Biosensors in Immersive Music Performance: *Andromeda* for Flute and Biofeedback

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ABSTRACT

In recent years, within the field of music technology, one of the fundamental topics that has engaged composers and researchers is the relationship between sound and control. Moreover, there is an increasing integration of biotechnology in interactive music performances. The piece *Andromeda* aims to utilise the biometric data of performers to enhance the sonic landscape, providing a multifaceted and deeply resonant dimension to the musical experience. This occurs notably during live performances and also within the context of theatrical roles, amplifying the artistic expression. This project not only emphasises the measurement of the human body during live music performances but also emerges within the framework of post-humanism. Its aim is to capture bodily data to track the performer's emotional changes during live performances. By mapping real-time physiological data onto sound processing parameters, the piece blurs the lines between performer and instrument, inviting a dynamic interplay between human expression and computational technology. Through a mixed media composition for flute and live electronics, *Andromeda* delves into the intricate relationship between theatrical conventions, emotional states, and musical narrative. By leveraging galvanic skin response, heart rate, and respiratory data, the composition transforms emotional fluctuations into immersive sonic experiences, fostering a deeper connection between performer and musical improvisation. The research methodology involves collecting biodata from individuals through biosensors while eliciting emotional responses, enabling the correlation of physiological indicators with emotional states. In performance, the piece's sound architecture responds dynamically to the performer's emotional fluctuations, creating a fluid sonic landscape trying to mirror the performer's inner state.

1. INTRODUCTION

Biotechnology in electroacoustic music primarily regards data that one can retrieve from a human body to map them on sound processing parameters for aesthetic purposes[1]. Blain, *in Biomusic: A novel technology for revealing the personhood of people with profound multiple disabilitie*s, states that biofeedback technology represents the future of control systems in various fields, including both art and science. This idea is not new; it has been evolving since the late 20th century and continues to evolve [2]. To further illustrate this, we can cite several examples of applications like the *BioMuse* system by Benjamin Knapp and Hugh Lusted in 1988, [3] that have captured the attention of the academic community due to their quality and aesthetics. For instance, the Conductor's Jacket designed by Teresa Marrin-Nakra and Rosalind Picard in MIT, 1998. Although the Conductor's Jacket was initially designed as a recording and monitoring device for scientific research, its ability to transmit data in real-time allowed Nakra to use it during live performances, where it functioned not as a passive monitoring device but as a body-instrument [4]. In the same logic, Michel Waisvisz's *The Hands* in the mid-1980s, progresses to Laetitia Sonami's *Lady's Glove* in the 1990s and 2000s, and also encompasses Atau Tanaka's BioMuse performances utilising electromyogram (EMG) signals of hand gestures. Today, artists are also experimenting with various tools that can easily provide them with data on computers, within environments like Max-MSP, where musicians feel they can engage in a dialogue with cognitive science, particularly data science, like Nino Liz Masclef. An example of this is seen in the creation of hypnagogic landscapes generated from EEG signals [5].

This paper presentation is about the work *Andromeda* (2023), a mixed media music composition for flute and live sound processing, inspired by the homonym tragedy of Euripides. The work is based on the use of data retrieved by bio-sensors placed on the body of the flautist. Moreover, the parameters of real-time sound processes are mapped linearly on bio-data deriving from the body of the flautist. This research revolves around examining the extent to which theatrical and performative conventions influence the emotional states of the performers; how the biometricall data retrieved from their reactions may contribute stimulatingly to the composition narrative, the development of the piece, and aesthetically. The core focus of the research is on understanding how incorporating real-time physiological data can enhance the immersive experience and emotional impact within the context of an interactive performance. This approach aims to bridge the realms of technology and musical expression, emphasising the interaction between performers and computational technology. Such exploration strives to contribute towards timbral exploration and artistic expression.

2. *ANDROMEDA* FOR FLUTE AND BIOSENSORS: AESTHETIC AND TECHNICAL ASPECTS

2.1. Aesthetics

While numerous studies explore the relationship between artistic practice and technology today, fewer delve into artistic expression within real artistic conditions[6]. This particular research project aligns with the fundamental concept of transhumanism. Technological posthumanism examines the profound implications of emerging technologies on humanity's future, navigating intersections of philosophy, science, and culture [7]. Grounded in the exploration of human enhancement, artificial intelligence, and ethical dilemmas surrounding technological progress, posthumanism envisions a future where humanity transcends current limitations [8]. Artists, in particular, are drawn to these themes, employing various mediums to engage with the complexities of posthumanist thought. This research aims to examine how the human body responds during the performance of an electroacoustic composition within a theatrical setting, specifically focusing on Euripides' *Andromeda*.

Exploring biometric data in music performance opens avenues for innovation and experimentation, enabling the creation of dynamic and responsive musical compositions. It is interesting to observe through electrode placement how the body responds to articulating music through bodily gestures[9]. Here, the performer's physiological state becomes an active component in shaping the evolving sonic landscape of Euripides' text, to explore how performers can control such data to enhance the musical experience by utilising expanded capabilities of the human body during music creation such as self-suggestion, concentration, and improvisation. Recent advancements in technology, particularly in artificial intelligence, machine learning and related fields, are ushering in an era of technological posthumanism characterised by human-machine symbiosis. The biosensors used for the making of this work were: a galvanic skin response sensor, a heart rate sensor and a 3D magnetic sensor for respiratory data. In this way, the particular work opens a dialogue with the idea of technological posthumanism, as it encourages the performing musicians to use contemporary technology to explore different ways of sound management with data derived from the human body.

Andromeda's text was chosen because it offered sonic landscapes that could create an auditory map but also a universal and timeless theme. This theme is none other than the theme of love, with which the majority of people usually identify. More specifically, the sonic themes in the soundscape, which is formed, are related to the story of Andromeda: echoes, the sensation of the waves surrounding her, and the wind. The music describes the first scene where Andromeda, tied to a rock and battered by the waves, speaks to her echo, pleading with the goddess of the night to allow her to live her love with Perseus. In this framework, Andromeda immerses the performer in audiovisual imagery, enabling them to extract from the narrative and generate corresponding biometric data reflecting varying dispositions. In conclusion, research endeavours (such as the one mentioned) hold the potential to influence various domains in music and theatre, extending to technology and the healthcare sector (music-sound/healing). To summarise, this research has transitioned from artificial intelligence to data technology (machine learning). Subsequently, sound processes are mapped to correspond to the performer's emotional fluctuations. Each emotional state is associated with a specific sound process, and since different performers yield different data, each performance becomes unique. The central goal is to explore the complexities of human emotion, viewing it as a unique phenomenon for each individual, and leveraging its potential creatively within computer-aided music composition and performance.

2.2. Technical Aspects and the Creative Process

The background research for the piece *Andromeda* was based on the collection of biodata from a group of 30 individuals. The data were retrieved from participants wearing biosensors while listening to music and observing images. Through a dialogue with an instigator, they were required to describe their emotions. This method facilitated the charting of a spectrum between different emotional states and their equivalent in data retrieved from the sensors: a galvanic skin response (GSR) sensor, a heartbeat sensor (HBS), and a respiratory sensor (RS). For example, an activation of the sweat glands results in moisture secretion through pores onto the skin, causing electrodermal activity. The alterations of positive and negative ions in the secreted fluid, is detected by the GSR as measurable changes in skin conductivity. Therefore the sensor's detection of changes in secretion results in data that can be mapped to underline different bodily states. Sweat secretion cannot be consciously controlled; rather, it is guided and balanced by our nervous system to respond to behavioural demands. The nervous system associated with emotional states represents a rapid response mobilisation system, facilitating immediate motor action. Increased emotional activity is linked to physiological indicators of "autonomic arousal," such as elevated heart rate, blood pressure, and sweating. For this reason, a respiratory and a heart rate sensor were also used in this study. While GSR is an ideal system for monitoring emotional arousal, it cannot directly reveal the emotion itself, i.e., whether one is emotionally stimulated by feeling pain, nostalgia, anger, love, or anxiety. This prompted us to monitor the function and rhythm of heart rate and correlate them with the values obtained from GSR. For instance, during a performance where the musician interprets a segment of the piece with a sense of nostalgia and concentration, it may register high values in the galvanic skin response sensor, surprisingly, indicating a state of calmness. Additionally, this calmness may coincide with a decrease in heart rate.

The sound architecture of the Andromeda was simple and the score easy to be read and understood by the musician. The main purpose was not to create a work with a deterministic character, but rather a piece based on the instructions and free interpretation. The tonality change controlled by the combination of measurements of GSR, heartbeat and respiratory sensors were applied more in the form of a choral effect, adding harmonics to the flute,

with resonant reflections. For example, the breath control sensor in combination with the heartbeat sensor in Max-MSP triggers many different reflections including a fourth, a seventh, an inverted fifth, a twelfth and interacts with the sequence change button of the reflections.The primary objective was to establish a dynamic interaction between Factor A and Factor B, fostering an internal cyclical flow as subsequent factors unfolded. Additionally, the GSR system played a pivotal role in influencing spatial values within the code, thereby shaping the spatial dimension of the piece. Moreover, it also impacted the sequence of chords, altering it based on fluctuations in the data captured by the heartbeat sensor. For instance, instead of following a conventional progression like A-C#-E-G#, the sequence could shift to E-C#-A-G# to reflect different levels of emotional arousal as depicted by the data.

The recorded values and observations from the sensors were set to MaxMSP as the minimum and maximum thresholds so that, during the piece, the performer could navigate between value boundaries that would create a sound processing, corresponding to their emotional state. The values of this measurement (1,100-3,500 MOhms-1 second per ohm to gauss = 898755224014.74 gauss- pair of electrodes placed close to each other) increased when there were changes in the individual's emotional state, particularly regarding anxiety levels. This is quite intriguing, especially when considering that during the musical performance of the piece in front of an audience, the baseline resistance value never dropped below 2 MOhms, while during periods of stress, it didn't remain below 3.500 MOhms. Specifically, some of the results collected during the flutist's calm state, with a one-minute difference, were: 2.655 to 3.120 MOhms, with corresponding heart rates of 85 to 125 bpm, respectively. Similarly, during intense stress induced either through performance anxiety and exposure to sound, or during preparatory exercises, the values fluctuated as follows: 3.500 to 4.100s, MOhms, with corresponding heart rates ranging from 98-145 bpm. During the flute performance, it became feasible, in combination with the other two sensors, to correlate the respiratory data with emotional stimulation. However, in general, it was observed that during high stress, tidal volume decreased due to rapid, shallow breathing, resulting in volumes less than 500 mL per breath. During moments of calmness, the typical respiratory rate ranged around 12-16 breaths per minute. The faster the musician breathed, the more it influenced her heart rate to some extent. Moreover, during pauses and moments involving extended techniques, such as playing with the keys of the flute, she made more body movements, consequently altering her breathing rhythm constantly.

2.3. Innovative Aspects in Biosensor Interactive Performance

The most intriguing aspect of this research lies in its exploration of biomusic and the role of the artist as a bridge between art and science. Here, the artist seeks to uncover methods for understanding and analysing the world while engaging in meaningful communication with others. Data analysis in music constitutes a narrative of reality. Artists and musicians may employ sonification techniques to craft musical compositions inspired by scientific data, environmental phenomena, or societal shifts, with the internal objective being both the exploration of these data and the deduction of scientific insights conveyed to the public through experimentation within the realms of art and music. Consequently, the methodology employed in this paper discerns, utilising biometric data, the alterations occurring in the body in response to real-life circumstances during the live presentation of an electroacoustic composition.

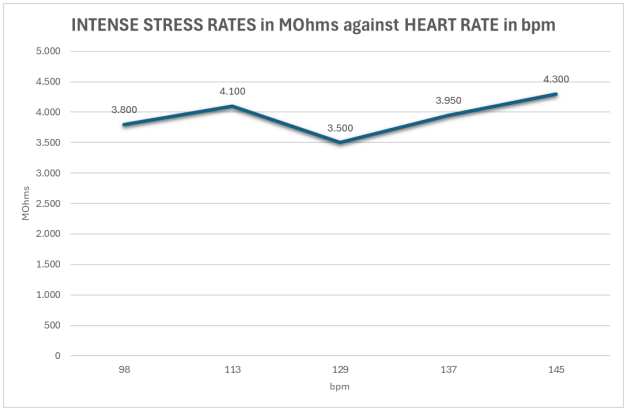

Figure 1. Intense stress rates in MOhms against heart rate in bpm**.**

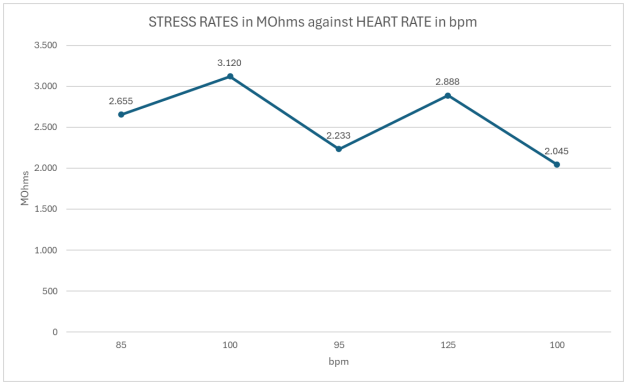

Figure 2. Stress rates in MOhms against heart rate in bpm.

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real-life circumstances during the live presentation of an electroacoustic composition. The conditions of this experimental procedure include a live performance of a piece (individual's exposure in front of an audience improvising), the theatrical convention of Euripides' tragedy, and lastly, the significant influence emanating from the sound itself. To derive conclusive findings, the experimental process was iterated in reverse. By this, we refer to the inverse procedure where biometric data were sourced directly from the performer. Through a combination of focused concentration and self-regulation, the performer achieved a remarkable degree of control over the galvanic sensor and cardiac pulse readings. Specifically, within the context of significant engagements such as public presentations and theatrical performances (e.g., the tragedy 'Andromeda'), the performer demonstrated the ability to modulate sound processing parameters on the flute, including reverb, delay, chorus, and panning. The data obtained from this reverse procedure, particularly during the initial two minutes, exhibited consistent readings in the range of 4000-5000 MOhms, accompanied by corresponding heart rates exceeding 130 and 300-400 LSb (Likely Significant bits).

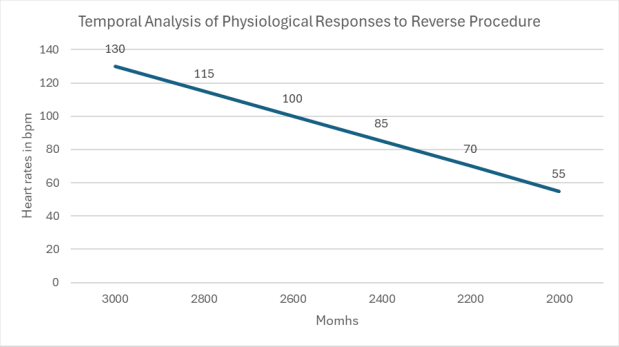

Figure 3. Temporal Analysis Physiological Responses to Reverse Procedure, heart rate in bpm against MOhms.

Subsequently, a steady decline was observed, with readings plateauing between 3000-2000, paralleled by reductions in both pulse rates and LSb values derived from the breath sensor. This reverse experimental approach serves to underscore a foundational tenet within contemporary discourse on technological posthumanism and cyborg theory. It illuminates how individuals, particularly since the latter half of the 20th century, leverage digital technologies to explore the capacities of the human body and express themselves artistically. Furthermore, from a methodological standpoint, this research endeavour not only contributes valuable data for interdisciplinary exploration, such as within the field of neuroscience but also enriches the realm of performative arts by fostering a symbiotic relationship between human biometric processes and artistic expression.[12][13]

3. CONCLUSIONS

Biomusic refers to the creation, manipulation, or interpretation of music based on biological processes, data, or principles, and relies on some kind of objectivity[14]. Embracing the fluidity between biology and technology, biomusic artists prompt listeners to reconsider their perceptions of sound, music, and the human condition, opening new avenues for creative expression and philosophical inquiry within posthumanist discourse. This research project concludes by discussing how the digital era's integration with nature has enhanced technological posthumanism, examining its impact on the arts and the broader community. In this particular research, the examination focused on whether practices such as technological transhumanism are capable of revealing the traditional musical experience [15]. Biometric data serves as a reflection of a reality occurring within the human body. However, how these data can be correlated with the performing arts is presented in two components.

The initial aspect entails real-time observation and data sonification. Observation links artists with science, emphasising scientific insights. Data sonification grants artists, generally, the liberty to interpret data critically. However, bio-music, exemplified by the Andromeda project, lacks this crucial freedom of movement, which we find significant.The objective was not the aesthetic of the sound form but the faithful representation of data at the moment of presentation. While performance thresholds were set, the primary aim remained to perceive the occurring changes, even if they occasionally deviated from anticipated aesthetic musical standards. As noted by Parker[16], data sonifications serve diverse purposes: representing real-time data, indicating alterations defined by designers within dataset-driven processes, and illustrating dataset trajectories. They notably influence user interactions with hands-on interfaces. For instance, Andrea Polli, a sound artist, employs sonification to translate data into sound, particularly in climate change installations, conveying complex atmospheric data to the public through immersive sound experiences. Referring to the examples, it is noted that the art of data sonification has a primary goal, which is to make scientific knowledge more accessible and understandable to the public. In other words, it aims to analyse and explain a truth while also enhancing it in an artistic manner[17]. Similarly, in the project presented earlier, *Andromeda*, the enhancement of the experience occurs both through the mapping of real-time data and through the theatrical analysis and representation of the work. Aesthetic considerations led to the selection of the sound design, which involves the flute with audio processing, to reflect the text of Euripides' lost tragedy. Specifically, as far as we know, in ancient tragedy, Andromeda symbolises both love and freedom, bound by her father and ready to be sacrificed to the sea monster sent by Poseidon. The waves strike her, and she pleads with the goddess of the night to allow Perseus to come and save her and love her. This was sonically rendered with intense reflections, exaggerated repetitions, recorded verses, and chorus effects. Andromeda in Euripides' work represents a symbol of defiance against patriarchy[18]and hope, an ancient Greek symbol that, rather than live a life she does not desire, prefers not to live at all. The choice to use the flute was made both as a means to connect with the ancient text, as ancient tragedies were commonly accompanied by the flute. Therefore, to conclude the components involving data sonification, the data transformed into sound includes both the performers' biometric data and the data extracted from the ancient text, in a mutually interactive format.

The second aspect delves into the convergence of technological augmentation and human expression in art,

particularly within the realm of performance arts. This intersection presents a rich ground for interdisciplinary exploration, with implications spanning neurobiology, psychophysiology, and performance studies. Contemporary discourse increasingly underscores the symbiotic relationship between technology and artistic expression, delineating terminologies such as "digital posthumanism" [19] to encapsulate this emergent paradigm. The integration of biometric data into theatrical and musical performances opens avenues for probing the neurobiological underpinnings of aesthetic experience and performer-audience dynamics[20]. The proliferation of sensor technologies capable of capturing physiological signals, including brainwave activity and autonomic responses, affords unprecedented insights into the physiological substrates of artistic expression. As the accessibility of biometric sensing devices expands, theatrical and musical practitioners are empowered to engage in empirical investigations of performance dynamics [21]. These endeavours encompass not only the elucidation of physiological correlates of artistic performance but also the exploration of therapeutic applications, such as stress modulation and psychophysiological self-regulation through artistic engagement [22]. For example, as the market opens up to sensors and brainwave measurement tools, including those used for this study, more theatrical and musical performances can utilise the function of biosensors. This results in small artistic experiments occurring under real conditions of pressure and creation, revealing not only how the human body reacts (biochemical changes) but also presenting a new method of studying music and, why not, a new way of stress therapy and body control through meditation. Besides the fact that the study of music can be enhanced through biosensor technology, electroacoustic music, due to the nature of its sound, can serve as a means of studying and understanding biometric changes. The present research aims to encourage efforts (using simple systems) like this, so that both data and observations can emerge during real performances, exploring more broadly the process of performance, both in theatre and music, and simultaneously how sound affects both the musician and the actor on stage.

Moreover, the domain of electroacoustic music emerges as a fertile ground for probing the perceptual and affective dimensions of biometric data. The inherent qualities of sound, as manipulated and synthesised in electroacoustic compositions, offer a unique lens through which to explore the complex interrelationships between auditory stimuli, physiological responses, and subjective experience. In sum, the research endeavours to catalyse interdisciplinary collaborations that leverage technological innovations to deepen our understanding of the physiological, psychological, and aesthetic dimensions of artistic performance [23]. By integrating empirical methodologies with artistic practice, scholars and practitioners seek to elucidate the mechanisms underlying human-machine interaction in the context of creative expression, thereby enriching both scientific inquiry and artistic discourse.

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