The Singing Skin: An Audience-Centered Biofeedback System for Musical Interaction Based on Galvanic Skin Response

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ABSTRACT

Music can evoke measurable physiological responses, yet these responses have been predominantly explored from the performer's perspective in interactive and biofeedback-based music systems. In contrast, the sonification of audience physiology remains relatively underexplored in live music contexts. We present The Singing Skin, a real-time, audience-centered biofeedback system for live performance that integrates listeners' physiological responses into musical control. The system measures galvanic skin response (GSR) and uses the phasic component of the GSR signal as an index of moment-to-moment audience engagement. This phasic GSR–based control signal is normalized and mapped to the rhythmic subdivision of a monophonic lead line generated by a wavetable synthesizer. Rather than directly modifying tempo or pitch, the control signal modulates the cutoff rate of a low-pass filter, producing an indirect pacing effect that influences perceived musical drive and energy. The system is demonstrated in a live performance setting involving a violinist and a listener equipped with GSR sensors. This work contributes a novel approach to audience-inclusive musical interaction by extending audience physiology as an active control source in live music performance.

1. INTRODUCTION

Music has the strong power to evoke emotional and arousal-related processes, which can be measured through physiological signals. Over the years, several artists have explored innovative ways to make physiology audible. Early biofeedback works, such as Alvin Lucier's *Music for Solo Performer* [1] and Richard Teitelbaum's synthesizer experiments [2], utilized performers' biosignals as control sources for sound production. David Rosenboom's *On Being Invisible* further advanced this approach by sonifying the performer's electroencephalography (EEG) alpha activity [3], while later projects, like Pamela Z's *BodySynth* [4], expanded performer-centered mappings using electromyography (EMG) data. Collectively, this body of work has primarily focused on biosignals from the performer's perspective.

In contrast, *audience*-centered biofeedback remains relatively underexplored in the realm of computer music, despite the inherently interactive nature of live performance. We therefore propose *The Singing Skin*, a novel audience-centered biofeedback system for live music that incorporates listeners' physiology directly into the performance. Our focus is on galvanic skin response (GSR), specifically its phasic component, as an indicator of moment-to-moment audience engagement. The system establishes a real-time feedback loop in which both performers and audiences can perceive and respond to each other's physiological states. We demonstrate this framework through a live performance, offering an exploratory performer–audience biofeedback framework that positions audience physiology as a primary musical control element and provides a basis for the implementation of audience-inclusive biofeedback systems.

2. BACKGROUND

2.1 Physiological Signals

Physiological signals are involuntary bodily responses that arise when an individual is exposed to external stimuli or experiences fluctuations in internal states. These unconscious responses are regulated by the autonomic nervous system (ANS), which maintains homeostasis in the human body and supports functions (e.g., stress regulation and blood pressure control) [5]. The ANS is composed of two complementary branches: the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). The SNS and PNS work together to regulate bodily function, but generally operate in opposing ways. The SNS is associated with "fight-or-flight" responses [6], preparing the body for action during emergency situations or physical exertion by increasing blood flow, heart rate, and muscle activity. In contrast, the PNS is activated during quiet, resting conditions to conserve energy and restore bodily balance, promoting relaxation by decreasing muscle activity and reducing cardiovascular activation.

Various physiological signatures reflecting ANS activity can be measured through different biosignals, including electrocardiography (ECG; German: *Elektrokardiogramm*, EKG), electromyography (EMG), galvanic skin responses (GSR; also referred to as electrodermal activity, EDA), and electroencephalography (EEG). Each biosignal provides distinct indicators of SNS or PNS activation. For instance, heart rate (HR) and heart rate variability (HRV) are the indicators commonly derived from ECG signals. Increased HR and lower HRV are typically associated with heightened arousal and SNS activation, whereas decreased HR and higher HRV reflect PNS dominance [7, 8]. In the case of GSR signals, both tonic skin conductance level (SCL) and phasic skin conductance responses (SCR) are widely regarded as direct indicators of SNS activation. SCL represents baseline arousal levels, whereas SCR reflects rapid, stimulus-evoked changes in sympathetic activity [7]. The choice of physiological indicators in the research varies depending on the goals of the study and the specific facets of autonomic functioning that researchers seek to examine.

2.2 Biofeedback Systems in Music

Music is closely linked to emotional and arousal-related processes. The link between physiological changes during musical activities and emotional arousal is well-established by empirical evidence [9, 7, 10, 11]. Based on this connection, various artistic and technological approaches have aimed to incorporate physiological responses within creative and performative contexts. A pioneering example is Alvin Lucier's *Music for Solo Performer* (1965), in which the composer utilized real-time EEG brain signals from the performer to activate percussion instruments on stage, thereby transforming internal physiological activity into musical expression [1]. Similarly, Richard Teitelbaum explored the use of biosignals to manipulate electronic synthesizers in the late 1960s [2]. In these early systems, biosignals primarily served to extend the performer's intentional control, with physiological data used as an additional means of instrument control during performance.

Building on this foundation, David Rosenboom introduced *On Being Invisible* (1975), which shifted the focus from controlling instruments to explicitly revealing the performer's internal states through sound using biosignals [3, 12, 13]. In this work, the performer's EEG alpha-band activity was sonified as a sustained tone [12, 14]. Because alpha-band brain activity is commonly associated with relaxed or meditative states, this sonification made aspects of the performer's internal cognitive state perceptible through sound. Accordingly, Rosenboom approached physiological activity not as a control signal, but as a core sound material shaping the musical work [15, 16]. A similar approach appears in Pamela Z's *BodySynth* [4], a performative interface in which the performer's muscle activity was used to manipulate electronic sound sources. Wearable sensors attached to the performer's body captured muscle activity and mapped it to Musical Instrument Digital Interface (MIDI) control signals, enabling real-time control of samplers and synthesizers [17].

These biofeedback-based music systems have focused on the performer, positioning biosignals as either control inputs or sonic material produced by the performer. In comparison, *audience* physiology has received relatively little attention in performance settings. However, musical outcomes in live performance are continuously shaped by interactions between performers and audiences. Accordingly, audience physiological responses can be understood not only as measures of reception, but also as active elements within an interactive feedback loop, through which performers and audiences mutually shape the sonic and formal structure of a musical work.

2.3 Audience-Centric Biofeedback Systems

To the best of our knowledge, audience biosignals have rarely been systematically integrated into music performance contexts. Nevertheless, several related explorations in performance art and dance have incorporated audience physiology as a means of fostering reciprocal engagement between the stage and spectators. An early example is Ruth Anderson's *Centering* (1979), which brought collective GSR signals from the audience into the structure of a live dance performance [18]. In this work, GSR signals from four observers were sonified as pitch height while they viewed the performance. This design formed an interdependent loop in which audience responses influenced the sonic outcome and, in turn, shaped performers' reactions [1] .

More recently, the *Boiling Mind* project (2021) employed real-time HRV and EDA data from the audience to generate audiovisual elements that shaped the performance environment in a live dance context [19]. Audience physiological responses were used as staging elements, influencing sound and visual components that interacted with the choreographers. Subsequent analysis of the performance revealed a relationship between increased HRV—reflecting PNS activation—and event-related phasic peaks in EDA associated with moments of heightened audience engagement and musical crescendos [20].

Related approaches have also appeared in installation-based works. For example, *Phantom Undulations* (2023) [21] incorporated biodata from both artists and visitors as musical elements, repositioning visitors from passive observers to active contributors in the creation of the artistic work. In this installation, artists' respiration, heartbeat, EDA, and HRV were sonified as timbre, duration, pitch, loudness, and sonic texture, respectively, while visitors' physiological responses, such as EDA and heartbeat, were also incorporated into the evolving musical artifact.

Building on these precedents, we propose a biofeedback system for music performance that integrates audience physiology as an integral component of the musical work itself. Grounded in collaboration across psychophysiology, music cognition, and computer music, our system transforms listeners' real-time physiological responses into an additional musical layer that is audible to both performers and audiences. We adopt a physiologically meaningful indicator informed by empirical findings on musical engagement during music listening. The indicator is mapped to rhythmic modulation—a musical dimension shown to shape perceived drive and temporal engagement in music—allowing physiological dynamics to function as an audible musical process within performance. The proposed system operates as an augmentation of performance texture by modulating expressive musical parameters within a fixed jazz standard, rather than generating novel musical material or dictating structural shifts. To evaluate this framework, we conducted an exploratory case study involving a violinist and a single listener equipped with GSR sensors. Through this design, the system establishes a performer-audience feedback loop in which performers respond musically to the audience's physiological state, while the audience, in turn, responds to the unfolding musical performance.

This work offers a conceptual contribution by demonstrating how empirically grounded insights from music cognition and psychophysiology can be translated into musically meaningful, real-time interactive systems within computer music practice. By transforming largely implicit and un-

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[1] https://www.encyclopedia.com/arts/dictionaries-thesauruses-pictures-and-press-releases/anderson-evelyn-ruth

conscious physiological responses into audible musical processes, the proposed approach enables both performers and co-present listeners to intuitively perceive and interpret each other's affective and physiological engagement with the music. This initial feedback loop in the current study provides a scalable foundation for future research aimed at integrating collective audience biosignals into a unified, shared musical response. Additionally, while the present work focuses on GSR-based modulation of rhythmic structure as one instantiation, the approach is not limited to this mapping and can be extended to other empirically validated physiological indicators to control a wide range of musical parameters (e.g., pitch or loudness) within interactive biofeedback music systems. Moreover, beyond concert performance, such biofeedback systems may also support communication in broader music-centered interaction contexts—including music therapy and education—by making otherwise unobservable internal responses perceptible and shareable through sound during musical engagement.

3. SYSTEM DEVELOPMENT

3.1 Physiological Indicator for Musical Engagement

In designing the proposed system to support a performer-audience feedback loop, we focus on physiological signals capable of capturing moment-to-moment changes in audience engagement. Following prior audience-centered performance works, we employ galvanic skin response (GSR) in our system. Within the GSR signal, we make a distinct design choice to focus specifically on a phasic component, which we use as a skin conductance response (SCR)-related indicator of musical engagement.

This design choice is further supported by empirical studies in music cognition. Prior research has shown that heightened musical arousal, as reflected in acoustic features such as tempo, loudness, and timbral brightness, is associated with increased autonomic nervous system (ANS) responses in listeners, including elevated SCR. For example, faster or accelerating tempi [22, 23], increased sound intensity [24], and brighter timbres [25] have been shown to correlate with greater SCR values. Moreover, studies examining the relationship between physiological responses, musical arousal, and listener engagement in live music concert have found that SCR closely tracks sympathetic arousal and is linked to higher self-reported engagement, with faster-tempo passages consistently eliciting elevated SCR values [26, 27].

Accordingly, our system maps a phasic GSR–based control signal, representing SCR-related activity, to MIDI continuous controller (CC) values that are intended to reflect relative changes in arousal in a musically perceptible manner. Increases in this control signal result in shorter note durations in a monophonic lead synthesizer, indirectly conveying a sense of increased pace and drive without explicitly altering tempo. Using this phasic GSR signal as a real-time modulator thus enables both performers and listeners to perceive changes in audience engagement through expressive variations in the melodic line. In this way, audience engagement can be incorporated as an active, real-time component of the performance structure.

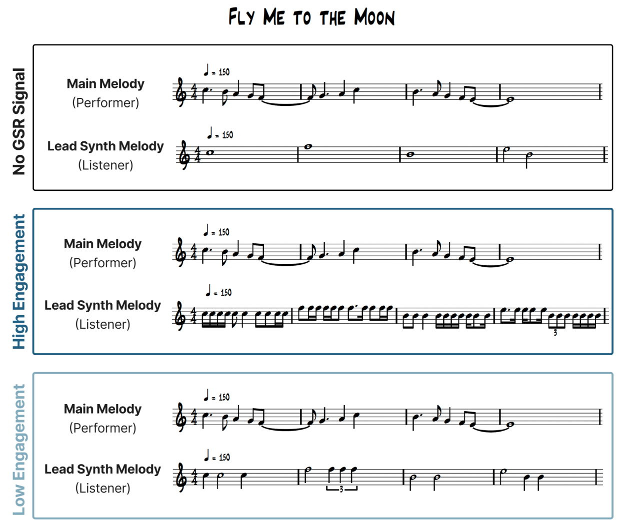

Figure 1. Musical design example illustrating three output conditions of the lead synthesizer. The top panel shows the default setting without an audience control signal, while the middle and bottom panels represent high and low audience engagement, respectively, expressed through increased or reduced rhythmic subdivision at a fixed tempo.

3.2 Musical Design

The musical design of the proposed system aims to make audience engagement perceptible through a musically coherent and interpretable manner. In prior research, musical engagement has been shown to be closely associated with changes in arousal, particularly via listeners' perception of musical pace and drive, which is strongly influenced by tempo. However, directly modifying tempo during live performance can be musically disruptive and may interfere with the performer's expressive control and phrasing. Rather than altering global tempo, we therefore adopt an indirect but musically meaningful strategy to convey changes in perceived pace by manipulating the rhythmic subdivision of a melodic line. For example, higher arousal levels are expressed through shorter note durations, while lower arousal levels result in more sustained melodic gestures. An example output of this musical design is shown in Figure 1.

This approach allows changes in engagement to be perceived as variations in rhythmic density and momentum, while preserving the notated tempo and the performer's intentional timing. By treating physiological influence as an expressive cue rather than an explicit command, the system supports musical interpretation. To implement this design, the melodic line is generated using a wavetable synthesizer (Serum, Xfer) [28], whose low-pass filter cutoff frequency rate is modulated by a phasic GSR–based control signal. As the magnitude of this control signal increases, the rate of the Low-Frequency Oscillator (LFO) modulating the filter cutoff frequency increases accordingly. This modulation perceptually subdivides a sustained note into multiple shorter articulations, creating the impression of increased rhythmic activity without altering pitch or tempo.

We chose this synthesis-based approach over direct note triggering or tempo modulation because it enables smooth, continuous transitions between states of engagement. As a result, higher levels of audience engagement are conveyed musically through more rapid rhythmic subdivision. This design allows physiological arousal to shape perceived pacing while remaining embedded within a musically coherent structure.

3.3 Overall System Architecture

The system architecture is divided into two primary computational units (see Figure 2): a data acquisition and processing unit (PC 1) and a sound generation unit (PC 2). The signal flow begins with GSR signals from the music listener, captured by an amplifier and transmitted to PC 1.

In the PC 1 environment, GSR signals are streamed into a Python-based processing pipeline via the Lab Streaming Layer (LSL) [29]. This pipeline consists of three sequential stages: (1) GSR pre-processing to obtain a phasic-dominant signal, (2) listener-specific calibration and sample-wise min—max normalization, and (3) extraction of a musically anchored feature using a sliding window.

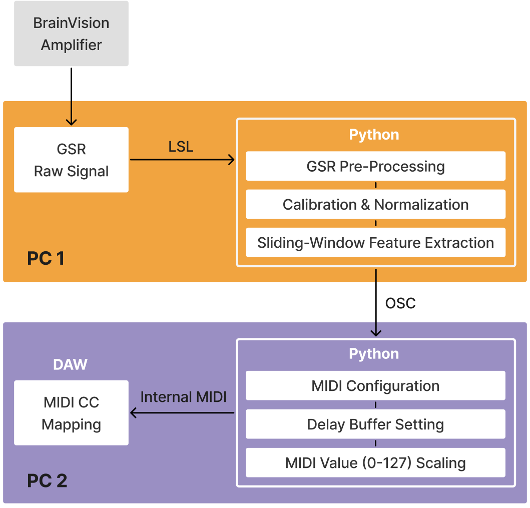

Figure 2. System architecture and signal flow of the proposed audience-centered biofeedback system for music performance. GSR: galvanic skin responses; LSL: Lab Streaming Layer; OSC: Open Sound Control; MIDI: Musical Instrument Digital Interface; CC: continuous controller; DAW: Digital Audio Workstation.

The normalized control signal is then transmitted to PC 2 via Open Sound Control (OSC) [30]. On PC 2, a second Python environment translates the physiological data into musical control parameters. This stage includes (1) setting a delay buffer to align physiological feedback with musical phrasing, (2) MIDI configuration, and (3) scaling the normalized control signal into MIDI continuous controller (CC) messages. Finally, the control data are sent via an internal MIDI connection to the digital audio workstation (DAW), where MIDI mappings modulate synthesizer parameters in real time.

3.4 Biosignal Acquisition and Processing

3.4.1 Acquisition

GSR was recorded using a BrainVision *actiCHamp* amplifier (Brain Products GmbH; see Figure 3). Using the BrainVision LSL Connector free software, the raw GSR stream was forwarded in real time to the performance computer (PC 1) via the LSL at a sampling rate of 10,000 Hz. This sampling rate corresponds to the minimum rate selectable in the BrainVision LSL Connector and was used for acquisition prior to downstream filtering and resampling. The same PC 1 ran a Python environment for online processing, ensuring low-latency transfer and a unified time base.

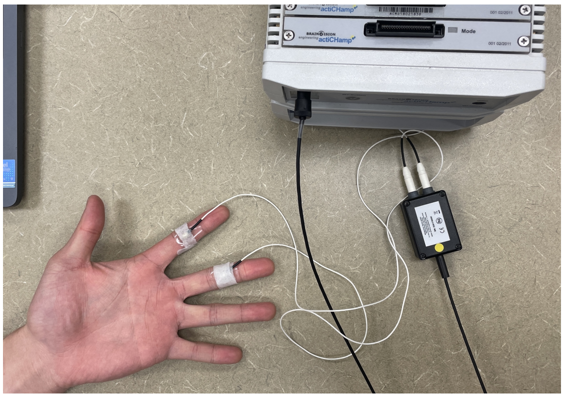

Figure 3. Setup of galvanic skin response (GSR) recording using BrainVision Ag/AgCl electrodes attached to the listener's hand.

3.4.2 Real-Time Preprocessing

In this work, the phasic component of the GSR signal is used as an index of skin conductance responses (SCR)–related activity. To emphasize this component, the incoming GSR stream was filtered online using a fourth-order Butterworth band-pass filter (0.01–3.0 Hz), implemented as a causal filter with second-order sections (SOS) (`sosfilt` in SciPy [31]). This filtering attenuates very slow tonic fluctuations as well as high-frequency noise, yielding a phasic-dominant GSR signal suitable for real-time control. The filtered signal was subsequently downsampled to 20 Hz, which provides sufficient temporal resolution for SCR-related dynamics while reducing computational load.

3.4.3 Calibration and Normalization

At the start of each run, 30 s of baseline data were collected to establish a listener- and session-specific operating range. Based on this calibration window, minimum and maximum values were estimated using percentile statistics, and subsequent samples of the phasic-dominant GSR signal were linearly mapped to the [0,1] range via min–max normalization. This sample-wise normalization yields a bounded control signal that is robust to inter-individual differences and facilitates stable inter-process communication (e.g., OSC transmission to PC 2).

3.4.4 Feature Extraction for Musical Engagement

Rather than performing model-based SCR decomposition or discrete event detection, we estimate SCR-related activity by computing a musically anchored control feature from the normalized, phasic-dominant GSR signal. Specifically, a sliding mean statistic is applied over a fixed analysis window defined in musical time.

Prior to performance, the tempo (beats per minute; BPM) is specified by the user. The analysis window spans four bars at the current tempo—a phrase-scale unit commonly used in musical practice—while the hop size corresponds to a thirty-second note (32nd note). Expressing both window and hop sizes in musical units, rather than absolute time, ensures that the resulting control feature remains aligned with musical phrasing and automatically rescales with tempo changes. At the 20 Hz analysis rate (50 ms per sample), hop updates are quantized to the analysis grid. When the duration of a 32nd note falls below 50 ms at higher tempi, the hop size is clamped to a single analysis sample. The resulting windowed control signal provides a smooth, tempo-aligned estimate of SCR-related activity, which is transmitted in real time to PC 2 via OSC for musical mapping.

3.5 Sound Generation

Although the proposed system is not tied to a specific musical genre, its sound generation design assumes the presence of an existing musical layer that can be continuously modified in real-time. This assumption allows audience physiology to be integrated into an ongoing performance without interrupting musical continuity. Accordingly, the system operates on pre-existing musical material, consisting of a pre-determined harmonic progression and a MIDI-based melodic line prepared in advance within a DAW.

The computed audience physiology values described in Section 3.4 are used as a MIDI control signal to represent moment-to-moment fluctuations in audience engagement as an explicit musical control parameter. Building on prior findings that SCR activity is closely associated with tempo-related musical features during heightened engagement, the system links physiological values indirectly to perceived rhythmic pace. Rather than directly altering the notated tempo, the system modulates rhythmic density by dynamically subdividing the rhythm of an existing melodic line. To realize this rhythmic modulation in a temporally coherent and perceptually meaningful manner, the following subsections describe the sound generation pipeline implemented on PC 2.

3.5.1 MIDI Synchronization

Before processing the incoming normalized phasic GSR–based control signal, the system establishes a synchronized temporal environment with the DAW. The Python script running on PC 2 listens for MIDI Transport messages (Start, Stop, and Clock) sent by the DAW. This configuration supports that the system's internal processing clock is synchronized with the tempo defined in the DAW. By conforming to the DAW's transport status, the system prevents temporal data drift and maintains musical coherence, ensuring that the physiological feedback loop begins and ends precisely with the musical performance.

3.5.2 Delay Buffer Setting

To account for the listener's perceptual response latency, a delay buffer is applied to the incoming control signal. Rather than mapping physiological changes to sound parameters instantaneously, the system is designed to reflect the listener's response to the musical phrase they have just heard. Accordingly, a sliding time window (i.e., delay buffer) is used to temporarily store the normalized phasic GSR–based control signal. Instead of reading the signal immediately, the system accesses the buffer with a fixed temporal offset corresponding to the desired delay duration. This design ensures that the current musical output is driven by the audience's physiological response to the preceding musical segment, aligning the feedback mechanism with perceptual and musical timescales.

3.5.3 Biosignal-to-MIDI Value Mapping

After temporal alignment through buffering, the delayed control signal is converted into discrete musical control values suitable for real-time synthesis. Specifically, the normalized control signal in the range $[0.0, 1.0]$ is mapped to MIDI values in the range $[0, 127]$ using a transfer function with an adjustable exponent:

$$y = x^{\gamma} \cdot 127,$$

where x denotes the normalized control signal, y the resulting MIDI value, and γ a sensitivity parameter that determines the curvature of the mapping function.

Setting $\gamma = 1.0$ yields a linear mapping, in which output values are directly proportional to the input. Values of $\gamma < 1.0$ produce a concave (logarithmic-like) curve that increases sensitivity to lower input values, whereas values of $\gamma > 1.0$ generate a convex (exponential-like) curve that reduces sensitivity in the lower range. The resulting continuous values are quantized into standard 7-bit integers to ensure compatibility with the MIDI protocol.

This flexible mapping function allows the system to accommodate inter-individual variability in physiological dynamics. For listeners exhibiting a narrow range of control signal fluctuations, smaller values of γ expand subtle variations into a broader range of MIDI outputs, preventing the musical response from sounding static. Conversely, for listeners with a wider dynamic range, larger γ values help prevent saturation at the upper end of the MIDI scale, preserving musically usable control resolution.

3.5.4 Transmission to MIDI Port

Following value mapping, the quantized MIDI control values are encapsulated into standard MIDI CC messages. Each message is assigned to a predefined MIDI channel and CC number specified within the script. The resulting data stream is transmitted via a virtual internal MIDI port (e.g., IAC Driver or loopMIDI) to the external sound generation environment.

3.5.5 Sound Modulation Strategy

The transmitted MIDI control messages serve as an intermediate representation that enables routing of the audience physiology–derived control signal to synthesis parameters within the sound engine (see Figure 4). In the present system, this control stream modulates the rate of an LFO.

The LFO is routed to modulate the cutoff frequency of a low-pass filter applied to the lead synthesizer voice. As the LFO oscillates, it periodically reveals and masks high-frequency transients that define the articulation of rhythmic pulses. The MIDI control values directly determine the frequency of the LFO oscillation, thereby shaping the perceived rhythmic subdivision of the sound.

This design results in the following musical behaviors:

- **High Engagement (Fast LFO Rate):** As the control value increases, the LFO rate accelerates, leading to more frequent articulations and a denser rhythmic

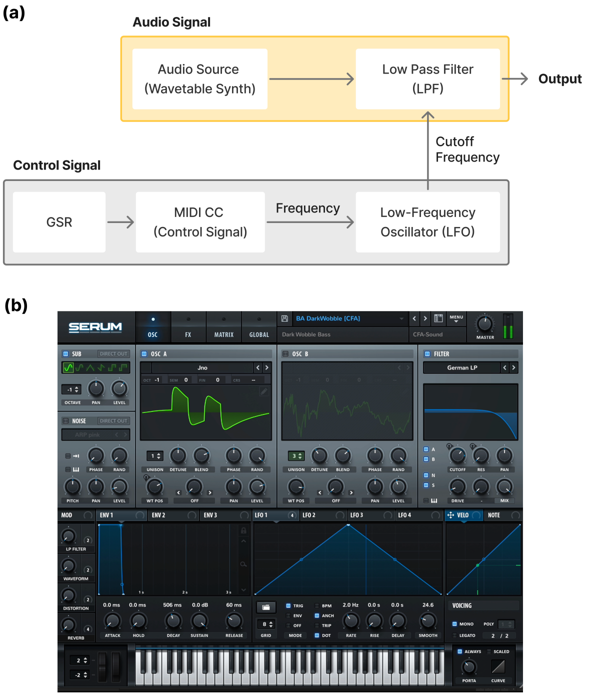

Figure 4. (a) Structure of the lead synthesizer used as the sound engine. (b) Screenshot of the Serum wavetable synthesizer (Xfer).

subdivision. This is perceived as increased musical drive and energy.

- **Low Engagement (Slow LFO Rate):** When the control value is low, the LFO modulates the filter at a slower rate. This produces fewer articulations and a more sustained rhythm, perceived as a relaxed musical pace.

Through this mechanism, variations in audience engagement are translated into changes in perceived musical pace without altering the notated tempo or pitch. This synthesis-based approach was chosen over direct note triggering or tempo modulation because it enables smooth and continuous transitions between engagement states. As a result, physiological arousal shapes the perceived pacing of the music while remaining embedded within a musically coherent and performer-controlled structure.

4. LIVE PERFORMANCE DEMONSTRATION

4.1 Music Selection

To demonstrate the system in a musical context, the jazz standard *Fly Me to the Moon* was selected. A jazz standard was selected to leverage the improvisational flexibility of the genre. The nature of jazz improvisation—operating within established harmonic and rhythmic rules while allowing for spontaneous variation—is an ideal format for reflecting listener-driven modulations. This framework allowed the performer to respond spontaneously to the evolving lead line. It facilitated a dynamic musical interplay, avoiding the conflict that often arises with rigid, pre-determined structures. Furthermore, this flexibility ensures that the listener's physiological feedback is integrated into the performance in a way that remains musically coherent, minimizing the risk of the system generating output that conflicts with the harmonic or rhythmic context.

4.2 Performance Setup

The performance setup involved one violinist and one listener. The performance structure comprised three components: a physiology-driven lead line, a live violin improvisation, and a backing track. For the lead synthesizer line, a pre-sequenced MIDI clip was provided, and the audience's physiological feedback modulates the rhythmic subdivision by modulating the rate of a Low Frequency Oscillator (LFO), which in turn controls the filter cutoff frequency. Over the backing track, a violin performed a melody and improvisation.

Galvanic skin response (GSR) sensors were attached to the fingers of the listener's non-dominant hand to minimize motion artifacts. A 30-second GSR baseline was then recorded to establish the listener's physiological range for normalization. Following this calibration, the normalized phasic GSR–based control signal was transmitted from PC 1 to PC 2 to verify that the Open Sound Control (OSC) connection and data scaling were functioning correctly.

Both the listener and the violin performer monitored the sound through separate headphones to ensure real-time perception of the modulated physiological feedback. The acoustic violin signal was captured using a microphone and routed through an audio interface (PreSonus AudioBox iOne) to the digital audio workstation (DAW), where it was processed and recorded using Pro Tools (Avid) [32]. All audio signals, including headphone monitoring and microphone input, were transmitted via wired connections, with the audio interface connected to PC 2 via USB.

4.3 Performance and Recording

Before the session, the listener was instructed to listen comfortably, while the violinist was asked to improvise freely in musical response to the evolving synthesizer. The tempo was set to 150 BPM according to the performer's preference, and the biosignal processing script was initialized prior to the performance. The session started with the activation of the DAW transport, which simultaneously triggered the backing track playback and the recording systems.

Once the backing track began, the violinist performed an improvisation lasting approximately three minutes. After an initial four-bar delay, the physiology-driven lead line started to modulate its rhythmic subdivision based on the listener's phasic GSR–based control signal. The four-bar delay was implemented to align the physiological response with the musical structure. During the performance, both the violinist and the listener were able to hear the physiological feedback in real-time. This auditory loop allowed the violinist to respond musically to the listener-driven modulation, while the listener simultaneously perceived changes in the sound corresponding to their own physiological responses.

For subsequent data analysis, both the acoustic violin audio and the MIDI CC automation data were recorded simultaneously in the DAW, while the normalized phasic GSR–based control signal was saved as a `.csv` file. Figure 5 presents the real-time normalized phasic GSR signals captured during the system demonstration.

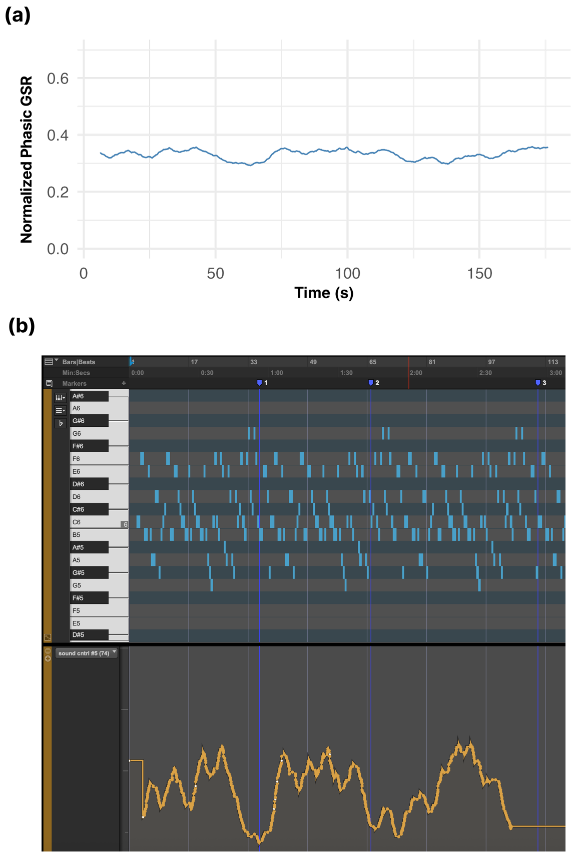

Figure 5. Real-time audience physiology–derived control signals during the system demonstration. (a) Min–max normalized phasic-dominant GSR signal over the full musical excerpt (time in seconds). (b) Digital audio workstation (DAW) view illustrating MIDI continuous controller (CC) data derived from the control signal and mapped to the Low-Frequency Oscillator modulates the filter cutoff frequency of the lead synthesizer line during the initial segment of the performance.

5. CONCLUSION AND FUTURE WORK

This work introduced an audience-centered biofeedback musical system that incorporates listeners' physiological responses into a real-time performance setting. Unlike previous approaches that primarily relied on performer-generated biosignals, our system utilizes galvanic skin response (GSR), extracting phasic skin conductance response (SCR)–related activity and mapping its moment-to-moment fluctuations to musical parameters. Through a exploratory live music demonstration, we showed that this approach can support a functioning feedback loop between performers and audiences.

By transforming physiological data into musical expression, the proposed system suggests a shift in the listener's role from passive observer toward active participant and co-creator in the performance. Audience engagement, expressed through unconscious physiological responses, shapes the rhythmic and structural evolution of the music, blurring the conventional boundary between stage and audience. While the framework was demonstrated in a jazz improvisation context, the underlying system architecture is a scalable and may be adapted to other musical genres and performance settings, including scenarios involving collective audience interaction.

Despite these promising outcomes, several limitations remain to be addressed in future work. First, the normalization of GSR signals poses inherent challenges due to significant inter-individual physiological variability, which can affect the consistency and robustness of mapping these signals to musical elements. Second, the limited scale of the current demonstration—conducted as an exploratory case study with a single listener—highlights the need for larger-scale evaluations to validate the system's effectiveness across diverse audience groups. Furthermore, while the system enables real-time interaction, it currently functions by modulating expressive parameters within a fixed musical form rather than serving as a shared compositional agency that fundamentally alters the work's structural evolution.

Future research will focus on extending this framework toward collective biosignal integration and exploring more generative mappings that grant the audience a more formative role in the compositional process. One practical challenge is the requirement of a calibration period prior to the performance, which is necessary to establish an individual physiological baseline but may interrupt the flow of a concert setting. Additionally, further investigation is needed to assess how reliably SCR-related activity reflects momentary physiological responses to music. Future systems could incorporate additional biosignals, such as heart rate variability (HRV), respiration, or electroencephalography (EEG), to provide a more comprehensive representation of audience engagement. Finally, controlled user studies are needed to evaluate whether audience-centered biofeedback enhances engagement for both performers and listeners, and to better understand its influence on live musical interaction.

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