Biofeedback Suite as an Instrument: Emotion Mappings for Musical Practice

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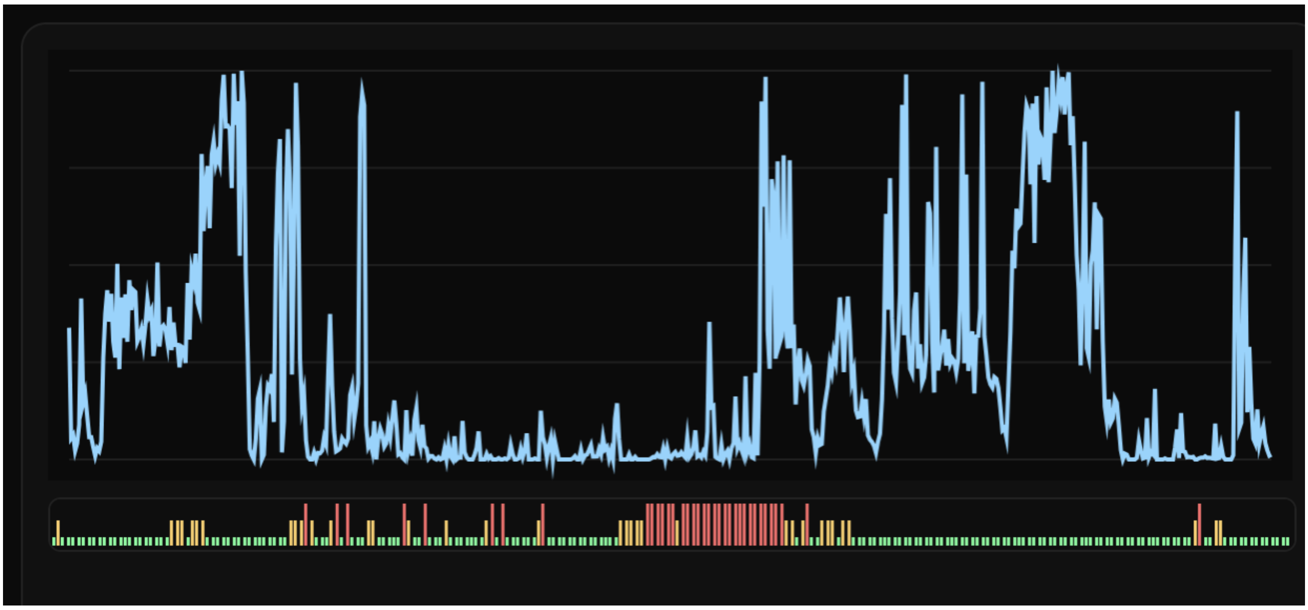

Figure 1: Motion data captured via webcam and discretised into activation levels in Python, prepared for sound mapping.

Abstract

This paper presents the Biofeedback Suite as a modular musical instrument for embodied exploration, focusing on the design and aesthetic evaluation of hybrid embodied sensing mappings combining physiological (GSR) and behavioral (motion and facial) signals in personal music practice. Rather than treating physiological or affective signals as variables to be inferred or controlled, the system is conceived as an interactive instrument whose musical behaviour emerges from the coupling of embodied signals, mapping strategies, and sound design decisions.

Through practice-based reflection and artistic experimentation, the paper discusses design tensions, breakdowns, and limitations encountered when integrating embodied sensing into live music-making. The contribution frames biofeedback not as a control mechanism, but as a compositional and instrumental resource, offering insights for the design of responsive musical interfaces grounded in embodied listening and aesthetic decision-making.

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Keywords

biofeedback, embodied interaction, musical mapping, interactive musical instruments, practice-based research

1 Introduction

Biofeedback technologies have long been associated with expressive potential in musical contexts [6], yet their practical integration into music-making has produced uneven results. While physiological and behavioral signals offer access to embodied processes and affective dimensions such as arousal and valence [5, 7, 9], translating these signals into musically meaningful outcomes remains a central challenge. In many cases, technical feasibility has outpaced musical coherence, resulting in systems that are conceptually interesting but difficult to inhabit as instruments.

This work builds on previous practice-based research on adaptive interactive music systems [4]. In musical practice, the requirement for real-time responsiveness constrains usable signals to those that can be captured and processed live, such as galvanic skin response (GSR), motion, or heart rate. Within these constraints, this work adopts a hybrid embodied sensing approach, combining physiological signals (e.g., GSR) with externally observable behavioral descriptors (e.g., motion and facial expression), using the Biofeedback Suite.

The system is conceived as a modular musical instrument that can be extended and shaped through practice. Its design prioritises the use of low-cost sensors, open software environments, and rapid iteration, allowing the creative process to remain central.

This paper frames the Biofeedback Suite as an embodied musical instrument. It examines mapping and sonification decisions through practice, analysing why certain configurations support coherent musical interaction while others do not. It also reflects on breakdowns and redesign strategies encountered during use, articulating a practice-based framework in which biofeedback mappings function as playable and musically coherent instrumental material.

2 Background and Related Work

Research on sensor-based and biofeedback musical instruments has explored a wide range of physiological and gestural inputs as sources of musical control and expression. Early biofeedback music researchers such as Alvin Lucier and David Rosenboom often focused on internal physiological processes, particularly through EEG-based systems[12], where sound was not always conceived as a directly controllable musical output but as a reflection of internal states. As such, these works were not primarily designed as playable instruments, but as experimental environments for perceptual and cognitive exploration.

More recent approaches have shifted towards forms of biocontrol, prioritising reproducibility and performer agency through sensors such as EMG and motion tracking. In parallel, listening has been proposed as a central mode of engagement with biological data, privileging responsiveness over control [10].

Mapping has been recognised not only as a technical problem, but as a central aesthetic and compositional decision shaping the identity of an instrument [11, 13, 14]. The present work situates biofeedback within an instrumental and musical design perspective, aligned with practice-based artistic research approaches [1]. Related work on physiological signals in music has largely adopted a signal-driven or cognitive perspective [8], prioritising explicit control and optimisation over embodied interaction.

3 Biofeedback Suite as a Musical Instrument

The Biofeedback Suite is conceived not as a measurement system or control interface, but as a musical instrument whose behaviour emerges through interaction. This framing represents a deliberate conceptual shift: instead of treating biofeedback signals as data to be interpreted or optimised, the system is designed to be played, explored, and learned through embodied practice [7, 11].

Bodily signals such as GSR, motion, and facial expression descriptors are not considered representations of internal states, but sources of musical material. What matters is not what these signals mean psychologically, but how they behave musically when coupled with sound processes. The instrument listens to embodied descriptors and responds with sound behaviours that retain a degree of indeterminacy [3], prioritising responsiveness and musical dialogue over precision and predictability [14].

Performer agency plays a central role in this configuration. While the system reacts continuously to bodily input, performers retain control through instrumental technique, attention, and contextual decision-making. The Biofeedback Suite therefore operates as a co-agent rather than an automated responder, opening a space for embodied listening in which performers can become aware of how bodily impulses influence and shape musical processes over time.

3.1 Technical Foundation

From a technical perspective, the Biofeedback Suite is implemented using Python as a middleware environment for handling sensor input and communication with the sound engine. Early prototypes employed an Arduino Nano and a low-cost GSR sensor (Figure 2) to validate the feasibility of real-time physiological input. These decisions were guided by musical usability rather than optimisation criteria.

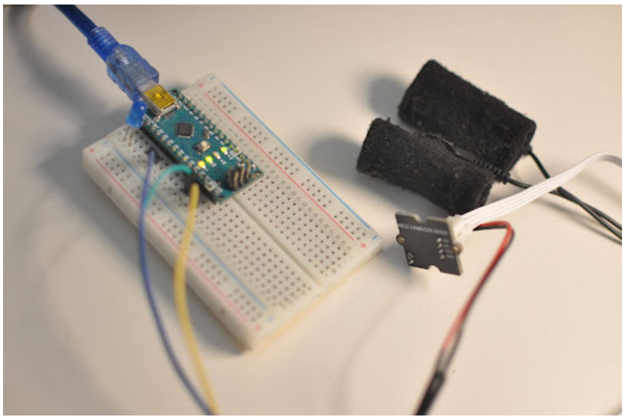

Figure 2: Arduino Nano and a low bugdet GSR biosensor.

Motion data were processed and discretised into activation levels (Figure 1), supporting the mapping of relative intensity to distinct sonic behaviours.

4 Mapping and Sonification Design in Pure Data

The central challenge addressed by the Biofeedback Suite is the translation of bodily signals into musically meaningful sound behaviour. Rather than assuming a direct or universal correspondence between physiological data and musical parameters, mapping is approached as an iterative design process grounded in listening, experimentation, and aesthetic judgement.

Pure Data was selected as the sound engine due to its open-source nature, modular structure, and low-level control over signal flow. This allowed mapping strategies to be rapidly prototyped, modified, and discarded without imposing predefined interaction paradigms.

4.1 Phase 1: GSR and Motion

The initial mapping phase focused on two real-time signals: galvanic skin response (GSR) and body motion. GSR was treated as a descriptor of physiological tension and activation, while motion represented embodied expressivity independent of instrumental gesture.

Each signal was assigned a distinct sonic identity to ensure perceptual separation: GSR modulated the frequency of a sine-based sound layer, while motion controlled the frequency of a sawtooth-based layer. To improve musical coherence and avoid excessive micro-variation, the mapping design also took advantage of discrete activation levels derived from recent signal history.

While frequency was controlled continuously, higher activation levels were interpreted as increased sonic density, resulting in the addition of layered sound processes (e.g. delays and reverb). Higher activation levels produced a perceptible thickening of the sound texture, reinforcing the instrumental character of the system.

4.2 Calibration and Signal Conditioning

Meaningful musical interaction depended on relative signal variation rather than absolute values. Adaptive calibration strategies were implemented using recent signal history to derive relative levels discretised into dynamic states with hysteresis. These mechanisms supported a balance between responsiveness and continuity.

4.3 Musical Integration

Once stabilised, the GSR and motion mappings were integrated into keyboard and piano performance contexts. In addition to reacting to momentary fluctuations, the system responded to sustained bodily activation through gradual changes in textural depth, modulating underlying frequency, allowing performers to experience bodily input as an evolving musical presence.

Motion-based control revealed a productive tension between instrumental gesture and expressive body movement. When bodily motion was independently mapped to electronic sound processes, a parallel expressive layer emerged alongside instrumental technique. This exploration led to the development of a video-performance titled *Motion–Piano Dialogue*.

GSR introduced a contrasting layer of agency. Reflecting largely unconscious physiological processes and evolving at a slower temporal scale, it interacted with motion-based mappings to produce layered textures in which deliberate and involuntary processes coexisted.

4.4 Phase 2: Facial Expression as Harmonic Trigger

A second mapping phase explored facial expression descriptors as a means of extending the system beyond arousal-oriented signals. Facial analysis was introduced as a high-level behavioural descriptor related to expressive valence. Rather than mapping these descriptors to continuous parameters, they were used as harmonic triggers selecting chords or modal frameworks within which GSR and motion modulated sonic detail. This was achieved in Pure Data through processes that reshaped the underlying frequency signal before its final rendering (Figure 3).

This approach shifted the system's influence from isolated sound attributes toward compositional harmonic structure, improving musical coherence while maintaining responsiveness.

4.5 Iteration and Redesign

All mapping strategies were evaluated through repeated listening and performance rather than predefined technical criteria. Several mappings that were conceptually promising were abandoned after revealing perceptual opacity or musical instability. Conversely, mappings that were simpler in structure but clearer in auditory consequence often supported more coherent musical interaction.

This iterative process reinforced the idea of mapping design as a compositional activity, where decisions about constraint, abstraction, and temporal mediation proved more decisive than signal richness.

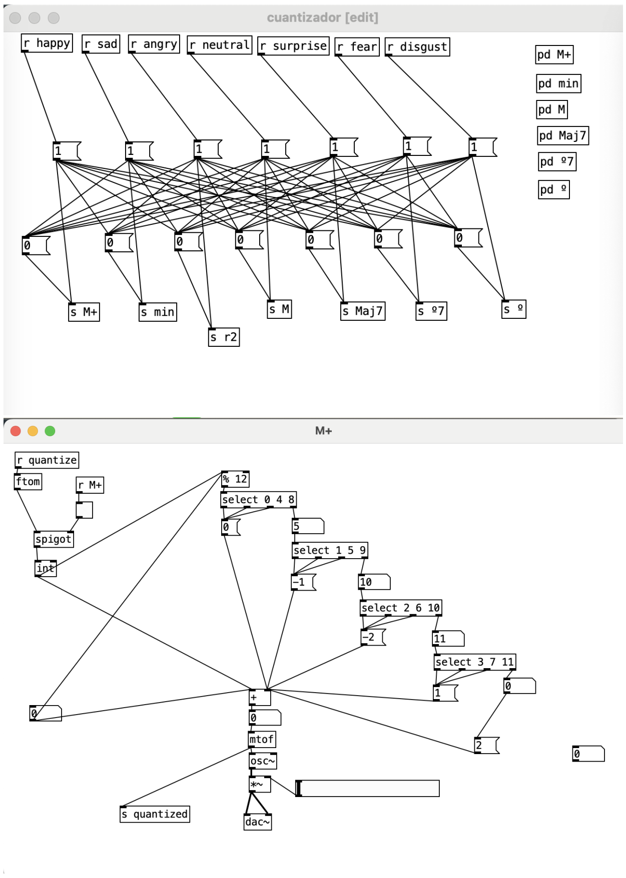

Figure 3: Frequency quantization to chord structures in Pure Data based on detected facial emotional expressions.

5 What Worked / What Didn't

The evaluation was conducted in two stages: an iterative exploratory phase focused on mapping design, followed by application in artistic contexts. The Biofeedback Suite was evaluated through iterative performance tests, including solo performance, duet and interactive score setups. Musical effectiveness was defined in terms of perceptual clarity and semantic richness rather than technical correctness, in line with evaluative approaches in practice-based artistic research [2].

The system proved effective as a generator of evolving textures rather than discrete control gestures. Sustained embodied activation translated into gradual changes in density, space, and harmonic context.

Different mapping strategies revealed consistent patterns across iterations:

– High-variability mappings produced unstable and musically fragile results, reducing perceptual clarity.

– Overly stable mappings led to monotony over extended durations.

– Discrete or constrained mappings improved perceptual legibility and performer control.

– Higher-level mappings (e.g. harmonic triggering) increased structural coherence but reduced immediacy.

– Mappings that prioritised perceptually recognisable musical identity proved more effective than those maximising raw signal utilisation.

Across contexts, these behaviours remained consistent, although the system's role shifted from textural augmentation (solo performance) to relational mediation (duet) and compositional selection (interactive score), reinforcing the importance of mapping as a compositional decision.

Overall, musically viable configurations balanced responsiveness with constraint and perceptual legibility, supporting the view of mapping design as an aesthetic and compositional negotiation rather than a problem of optimisation.

These recurring patterns suggest that the observed behaviours are not specific to individual conifgurations, but reflect generalisable design principles for embodied mapping systems.

6 Artistic Outputs and Practice Context

Following the exploratory phase, the system was applied in real artistic contexts to examine how the identified mapping behaviours function under real performance conditions. The Biofeedback Suite was primarily used as an extension of keyboard and piano performance, where the biofeedback layer functioned as an autonomous but dialogic musical presence. One documented output is the video-performance *Motion-Piano Dialogue*, in which bodily motion and physiological activation generate parallel electronic textures that interact with acoustic piano performance, consistent with texture-oriented mappings and constrained variation patterns identified earlier (Figure 4).

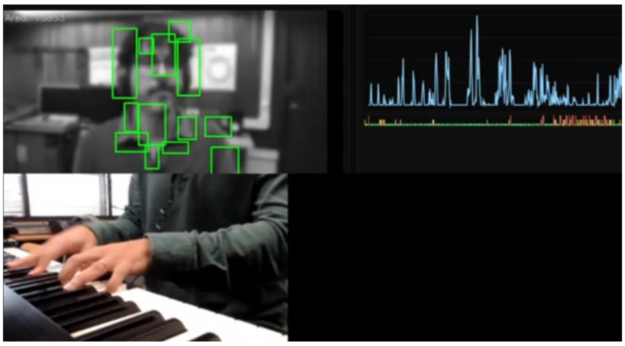

Figure 4: Video performance *Motion-Piano Dialogue*.

The system was also explored in an improvisatory duet involving piano and guitar, titled *Emotion-Driven Dialogue Improvisation*, where perceptual clarity and responsiveness were critical for maintaining interaction. Finally, the Biofeedback Suite was applied to an interactive score system reacting to GSR and motion input, used in a piano composition called *Marvila*. The piece is based on a modular structure in which different precomposed sections are selected in real time. Textural depth is materialised through layered compositional material, reflecting the effectiveness of higher-level mapping strategies for structural coherence (Figure 5).

Figure 5: Compositional aplication of the Biofeedback suite in the composition *Marvila*, using an interactive score

7 Discussion

Framing the Biofeedback Suite as a musical instrument rather than a control system shifts the role of biofeedback from data-driven automation to embodied musical material. Within this framework, mapping functions as a compositional act, and meaningful interaction emerges through learned embodied listening rather than signal transparency or emotional inference accuracy.

These observations suggest that biofeedback-based musical interfaces benefit from being designed as instruments to be learned over time, rather than as responsive systems optimised for immediate correctness.

8 Limitations and Future Work

Despite its artistic potential, the Biofeedback Suite presents several limitations. The system remains technically complex, requiring familiarity with multiple software environments and stable hardware configurations. Sensor reliability and connectivity, particularly in live performance contexts, remain critical challenges.

From a usability perspective, the learning curve for performers is non-trivial. Effective interaction depends on developing embodied listening skills and understanding delayed or indirect mappings. Future work will focus on streamlining the user experience and exploring collective biofeedback scenarios involving multiple performers.

9 Conclusion

This paper presented the Biofeedback Suite as an embodied musical instrument grounded in practice-based design and evaluation. Rather than prioritising emotional inference or signal accuracy, musical meaning emerged through mapping decisions, sound design, and embodied listening developed over sustained use.

By framing biofeedback as compositional material and mapping as an aesthetic act, the work contributes design insights relevant to the development of responsive musical interfaces that support musical coherence, performer agency, and embodied interaction over time.

10 Acknowledgements

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11 Ethical Standards

All data used in this research were collected in the context of artistic and research practice involving voluntary participants. Participants were informed about the purpose and nature of the system and provided informed consent prior to participation. Participation was voluntary and participants could withdraw at any time.

Physiological and motion data (e.g., GSR and webcam-based motion capture) were used exclusively as expressive input parameters for interactive musical processes. The system does not aim to infer psychological, medical, or diagnostic information.

No sensitive personal data beyond the physiological signals required for the interactive system were collected. Data were anonymised and securely stored. No personally identifiable information is disclosed in this submission. The research followed accepted ethical principles for research involving human participants.

References

[1] Henk Borgdorff. 2012. *The Conflict of the Faculties: Perspectives on Artistic Research and Academia.* Leiden University Press.
[2] Linda Candy and Ernest Edmonds. 2018. *Practice-Based Research in the Creative Arts.* Bloomsbury.
[3] Rebecca Fiebrink, Dan Trueman, and Perry R. Cook. 2010. A Meta-Instrument for Interactive, On-the-Fly Machine Learning. In *Proceedings of the International Conference on New Interfaces for Musical Expression (NIME).*
[4] Luis Guerra Recas. 2021. *Personalización subjetiva en los sistemas de música interactiva en los videojuegos. En busca de una experiencia de juego a la medida del individuo.* PhD Thesis. Universitat Politècnica de València.
[5] Patrik N. Juslin and John A. Sloboda (Eds.). 2011. *Handbook of Music and Emotion.* Oxford University Press.
[6] R. Benjamin Knapp, James Lyon, and Ahmed Tewfik. 2009. Physiological Signals and Musical Performance. *Interaction* 14 (2009), 15–18.
[7] Marc Leman. 2007. *Embodied Music Cognition and Mediation Technology.* MIT Press.
[8] Eduardo Reck Miranda and Julien Castet. 2014. *Guide to Brain-Computer Music Interfacing.* Springer.
[9] James A. Russell. 1980. A Circumplex Model of Affect. *Journal of Personality and Social Psychology* 39, 6 (1980), 1161–1178.
[10] Alexandria Smith. 2025. Modes of listening: Practice-led perspectives on performing biofeedback music.
[11] Atau Tanaka. 2000. Musical Performance Practice on Sensor-Based Instruments. In *Trends in Gestural Control of Music*, Marcelo M. Wanderley and Marc Battier (Eds.). IRCAM, 389–405.
[12] Claudia X. Valdes and Phillip Thurtle. 2005. Biofeedback and the arts: listening as experimental practice.
[13] Marcelo M. Wanderley and Marc Battier (Eds.). 2000. *Trends in Gestural Control of Music.* IRCAM.
[14] Marcelo M. Wanderley and Philippe Depalle. 2004. Gestural Control of Sound Synthesis. *Proc. IEEE* 92, 4 (2004), 632–644.