping the performance through mapping decisions, threshold tuning and parameter adjustments. Even in moments without active parameter changes, the knowledge that mappings could be modified at any time created an increased sense of agency, as the system remained playable.
Mover Perspective: Asked about her agency during the performance, she stated that she felt in control of the sonic feedback through her movements while being aware of the mapper's role in shaping it. She reported co-performing primarily with the system rather than with an operator. She explained: "*I think the bridge was the system in a way… like non-verbal communication somehow. We were connected.*"
Structural Observation: Agency was distributed but asymmetrically perceived. The mapper directly manipulated responsiveness through parameter adjustments, while the mover exercised agency through movement variation and adaptive response to the audible feedback.

6.2.6 Performance Stabilization. Over the rehearsal period and public performances, aspects of the interaction gradually stabilized, allowing reflections on how predictability and adaptation developed over time.
Mapper Perspective: Mappings gradually stabilized during rehearsals, though certain parameters remained adjustable during public runs. Over time, movement patterns became more predictable and while some parameters still required adjustment, the points at which recalibration was typically needed became increasingly familiar to the mapper.
Mover Perspective: The mover reported that mappings felt more predictable over time. She described rehearsals as "*more internally focused*" and during performance she felt she was "*trying to demonstrate more what was happening… like look now when I move like this, this sound is happening.*" Asked about the stabilization of the mappings over time, she responded: "*Yeah, maybe because I also started to remember more and more what I had to do with each run.*"
Structural Observation: Stabilization occurred not only technically, but also performatively. Predictability supported confidence, while live adjustment preserved responsiveness. While the fixed score provided a stable macro-structure, aspects of the micro-level (e.g., recurring parameter adjustments and mapping decisions) also stabilized over rehearsal.

7 Design Considerations for Role-Separated Live Sonification Toolkits

The observations and insights derived from the enacted configuration presented in section 6 informed the set of design considerations which we will present in this section. These design considerations aim to support designers developing role-separated live sonification configurations. They are non-prescriptive guidelines, articulated in dialogue with the related work discussed above and intended as an inspirational resource for similar contexts.

7.1 Role-Dependent System Framing

The division of roles in the presented case demonstrates the perceptual organization within the performance. The mover described the system primarily as a *"sonic universe"* and occasionally as an "*invisible instrument*", suggesting that sound operated more as a perceptual layer and not just as a direct gestural output. This aligns with perspectives in dance sonification research that frame sonification as oscillating between artistic construction and perceptual modulation [20]. Role-separated live sonification configurations can support role-dependent perceptual framings, where one participant engages the system as an instrument while another experiences it as an environment.

Design Consideration: In role-separated configurations, designers should consider how different roles frame the system experientially. Given the mover enacted the system not as a control interface, parameter adjustments needed to remain audibly legible. In the presented case, threshold, scaling and filtering altered responsiveness in perceptible ways, enabling adaptation without shared parameter visibility.

7.2 Instability

In the reflective case, instability, while at times being perceived by the mover as a technical limitation, functioned as a condition shaping distributed engagement. Additionally, the mover reported that variability in triggering heightened alertness during performance, while emphasizing the necessity of predictability for confidence. This tension mirrors findings that performers in the NIME context report on unpredictability being a productive quality within performance contexts [35]. However, these accounts often assume instrumental ownership by the performer, which was seldom the case for the mover. The present case suggests that productive instability can emerge even when instrumental control is asymmetrically distributed. In the presented performance, instability was present as a distributed condition, demanding adaptation across roles.

Design Consideration: Designers should consider using a stable macro-structure (e.g., fixed score or scene structure) while allowing bounded micro-level variability (e.g., parameter tuning or mapping reassignment). This preserves performer confidence while sustaining adaptive engagement.

7.3 Interconnected Role Trajectories

The presented performance configuration introduced hybrid roles: mover, mapper, and coupling environment. These roles did not function in isolation but were interconnected. Prior work on interaction trajectories emphasizes that complex experiences unfold across space, time, roles and interfaces [4]. In the presented case, stabilization across rehearsal gradually aligned participant trajectories with the trajectory of the fixed score. The mapper's real-time adjustments mediated between emergent interactions and structural constraints.

Design Consideration: Designers should consider that role-separated live sonification configurations benefit from mechanisms that support gradual alignment between movement dynamics, mapping responsiveness and performance structure. The ability to recalibrate without interrupting the fixed score allows responsiveness to stabilize over rehearsals while remaining adaptable during performance.

7.4 Mutual Modification

Mutual engagement research conceptualizes collaboration in terms of observable mutual modification [8]. In the performance case, both roles adapted in response to perceived triggering behavior and sonic outcomes. However, control was asymmetrically distributed: the mapper had direct access to parameter controls, while the mover perceived adjustments primarily through the immediate auditory feedback. The absence of direct parameter visibility for the mover structured engagement through mediated feedback. Prior research suggests that reducing explicit identity cues may support collaborative modification by reducing perceived ownership barriers [8].

Design Consideration: Designers should consider that mutual modification can emerge even when parameter modulation access is asymmetrically distributed. Designing for perceptible sonic consequences of parameter changes allows participants to adapt responsively without requiring shared control surfaces or direct visibility of adjustments.

7.5 Summary of Design Considerations

Across these dimensions, role-separated live movement sonification foregrounds the coupling environment as a mediator of perceptual organization, temporal alignment and distributed modification. By framing sonification environments as collaborative performance infrastructures in role-separated live contexts, the paper situates toolkit design within the broader ecology of hybrid roles, trajectories and mediated agency in live artistic practice.

8 Conclusion

This paper reframed live movement sonification as a configuration that redistributes agency across roles. Through the Advanced Sonification Toolkit, a role-separated setup was enacted in which a mover and a mapper interacted indirectly through a shared coupling environment. We examined how this structure manifested in the rehearsal phase and public performances through comparative reflection across roles. The case revealed asymmetrical anticipation, threshold tuning as negotiation, instability as a distributed condition and divergent experiences of instrumental identity. Productive variability emerged through mediated adaptation between roles. We extracted generative design considerations grounded in this enacted artifact. These implications suggest that live sonification toolkits should support perceptual reorganization, calibrated instability, orchestration across hybrid roles and asymmetric and mutually modifiable participation structures.

By treating toolkits as collaborative performance infrastructures, this paper contributes a conceptual and interactional articulation of role-separated live sonification. It positions movement–to–sound coupling not as a fixed interface problem, but as a dynamic ecology in which agency, control and engagement are continuously negotiated.

With this perspective, we aim to open up a design space for live movement sonification that highlights role-based aspects and to support designers and researchers in reflecting on such systems in terms of how they organize roles, participation and distributed control.

Ethics Statement

This research involved an artistic workshop and public performances with voluntary collaborators, including one dancer whose perspective informed the reflective analysis. The participant provided informed consent for participation, audio recording of an interview and the use of anonymized excerpts in this publication.

Participation posed no risk beyond ordinary dance rehearsal and performance activities. Non-invasive wearable sensors were used solely for movement data capture. No sensitive personal data were collected.

Interview data were stored securely and identifying information was removed where possible. The research was conducted in accordance with applicable institutional and data protection guidelines.

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