From Control to Co-Agency: Reframing Instrumentality through Sonic Traces in Augmented Musical Practice

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Abstract

Contemporary practices with augmented and digitally mediated musical instruments increasingly question familiar ideas of control, mastery, and instrumental agency. In many such practices, agency is distributed across bodies, technical configurations, spaces, and temporal processes, reorienting instrumental design toward shared agency rather than a primary focus on parameter extension or mapping within a constrained digital domain. From this perspective, musical instruments can be understood less as interfaces to be controlled and more as entwined systems, relational ecologies shaped through listening, bodily awareness, and adaptive (inter-)action.

Grounded in artistic practice, this paper explores how subtle, non-dominant sonic phenomena can function as meaningful resources for interaction with an augmented acoustic instrument. Focusing on a solo bandoneon augmented through live electronics and machine learning, the work articulates the three interrelated concepts of peripheral sounds, gestural remains, and residual resonances that become perceptible through practice, amplification, and learning. Sounds arising from the instrument's materials, friction with the body and lingering resonances are approached not as side effects, but as sonic traces that orient listening and action.

Across the design and composition of a live-electronic ecosystem, a concert performance, and a performative sound installation, these subtle sounds operate as cues for action, shaping movement, timing, and decision-making for both performer and technical system. Attending to such phenomena leads to new gestural strategies, alternative modes of augmentation, and shifts in how listening is organised within performance situations. By reconsidering what counts as signal in augmented instruments that use machine-learning, this work contributes to NIME discussions on affordances, agency, and relational instrument design, foregrounding co-agency grounded in responsiveness and emergent behaviour.

Keywords

Augmented musical instruments, adaptive performance practice, co-agency and relational ecologies, practice-based research approach

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1 Introduction

In acoustic instrumental practice, certain sonic events emerge that are neither intentionally produced nor foregrounded as musical material. Even without amplification or electronics, these sounds appear at the edges of attention: a resonance lingering after a sonic or instrumental gesture, the sound of air moving through bellows, friction between body and instrument, or subtle timbral shifts caused by movement. Such phenomena are often treated as secondary or incidental, yet they persist beyond intentional actions and continue to interact with the body, the instrument, and the surrounding space. For example, the quality of a resonance left after releasing a chord may prompt a performer to pause or adjust their posture, or the sound of air passing through the instrument may subtly guide the timing and direction of the next passage.

When instruments are augmented through amplification, sensing, and digital processing, these marginal sonic phenomena become especially consequential. Augmented musical instruments and machine-learning-based systems frequently rely on clearly identifiable gestures and dominant sonic features as primary inputs for interaction. Training strategies in machine-learning often reinforce this tendency by privileging salient, intentional sounds that are easily separable and classifiable. As a result, subtle sonic behaviours are commonly treated as noise to be suppressed rather than as valid interaction material. While research in NIME has extensively explored sensing, mapping, and machine-learning techniques, comparatively less attention has been given to how such phenomena are experienced from within performance, how shaping listening, movement, timing, and decisions unfold in interaction with augmented acoustic instruments [16].

In this article, we argue that non-dominant sounds function as cues for action in acoustic performance and can play an active role in the development of augmented acoustic instruments, particularly when the objective is not to optimise control, but to preserve and extend embodied performance practices. We present an artistic research investigation grounded in two laboratory-like artistic experiments, a solo concert performance and a performative sound installation, through which issues emerging from sustained instrumental practice are explored. Both experimental processes are developed through sustained practice with a solo bandoneon augmented by amplification, live electronics, and machine learning [20].

The first experiment took the form of a solo concert performance, *Neons & Neutrals*, in which a sound bank composed exclusively of bandoneon sounds was used to train a regression-based machine-learning system. The dataset was developed through extended periods of iterative sonic explorations that included recording, listening, and refinement of both the sound material and the system's training processes. Initial training material focused on conventional bandoneon sounds, such as pitched tones and airflow, before expanding toward less commonly foregrounded sonic phenomena and extended techniques. The machine-learning system was trained to recognise specific

features of the performer's playing, allowing detected sounds to trigger and modulate electronic processes such as looping, gating, filtering, and spatialised sound movement. Through developing this process, it became apparent that subtle, yet temporally stable sonic phenomena were recognised more reliably than dominant pitched material, leading to a deliberate choice to shift the compositional focus toward using residual resonances, subtle air sounds, and mechanical noises as primary sonic material for adaptive play.

The second experiment, a performative sound installation entitled *Scratched Surfaces*, extended this approach by isolating, spatialising, and thus recontextualising the desired qualities of marginal sonic elements. Here, peripheral sounds informed the sonic structure and temporal organisation of the installation, with the extended processes of recording, isolating, and rehearsing of these materials allowing to reveal their perceptual salience and under-explored potential as material for adaptive play. In both experiments, machine-learning functioned not as a tool for classification or prediction, but as a mechanism for the instrumental system to produce responses that gradually became attuned to subtle sonic traces through sustained practice and adjustment.

Methodologically, this inquiry draws on an embodied, practice-led research approach [22] grounded in reflexive performance [14] and situated listening [19]. Listening is considered as an active mode of orientation within an unfolding performance situation, shaped through attention, movement, and reciprocal adaptation. Across both experiments, knowledge emerges through sustained engagement with the augmented bandoneon in an iterative process of rehearsal and performance, allowing for subtle sonic phenomena to guide action and decision-making in real time. By foregrounding peripheral, residual, and discarded sounds as actionable signals, this article reframes augmentation as the invention of an instrumental system to be performed rather than of an interface to be controlled. With this perspective, we hope to contribute to the NIME discussions on affordances, agency, and relational instrument design by proposing a shift in attention from control-oriented mappings toward shared agency, unfolding through the responsive interplay between performer and augmented environment that gives rise to emergent behaviour.

Figure 1: Practice session with the Augmented Bandoneon for the Performative Installation

2 Relational Instrumentality in Augmented Musical Practice

2.1 Instrument as Relational System

Within an ecological perspective, the augmented bandoneon cannot be understood as a neutral interface for sound production and control. Instead, instrumentality emerges as a relational principle shaped by bodily gesture, resonant materials, technological mediation, and spatial conditions. This view aligns with ecological and relational approaches to musical practice, in which instruments are conceived as dynamic systems constituted through interaction rather than as stable interfaces [11][20][25].

In an augmented performance context, the bandoneon does not function as a closed sound-producing entity. Its material properties such as airflow, resistance, mechanical noise, and friction interact with amplification, live electronics, and space, producing sounds that exceed intentional control [2]. These interactions generate sonic phenomena that persist beyond discrete gestures and thus challenge linear models of action and response. Listening, in this context, becomes a way of navigating the system rather than evaluating its output. The performer acts *within* the system, responding to its overall modulations as they unfold over time.

This understanding resonates with artistic research perspectives that frame musical practice as situated action, in which insights and understanding emerge through multi-modal engagement with materials, technologies, and contexts [5], [24]. From this perspective, instrumentality is not something to be mastered in advance, but something that takes shape through shared agencies, responsiveness, and ongoing negotiation with the performance environment [26][8][2].

2.2 Practice-Led Inquiry as an Alternative to Evaluation

This work adopts a first-person, practice-led and practice-based research approach situated within research-through-performance traditions at NIME. The contribution emerges from sustained engagement with an evolving instrumental system, continually refined through practice and reconfigured across different spaces and performance situations, rather than through controlled user studies or comparative evaluation.

Performance is treated here as a site of inquiry rather than as a final demonstration of a completed design. Design decisions, training strategies, and interaction behaviours evolve through use, allowing the instrument to be discovered, reshaped, and reconfigured through practice. The performer is not understood as a user operating an external system, but as an active agent embedded within it [17].

Such an approach foregrounds forms of knowledge that cannot easily be accessed through laboratory-style evaluation. Subtle shifts in attention, timing, bodily orientation, and responsiveness emerge only through long-term engagement and are inseparable from the material and sonic conditions of performance. In this sense, the performance situation itself functions as a laboratory: embodied, situated, and re-invented with each iteration [27, 29].

2.3 Listening as Action and Method

Central to this inquiry is an understanding of listening as an active process that guides action rather than evaluates outcomes [13]. Listening is not positioned as a post-hoc analytical act, but

as a mode of orientation and within an unfolding performance situation. Through listening, the performer becomes attuned to ongoing sonic feedback, temporal persistence, and spatial behaviour, allowing decisions to arise *in response* to what is perceived rather than according to predefined goals.

This mode of listening is inseparable from bodily movement, instrumental skill, and timing. Small variations in posture, pressure, or distance become consequential when subtle sonic phenomena are amplified and made perceptible. Listening thus operates as a form of priming for a readiness to respond, informing the decision of when to act and when to wait, and how to adjust within the system and towards a "machinic" co-agent [33]. While reflection and analysis may occur after performance, insight and understanding [4] originates within and through action, by attending to the continuous coupling of sound, movement, and attention.

Augmentation through machine learning alters what the performer listens for. By enabling the system to respond to subtle sonic behaviours, listening shifts away from dominant events toward micro-variation, residual resonance, and peripheral sound. This reorientation transforms interaction from the execution of commands into an ongoing negotiation within the behavioural space of the augmented instrument's ecosystem [20].

2.4 Sound as Relational and Emergent

Within this inquiry, sound is approached not as a stable object or a predefined result, but as something that unfolds through relation. It emerges through the interactions of body, instrument, technical apparatus, and space, leaving traces of action and inviting further response through listening and attention. Sound can carry intention, but it can also disclose relations, between gesture and resistance, action and persistence, presence and absence, relations that become perceptible only through attentive listening within and during the practice [21].

When machine learning is introduced into such an instrumental ecology, it can reshape attention and affects the musician's sensitivity to sonic behaviours that orients already present practices, extending their capacity to inform action.

In this sense, a machine-learning response system operates less as a representational tool and more as a material participant in the instrumental ecology, with ethical implications for what gradually becomes perceptible, actionable, or ignored [9].

This perspective prepares the ground for the conceptual tools introduced in the following sections. The concepts articulated in this article function as lenses for attending to interactions and co-agencies as they unfold in practice. They foreground sensitivity to sonic behaviours that influence action without occupying the focus of musical material, and point toward a design orientation grounded in attentiveness: one in which augmentation extends and intensifies modes of listening and response that are already active in acoustic instrumental practice. Approached in this way, subtle sonic phenomena can gradually acquire relevance and agency within instrument design, thus opening further space for exploration [1].

Ethically, such an approach invites an attitude of care towards what is amplified, attended to, or ignored within augmented systems. Treating sound relationally foregrounds the artist's responsibility in design choices, particularly when machine-learning processes shape which sonic behaviours become actionable.

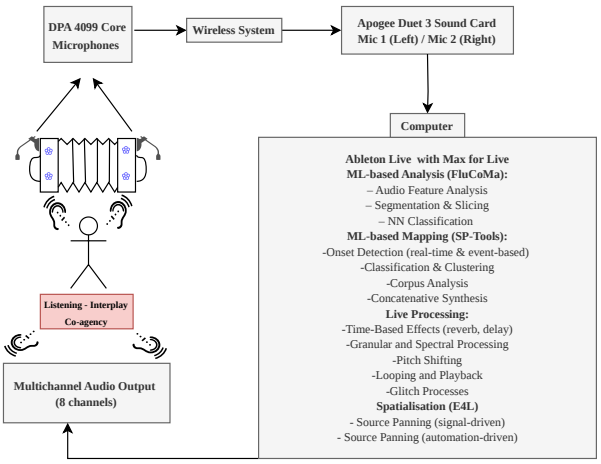

Figure 2: A systems diagram of the player's entwining with the augmented instrument, including the action-perception loop and Co-Agency through listening and interplay

3 Instrument and Augmentation Setup: Experimenting in Practice

This section describes the augmented bandoneon system as it is developed and explored through ongoing practice, outlining the acoustic instrument, the audio capture and processing chain, and the machine-learning components as they appear in rehearsal and performance (all supplemental material referenced below is located at https://www.extendedbandoneon.com/articles/from-control-to-coagency).

3.1 The Augmented Bandoneon as an Instrumental System

The acoustic instrument and its characteristics. The bandoneon explored in this work is a bisonoric aerophone, approached through sustained solo practice, whose sound production is inseparable from bodily movement, mechanical resistance, and air circulation. Sound arises from the continuous interaction between bellows, buttons, internal mechanics, and the performer's body.

The bellows play a central role in this sonic ecology. Beyond regulating volume, their movement produces audible airflow, inertia, and resistance. Directional changes, opening and closing, are structurally embedded in the instrument's logic, shaping pitch, timbre, and articulation while simultaneously generating non-pitched sonic material. Air sounds, pressure fluctuations, and delayed responses emerge naturally through sustained playing, particularly in slow or transitional passages. Because each button produces different notes depending on the direction of airflow, and because each note is voiced through paired reeds, movement and sound remain tightly coupled, with subtle variations in pressure and timing producing distinct timbral outcomes.

Button interaction is equally consequential. Each action activates a chain of mechanical events involving springs, levers, the valve, and reeds, producing subtle noises, such as clicks, friction, resonances within the wooden casing, and sympathetic vibrations, that often linger beyond the initial gesture.

Many of these sonic events occur at the threshold of intention. They may not be explicitly produced, yet they remain perceptible to the performer and continue to influence timing, movement, and attention. In practice, they function as feedback, signalling resistance, fatigue, balance, or the need for adjustment. Listening to these sounds becomes a way of sensing the instrument's state and orienting action in response.

This physical characteristic has historically shaped bandoneon practice. As discussed in earlier organological and practice-based work [15], the instrument's layout and mechanics have encouraged intuitive learning, adaptive strategies, and forms of notation that function more as orientation than instruction. In this sense, the bandoneon already operates as a relational system, in which sound mediates action, memory, and decision-making.

Audio Capture. In the configurations discussed here, the bandoneon is captured using a pair of DPA 4099 Core microphones attached directly to the instrument. This choice responds to the physical and spatial nature of the bandoneon, which functions as a stereo instrument: sound from the right-hand keyboard radiates primarily from the right side of the instrument, while the left-hand keyboard projects from the opposite side. As the bellows open and close, the spatial relationship between these sound sources continuously changes, producing a dynamic stereo image that expands and contracts with movement (cf. 1 on suppl. material).

Because the sound source is in constant motion, using microphones positioned at a fixed distance from the instrument proved challenging if not limiting. The attached microphones allow the relative distance between microphone and sound source to remain stable regardless of bellows opening, preserving spatial detail while accommodating continuous movement. Although designed for accordion, the microphones are well suited to the bandoneon, which shares similar free-reed principles despite differences in construction and layout. In performance and throughout many iterations of practice, the microphones were used with a wireless system, allowing full bodily mobility and avoiding the constraints of cables. This supported extended playing techniques, changes of posture, and movement in space without disrupting audio capture.

Audio Signals and Sound Files. The bandoneon signal is routed from the microphones to a laptop via an audio interface, where it becomes part of a live electronic ecosystem (cf. Figure 2). From this point, the audio can be amplified, analysed, processed, and spatialised in real time, while remaining continuously linked to the performer's actions on the acoustic instrument. Within this setup, audio is routed to real-time processes developed using SP-tools for Ableton Live,[1] the FluCoMa toolkit,[2] and Ableton Live itself.[3] Together, these environments support feature extraction, machine-learning training, and responsive electronic behaviour, forming the basis for interaction between acoustic sound and electronic processes.

Sound banks play a dual role within this workflow. On the one hand, they provide material for training machine-learning models on specific sounds of the bandoneon. On the other, they function as test signals, allowing the system's responses to be explored, refined, and listened to independently of live playing (cf. 2 on suppl. material).

[1]https://github.com/rconstanzo/sp-tools (all URLs last accessed 11. February 2026)
[2]https://www.flucoma.org/
[3]https://www.ableton.com/

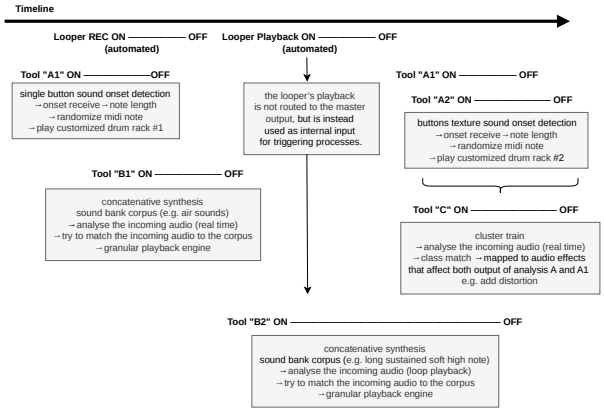

Figure 3: Temporal Organisation of the Augmented Bandoneon and Machine Learning.

Listening in this system operates across performer and computational processes. Machine listening is organised temporally and conditionally, with certain analytical modules active only at specific moments, while others are triggered when particular sonic features occur (cf. Figure 3). In parallel, performer listening remains attuned to the evolving acoustic and electronic feedback. In this way, machine analysis unfolds alongside the performance, with different listening modes opening and closing over time. These subtle sounds function as analytical input and also as cues for action, shaping how and when the system responds.

When detected, these sonic cues activate a range of electronic responses, from simple actions, such as triggering samples or opening signal paths, to more complex chains of events. These may include recording short fragments of live sound that are later replayed with transformations such as temporal stretching, reversal, delay, distortion, or spatial redistribution. Some responses incorporate degrees of randomness, ensuring that system behaviour remains variable and that performances do not unfold in exactly the same way. The electronic processes extend, layer, or reposition sound in time and space, remaining closely tied to the performer's ongoing activity.

3.2 Experimentation as Thinking-Through-Prototype

Experimentation with the augmented bandoneon takes shape through practice, where making and use continuously inform one another. The system is assembled through cycles of playing, listening, modification, and reconfiguration. Dataset curation, model training, and system testing are treated as integral components of musical practice, shaping how the instrument becomes playable over time [30]. This approach frames experimentation as a way of thinking through the prototype itself. Certain configurations prove unresponsive or unstable, while others reveal unexpected sensitivities in the relationship between sound, gesture, and how the system reacts. Moments where the system resists intention, for example by misclassifying, remaining silent, or responding ambiguously, often draw attention to sonic details or patterns that would otherwise remain peripheral. Development proceeds across rehearsals and performances, with adjustments guided primarily by perceptual experience. What matters is not recognition accuracy or technical robustness, but whether the system sustains a coherent and repeatable mode of interaction with performer-specific sonic phenomena. Through this process,

the augmented bandoneon is continuously redefined, with experimentation as an ongoing negotiation between instrument, electronics, and practice [31].

3.3 Phases of Practice and System Development

The development of the augmented bandoneon can be described through four interrelated phases, which recur iteratively throughout the two laboratory settings.

Phase 1: Dataset Curation
After the sound bank has been built and many sounds have been recorded and practised, the first major phase of practice centres on dataset curation. Training material is collected through extended periods of solo practice, where attention is given not only to intentional musical sounds, but also to those that arise incidentally through movement, instrumental resistance, air flow, and bodily contact. Recording sessions become listening situations, making it possible to notice sounds that often pass unnoticed during playing.
This work takes place before introducing electronics in a performative sense. Time is spent learning how to produce and sustain subtle sounds without triggering dominant pitched material. This pre-electronic awareness sharpens listening and reveals how these sounds already function as feedback in acoustic practice, signalling changes in pressure, balance, or resistance (cf. 3 on suppl. material).
In this phase, dataset curation is understood as a way of shaping how the system will later listen. Choices about what to record, what to preserve, and what to exclude directly influence which sounds become perceptible and actionable. Working with a small, performer-specific collection allows the dataset to function as a sonic archive of practice, embedding personal habits, sensitivities, and ways of listening into the augmented instrument.
Importantly, this process also transforms listening on the performer's side. Through repeated recording and playback, subtle sonic phenomena become easier to recognise, reproduce, and work with. Dataset curation thus trains attention as much as it trains models, laying the perceptual ground for the later integration of machine learning into the instrumental system.

Phase 2: Model Training — Calibrating Responsiveness
Model training marks the point at which listening extends beyond the acoustic instrument to include the system's responses. Curated sound material is used to train machine learning models, not to achieve general recognition accuracy, but to calibrate how the system reacts to specific sounds of the bandoneon. Training sessions are approached as moments of rehearsal, where sound, response, and feedback are explored together. This process is implemented using audio-based machine learning tools from the FluCoMa and SP-Tools, embedded within a live performance environment.
As training progresses, certain sounds prove more stable and perceptually distinct than others (cf. 4 on suppl. material). For instance, low-level air sounds or mechanical noises often elicit clearer and more consistent responses than louder pitched material, which can vary widely in intensity and articulation. Such observations inform subsequent adjustments to the dataset and training process, creating a feedback loop between listening, playing, and system behaviour. Through repeated training and testing, the system gradually becomes sensitive to performer-specific sound qualities. What emerges is not a model that recognises sounds in isolation, but one that responds in ways that remain coherent across time and practice.

Phase 3: Rehearsal and Performance
The system is explored through rehearsal and performance situations, where responsive adaptation unfolds in real time. These contexts expose temporal dynamics, spatial behaviour, and perceptual thresholds that cannot be accessed through isolated testing. Through repeated engagement and the refinement of practice, a more skilled mode of interaction develops within the system [3].

Phase 4: Reflection and Documentation
Even though insights emerge during practice and performance, they can easily be lost afterwards. Post-performance reflection, supported by audio and video documentation, rehearsal notes, and 'embodied recall' (for example, by repeating a pattern or playing along with recordings), makes it possible to revisit these moments and develop a broader understanding. Documentation does not only function as material for external, a posteriori analysis, but feeds back into subsequent phases of practice and system development.

3.4 Performance Contexts as Experimental Conditions

The augmented bandoneon system is explored across two primary performance contexts: a solo concert performance, *Neons & Neutrals* (cf. 5 on suppl. material), and a performative sound installation, *Scratched Surfaces*, (cf. 6 on suppl. material). These contexts differ in spatial configuration, audience positioning, and temporal structure, but both function as experimental conditions in which the potential of the sonic behaviours are tested and refined.

In the concert setting, interaction unfolds through close coupling between gesture, sound, and electronic response, foregrounding temporal persistence and the continuity of action. In the installation context, sonic behaviours are spatialised and detached from the immediate presence of the performer, allowing residual and peripheral sounds to organise listening and movement within the space for audience and musician alike. Together, these contexts enable the investigation of subtle sonic phenomena and their effectiveness and impact across different scales of co-agencies in interplay.

Rather than treating performances as final outcomes, they are approached as moments within an ongoing experimental process. Each performance reconfigures the instrumental system and reveals new relational dynamics between sound, body, technological arrangements, and the performance environment.

4 Sonic Traces and Cues for Action

This section turns to the moment when the different elements of the augmented bandoneon are brought together in sustained practice and performance. It is here, in the midst of playing, listening, and interplay, that certain sonic layers prove to be especially important for navigating the live-electronic ecosystem. These organise attention, timing, and decision-making. They function as cues for action.

Through performance and rehearsal, three recurring types of sonic phenomena become particularly evident: **peripheral sounds**, **gestural remains**, and **discarded sounds**. These concepts are not proposed as fixed analytical categories, nor as universal descriptors of augmented musical interaction possibilities.

They function as situated lenses for attending to subtle sonic elements and behaviours that orient action without occupying the foreground of musical material.

What became clear during practice and performance is that interplay is rarely driven by a single, intentional gesture. More often, it unfolds through what lingers, what slips through, or what quietly insists on being noticed. A faint air sound suggests slowing down. A lingering resonance delays the next movement. A mechanical noise suddenly becomes a reliable point of reference.

The following sections articulate these phenomena as they operate within the relational instrumental system described in sections 2 and 3. Each offers a different perspective on how sound can guide action, shape interaction, and support co-agency within a live-electronic performance environment.

4.1 Peripheral Sounds: Orientation at the Margins of Attention

Peripheral sounds refer to sonic events that remain outside focal attention while nonetheless shaping action [13]. Within the augmented bandoneon practice, peripheral sounds are not incidental by-products, but deliberately foregrounded elements of interaction. They are intentionally selected during dataset curation and training, becoming functional points of communication between the performer and the electronic system. Through amplification and repeated exploration, these sounds gain presence and reliability, offering a way to engage with the electronics without interrupting the flow of performance. Their relative subtlety makes them both robust, less prone to masking or feedback, and playful to work with, encouraging exploratory adaptive play while remaining closely tied to the instrument's material affordances.

Crucially, these sounds are already part of acoustic bandoneon practice. They have long informed timing, pressure, and movement decisions, even if they are rarely treated as musical material. By incorporating them into the augmented system as fundamental material, the electronic layer extends existing modes of communication rather than introducing foreign control gestures. In this way, the augmentation supports continuity with the instrument's playing technique and preserves the characteristic "personality" of the bandoneon.

By attending to peripheral sounds, actions and interplay shifts away from discrete cause–effect relationships toward a more continuous negotiation with the system. Sonic 'Gestalts' [12] emerge not through command, but through sensitivity to what is already happening. Peripheral sounds thus support a mode of engagement grounded in attentiveness and readiness rather than execution [28].

4.2 Gestural Remains: Temporal Persistence and Continuity of Action

Gestural remains describe the traces of action that persist beyond the execution of a gesture. These may take the form of lingering acoustic resonances, delayed electronic responses, residual vibrations, or spatial remnants. Rather than marking the end of an action, these remains extend and modify it in time, shaping subsequent decisions and actions.

Within the augmented bandoneon system, gestural remains foreground time and resonance as an active component of interaction. A gesture does not conclude when physical movement stops; it continues to act through its sonic consequences. Listening to these remains becomes a way of maintaining continuity across actions, allowing performance to unfold through accumulation, interruption, and return to previously sounded material rather than linear progression.

This phenomenon becomes particularly evident when comparing acoustic and augmented contexts. In acoustic bandoneon playing, the spatial field of attention tends to remain close to the performer's body and the instrument, even in resonant spaces. With amplification and live electronics, this field expands and redistributes. Sounds are projected through loudspeakers and spatial processes, allowing gestures to leave traces that appear elsewhere in the room or later in time. These spatial after-resonances detach from their point of origin and continue to orient attention and movement.

In the two laboratory settings, this phenomenon was particularly evident in situations where electronic responses prolonged or transformed acoustic traces, making persistence audible and spatially distributed. Gestural remains thus contribute to an aesthetic of retention, in which musical form is shaped by what endures rather than by what is completed.

4.3 Discarded Sounds: Recontextualising the Excluded

Discarded sounds refer to sonic phenomena that are present in instrumental practice but typically deprioritised, corrected, or trained away from in performance and pedagogical contexts, such as mechanical noise, air leaks, bodily friction, incidental contact with surfaces, or sounds produced by instability, wear, or partial malfunction. While some of these sounds remain peripheral, others are actively suppressed or avoided, as they are often associated with error, loss of control, or technical failure.

In acoustic practice, many discarded sounds emerge through changing conditions rather than intentional action. Environmental factors such as temperature and humidity can alter the behaviour of the instrument: wooden components expand or contract, buttons become tighter or less agile, and passages that are normally fluent may suddenly become challenging. These moments often produce unintended noises or delayed responses that signal a change in the instrument's state.

Within the augmented bandoneon system, discarded sounds are not treated as fully controllable interaction material, but are recontextualised through attentive listening, selective amplification, and their inclusion in exploratory training processes. Many of these sounds cannot be reliably reproduced on demand. Their value lies not in predictability, but in their capacity to signal shifts in the instrumental and environmental situation.

Through dataset curation and rehearsal, these sounds become more recognisable and easier to work with when they occur. In the electronic domain, discarded sounds may also appear as digital artefacts, for example glitches, mis-triggers, delayed activations, or unexpected feedback, emerging from system latency, thresholding, or model ambiguity. When attended to rather than corrected, such artefacts are integrated into the interaction logic as situational events rather than errors to be eliminated.

4.4 Sound as Cue for Action

Taken together, peripheral sounds, gestural remains, and discarded sounds shift attention away from isolated events and toward sound as an ongoing orienting force within performance. What becomes significant is not a single gesture or outcome, but how sonic traces accumulate, persist, and reappear across time and space.

In this context, sonic events, whether acoustic, processed, or spatialised, inform decisions about movement, timing, intensity, and orientation as performance unfolds. These cues are not interpreted after the fact, nor are they followed as instructions. They operate within the moment, shaping action through listening that is continuous and situated [23].

This mode of cueing is not foreign to instrumental practice. Acoustic performance already relies on subtle sonic feedback to guide action. What changes in the augmented context is the scale and distribution of these cues. Through amplification, live processing, and spatialisation, sonic traces are extended beyond the immediate body–instrument relation [18]. Cues may persist longer, appear at a distance, or return transformed, allowing interaction to develop across expanded temporal and spatial fields.

In practice, this redistribution of cues alters how orientation is maintained [10]. Rather than relying on a separate monitoring channel, the electronic ecosystem itself becomes the point of reference [6]. Sound does not confirm what has been played; it suggests how to proceed. Listening becomes the primary means of navigation within the system, allowing action to remain responsive to an environment that continues to answer back [32].

This perspective aligns with the relational understanding of instrumentality developed in section 2, in which agency emerges through ongoing negotiation between performer, instrument, system, and environment. By attending to what persists, leaks, or remains, interaction shifts from control toward participation.

5 Observations and Implications for Augmented Instrument Design and Practice

This section gathers observations from extended rehearsal and performance with the augmented bandoneon across the two artistic experiments. It focuses on which elements sustain the interplay only when the full ecosystem is in use: which sonic traces turn into consistent cues, how electronic responses extend gestures across time and space, and how attention redistributes once the setup begins to answer back. The goal is to describe the practical interaction patterns and variabilities that shape what the instrument can do, musically, perceptually, and performatively, over time.

5.1 Reconfiguring Performance Attention: Performer–Instrument Relations

Extended practice with the augmented bandoneon reconfigures performance behaviour. Attention no longer centres primarily on producing discrete, goal-oriented gestures, but on tracking ongoing sonic responses within the augmented environment. Because subtle peripheral and residual sounds are mapped to electronic processes, small variations in pressure, posture, or proximity trigger audible changes, for example activating samples, modulating spatialisation, or initiating delayed responses. These reactions, in turn, influence subsequent movement.

Interaction therefore becomes recursive. Action generates response; response reshapes action. Over time, this forms interdependent sonic patterns in which neither performer nor system operates independently. What emerges is not a fixed interaction strategy, but a mode of attunement to evolving feedback. Performance unfolds as continuous adjustment more than execution, sustained by sensitivity to what persists, resonates, or unexpectedly returns.

The temporal extension introduced by gestural remains further alters the perception of musical time. Actions are shaped not only by what was intended, but by what continues to sound and circulate within the system. This supports a non-linear sense of form, in which interruption, return, and accumulation play a more central role than progression or repetition.

The inclusion of peripheral and discarded sounds in the training process reconfigures the performer's *relationship to the instrument*. Sounds that would typically be ignored or actively suppressed become sites of exploration. Their incorporation expands the available gestural vocabulary and invites alternative techniques that would otherwise remain marginal in conventional practice.

As these sounds gain functional relevance within the augmented ecosystem, interplay becomes explicitly reciprocal. The performer selects and shapes sounds in anticipation of possible system responses, while the system's reactions influence subsequent choices of gesture, pressure, timing, and material focus. Selection and shaping of sound therefore unfold within a feedback loop: subtle air noise may trigger a spatial diffusion that encourages sustained bellows movement; a mechanical click may activate a delayed response that alters pacing. Over time, this mutual adaptation supports a form of co-agency in shaping the evolving sonic field.

5.2 Audience Engagement and Listening Conditions

Audience engagement is also affected by the emphasis on subtle sonic phenomena. In both the concert and installation contexts, listeners reported heightened attentiveness to quiet, residual, and spatialised sounds. Performance situations thus encouraged close listening and focused perception, with attention often drawn to sounds that would typically remain unnoticed.

In the installation context in particular, the redistribution of agency extended to the audience. Listening became an active process shaped by movement, duration, and spatial orientation, allowing each listener to construct their own temporal path through the work [7]. This further reinforces the shift from control-oriented performance toward participation grounded in interdependent co-agency.

6 Discussion: Implications for NIME Design Practices

The observations presented here suggest several implications for the design of augmented musical instruments within the NIME community.

First, they challenge the assumption that interaction must be organised around dominant or easily identifiable signals. Subtle sonic phenomena can function as rich interaction material when systems are configured to respond to them. Treating such sounds as actionable rather than suppressible opens alternative pathways grounded in attentiveness and sensitivity rather than efficiency or control.

Second, this work suggests that machine learning can operate as a means of amplifying sensitivity to micro-variation. When trained on performer-specific, subtle sonic traces, the system does not simply classify or predict; it participates in a recursive feedback loop. This produces three interdependent forms of responsiveness:

(1) Performer responsiveness, in which listening becomes a mode of action and subtle cues guide movement, timing, and intensity.

(2) System responsiveness, in which electronic processes react to micro-variations in sound and shape subsequent actions without requiring explicit commands.
(3) Audience responsiveness, in which distributed spatial and temporal traces invite heightened attention to quiet or peripheral phenomena that might otherwise remain unnoticed.

Finally, these observations support a reframing of affordances [10] as *emergent* rather than predefined. Interaction arises through ongoing negotiation between performer, augmented instrument system, and environment. In this sense, augmented instruments are not interfaces to be mastered, but relational systems that sustain co-agency through continuous feedback, adaptation, and care.

7 Conclusion

This article has explored how subtle, non-dominant sonic phenomena can function as meaningful interaction material in machine-learning-augmented acoustic instruments. Through a practice-led research investigation grounded in a solo concert performance and a performative sound installation, the study has shown how peripheral sounds and residual resonances actively shape musical choices, attention, and decision-making within and in interplay with an augmented instrumental system.

Foregrounding such traces reframes instrumentality as a relational process. Sound is not treated as a predefined outcome to be produced or controlled, but as something that orients action as it unfolds. Listening becomes tightly linked to movement, and musical form emerges through accumulation, persistence, and feedback across acoustic and electronic space.

In this configuration, machine learning does not automate musical choice. It participates in shaping an ecology in which performer and system continuously adapt to one another. The aim is not prediction or optimisation, but heightened sensitivity to performer-specific micro-variation.

Taken together, these observations contribute to ongoing discussions in NIME around agency, affordances, and instrumental development. They suggest that augmented instruments may be approached as evolving systems that cultivate co-agency through attentiveness, negotiation, and care. More broadly, this work advocates compositional and instrumental practices that value subtlety, persistence, and situated listening as central resources in contemporary musical performance.

8 Ethical Standards

This research is a practice-led artistic inquiry and did not involve human participants beyond the authors. No experiments were carried out on external participants, not requiring institutional ethics approval. All audio material used for training and system development was generated and recorded by the authors with their own instrument and equipment. No third-party or copyrighted datasets were used. Relevant open-source tools and projects are acknowledged and cited appropriately. The authors take care to respect the cultural and historical context of the bandoneon, particularly its significance within the Río de la Plata region.

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