Exploring Musical Creation Through Brain-Body Digital Musical Instruments

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Abstract

Brain-Body Digital Musical Instruments (BBDMI) merge physiological signals with real-time sound processing, enabling performers to use Electromyographic (EMG) data for musical expression. This study explores the creative and technical potential of BBDMI, focusing on signal acquisition, adjustment, and mapping for use in composition and performance. Demonstrations with flute and piano showcase its ability to enhance expressivity through gestural control. While key advancements include improved signal stability and refined mapping, challenges such as connectivity issues and notation limitations remain. This research highlights BBDMI's promise as a transformative tool in contemporary music.

Keywords

BBDMI, Gesture control, Composition

1 Introduction

The development of digital musical instruments has long been driven by the intersection of technology and artistic expression. Among these, Brain-Body Digital Musical Instruments (BBDMI) offer a particularly unique avenue for exploration, merging physiological signals with real-time sound processing. Using electromyographic (EMG)[6] data representing electrical activity produced by muscles, BBDMI enables performers to translate subtle muscular movements into dynamic sonic outputs, thereby fostering a novel form of interaction between the human body and sound.

Despite the innovative potential of BBDMI, existing research has largely focused on technical aspects, such as signal reception, transmission, and mapping. While these studies are crucial, the compositional and performative dimensions of BBDMI remain underexplored. How can composers effectively integrate BBDMI into their creative processes? What new modes of performance and expression does it enable? Addressing these questions is essential for advancing the artistic application of this technology.

This article seeks to bridge this gap by examining the development of BBDMI from both technical and compositional perspectives. Through the design of a robust system for EMG signal acquisition and mapping, as well as the creation and performance of mixed musical works, this study explores the expressive possibilities of BBDMI. By focusing on its potential to shape interactive and dynamic musical compositions, this research aims to push the boundaries of contemporary music-making and redefine the role of the performer in digital sound environments.

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2 Previous Work

Research on the integration of physiological signals into musical interaction has evolved significantly over the past decade. Several studies have explored how electromyographic (EMG) and electroencephalography (EEG) signals can be harnessed for expressive control in music performance and composition. These efforts have laid the foundation for the development of Brain-Body Digital Musical Instruments (BBDMI), providing valuable insights into signal acquisition, real-time processing, and interactive mapping techniques. Donnarumma [3], Caramiaux, and Tanaka (2013) investigated the combination of EMG and MMG (mechanomyography) sensing for musical interaction, highlighting how muscle-based signals could inform gestural control in performance environments. Their findings demonstrated that multimodal sensing approaches could enhance expressivity by capturing different physiological parameters simultaneously. This work was further extended by Donnarumma (2012)[2] in Music for Flesh II, where he explored the viscerality of the body system in interactive music performance, emphasizing the physical and perceptual dimensions of muscle-driven sound interaction. Beyond EMG-based systems, research on biofeedback devices for musical applications has expanded. Di Donato, Bullock, and Tanaka (2018)[1] introduced Myo Mapper, a tool that maps Myo armband signals to OSC, facilitating real-time communication between muscle activity and digital sound synthesis. This work contributed significantly to developing flexible, open-ended frameworks for bio-signal processing in interactive music. More recently, Tanaka et al. (2023)[13] presented the EAVI ExG, a hybrid physiological sensing system combining muscle (EMG) and brain (EEG) signals to explore new paradigms of physiological interaction in music. Their research bridges the gap between different bio-sensing modalities, pushing forward the possibilities for adaptive, performer-responsive instruments. Additionally, feminist perspectives on biofeedback systems in music were explored by Erin Gee (2023)[5] in the BioSynth, a device designed to integrate affective biofeedback into sonic environments. This study underscores the potential of physiological sensors not only for technical innovation but also as tools for reshaping artistic discourse around embodiment and affect in digital music-making. Building on these prior works, our research aims to integrate EMG-based signal acquisition and mapping within a compositional framework that allows for real-time musical interaction. Refining the mapping techniques and exploring new performative applications aim to extend the expressive capabilities of BBDMI and further establish its role in contemporary music composition and performance.[4] Our project advances prior research by developing a multi-channel EMG calibration system, introducing a two-mode mapping interface (Direct and Regression modes), and proposing a novel bodily gesture notation framework for musical performance. These innovations offer new possibilities for performer expressivity and compositional design.

3 Objectives

Currently, research on BBDMI is quite limited and mainly concentrates on technical aspects, such as signal reception, transmission, and mapping. There has been little exploration of this instrument's development from a compositional point of view. In addition to continuing technical research, this project will also examine BBDMI development from the perspectives of composers and performers. The study has three main objectives: 1) Develop a system for capturing EMG signals and mapping them effectively to sound synthesis parameters. 2) Compose and perform mixed musical works in which BBDMI plays a central role in real-time sound processing. 3) Investigate the potential of EMG signals in shaping expressive and interactive musical compositions.

4 Methodology

The methodology for this study focuses on three critical aspects of Brain-Body Digital Musical Instruments (BBDMI): receiving and converting EMG signals, debugging and mapping signals to sound synthesis parameters, and selecting appropriate muscle groups for optimal performance interaction. These components form the foundation of an integrated system designed to enhance expressivity and interaction in music performance. In this process, a BITalino device is used to capture the raw muscle signals. A PC is employed to receive and convert the raw signals, then forward them onward, while a Mac is used to receive and map the signals. The workflow is as follows: BITalino first receives the signals and sends them to the MappEMG program on the PC. MappEMG[10] then converts the raw signals into OSC signals and transmits them to Max/MSP, where real-time sound processing is performed. The reason for using two computers is that the BITalino system had trouble establishing a Bluetooth connection with macOS, hence the need for a PC to handle the data transmission.

4.1 Receiving and Converting EMG Signals 'MappEMG'

When receiving signals, the MappEMG system, developed by Ziyue Piao, Marcelo M. Wanderley, and Felipe Verdugo (2023), was used. The BITalino (r)evolution board, an open-source biosignal acquisition system, was employed for EMG capture. This system features a modular live-streaming architecture capable of acquiring EMG data, processing it, streaming it in real time, and transmitting the processed signals to iPhones. Comparable platforms include IRCAM's R-IoT, a wireless sensor toolkit designed for real-time interactive applications. Additionally, MappEMG provides real-time vibration feedback across multiple mobile devices, enhancing interactive responsiveness in performance settings.

In this project, modifications were made to the Mapp EMG system to improve its functionality. Previously, it could only send one EMG signal, but with these changes, it can now transmit multiple signals. The workflow is illustrated in Figure 1.

4.2 Signal Adjusting and Mapping (Patch BBDMI)

Once the BITalino signal is successfully received in Max/MSP, the process transitions to the adjustment and mapping stages. A patch has been developed to perform these tasks, as illustrated in Figure 2. This patch is based on the "BBDMI package" for Max/MSP, created by David Fierro and Alain Bonardi in 2023. It

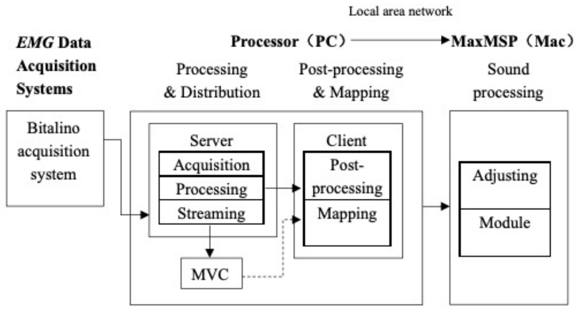

Figure 1: a. EMG Data Acquisition Systems: EMG signals are obtained from BITalino acquisition systems via a Bluetooth connection. b. Processor: The server receives the live-streamed data, the Maximum Voluntary Contraction (MVC) collects data for processing, and the client forwards this data to Max/MSP.

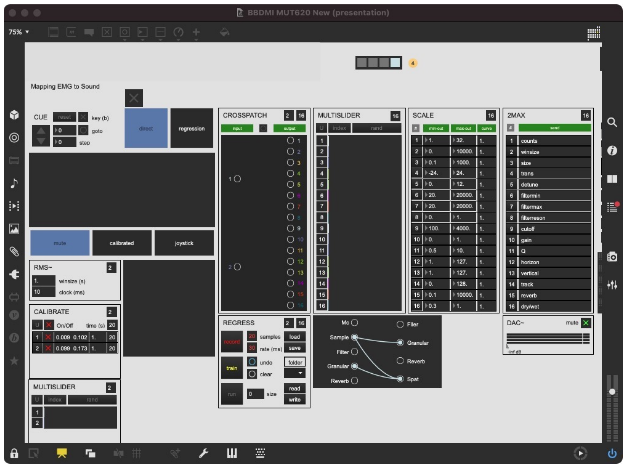

Figure 2: Patch BBDMI

is structured into three main sections: signal reception, adjustment, mapping, and the module. The signal processing workflow follows four steps:

1. Signal Reception: BITalino captures EMG data via Bluetooth and streams it to the PC server.
2. Dynamic Range Adjustment: The received EMG data are processed through RMS~ and Calibrate modules for normalization.
3. Mapping: The normalized signals are mapped to control parameters via Direct or Regression modes.
4. Sound Module Control: The mapped signals modulate spatialization, granular synthesis, filtering, and reverb effects in Max/MSP.

The Max/MSP patch BBDMI[1]. used in this study is available for download to facilitate replication and further exploration."

4.2.1 Reception and Adjustment. This section includes the RMS~ and adjustment modules. After receiving the raw signals from BITalino, they are sent as a list to the RMS~ module. The RMS~ object performs a Root-Mean-Square (RMS) operation on an

[1] https://gitlab.huma-num.fr/bbdmi/bbdmi

'mc.~list ' of audio signals. It accepts a single 'mc.~list' as input and outputs a root-mean-squared list for each channel, using a common sliding time window (in milliseconds). It outputs RMS values as messages within the range [0,1].

Next, the signals are sent to the Calibrate module for calibration. Calibrate can dynamically adjust the minimum and maximum input values of a list of control signals over a configurable period (in seconds). It takes one input list and outputs a time-calibrated version of that list. Here, 'Calibrate' does not serve as a strict "calibration" in the technical sense, but more as an "adjustment." In a real performance scenario, the performer cannot always maintain a state of complete muscle relaxation or full tension. Therefore, it is necessary to adjust the signal's range according to the actual physical conditions during the performance.

4.2.2 Mapping Section. This section includes the "Crosspatch," "Regress," and "Multislider" objects. After the signal is adjusted, it is sent to the first "Multislider," which displays both the number of signals and their dynamics. From there, the signals can be mapped to the corresponding parameters of the module, achieving real-time sound processing.[9]

Two mapping methods are available. The first, known as "Direct," transmits EMG signals directly into the "Crosspatch." On the left side, labeled "input," the EMG signals are received, while on the right side, labeled "output," the corresponding module parameters are assigned. By connecting "input" and "output," the signals can directly control these parameters. In this mode, the changes in the signal values correspond directly to parameter changes. For example, if the performer is fully relaxed, the signal is 0, and thus the module parameter is also 0. As the performer exerts force and the signal increases, the parameter value also rises accordingly.

The second mode is "Regress." Regress is a wrapper around the rapid object, which performs regression tasks similar to Wekinator, predicting continuous values in response to new input. It is based on the RapidLib C++ machine learning library. This module allows the user to interactively record example pairs of input and output, then train, edit (add/remove examples), and run models. It takes an input list in the first inlet and an integer output count in the second inlet, and then outputs a prediction list based on the new input data. All the parameters of the controlled modules are reflected in real-time in the second "Multislider."

4.2.3 Module. The third section is the module, which includes "Scale" and "2MAX." In the patch, I have implemented four effects: Spatialisation (4-channel), which allows for real-time control of the sound's trajectory and enables recording and playback of this trajectory; Filter; Granulator; and Reverb. All parameters that require control can be named in "2Max," and their parameter ranges can be adjusted in "Scale." All mapping can be carried out in "Presentation mode."

4.3 Selecting Muscle Groups for Performance

Choosing the appropriate muscle groups was a critical aspect of the methodology. The study focused on muscle regions that are both accessible for sensor placement and relevant to the performer's instrument and gestures. For flute and piano performances, arm and forearm muscles were prioritized to capture subtle finger and wrist movements. In piano demonstrations, upper arm and shoulder muscles were included to monitor larger, more dynamic gestures. The selection process balanced physiological considerations with the need to capture expressive and varied input data. Selecting the muscle area is also a crucial step in using the BBDMI. Indeed, depending on the instrument played, the muscle contraction area differs, and the most effective location for parameter control varies. For sound processing, it is important that the signal be stable and manageable.

For example, when playing the flute, placing the sensor on the abdomen resulted in highly unstable signals. Due to breathing, abdominal muscle activity fluctuated constantly, making accurate parameter control impossible. When applied to piano performance, positioning the sensor on the forearm produced signals that were too weak for effective module control. Forearm muscles generate lower-amplitude surface EMG signals compared to larger muscle groups, making it challenging to achieve stable control. This observation aligns with findings reported by Kuriki and De Azevedo (2012) regarding the limitations of forearm surface EMG acquisition.[7]

Ultimately, the deltoid muscle was selected as the optimal placement. This area enables the musician to control parameters with precision and efficiency while maintaining natural performance movements.

Through these three components, the methodology ensures a robust system for integrating EMG signals into musical performance, providing a platform for exploring the creative potential of BBDMI. The iterative approach allowed for continuous refinement, addressing technical challenges while enhancing the performer's experience.

5 BBDMI in Composition

This project resulted in the composition of two demos that employ Body-Based Digital Music Interaction (BBDMI) for real-time sound processing. During the composition process, a preliminary system for bodily gesture notation was developed. The following sections will introduce the BBDMI bodily notation system, describe the two demos, and share insights on using BBDMI from both compositional and performative perspectives.

5.1 Notation

The bodily notation system draws inspiration from traditional piano notation, utilizing two sets of staves to represent the left and right hands: the upper staff for the left hand and the lower staff for the right hand. Graphical representations, as shown in Figure 3, are used to indicate the intensity of the input signals, corresponding to the force exerted by the performer. A screen is placed in front of the performer, displaying the 'Multislider' so that the performer can match their gestures with the graphical signals and observe whether the force of their movements is accurate. The middle of the score marks changes in module parameters, allowing the performer to clearly understand the module's state. In the following demo descriptions, the explanation will be provided in detail on how this notation system is applied in composition.

5.2 Explanation of Demonstrations

The Bitalino sensor is affixed to the lateral aspect of the performer's left upper arm. The EMG signals are mapped onto corresponding effects processors during the performance.

5.2.1 Piano Demonstration: Demo 1. [2]

[2]Video link for Demo 1: https://vimeo.com/1053606021/31f1f3907e

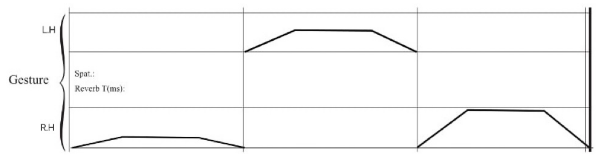

Figure 3: The diagrams above show three levels of force exerted by the performer's body. 1. slight force results in muscle signals displayed on the slider below 0.5. 2. moderate force produces muscle signals around 0.5. 3. maximum force under natural performance conditions generates muscle signals close to or equal to 1.

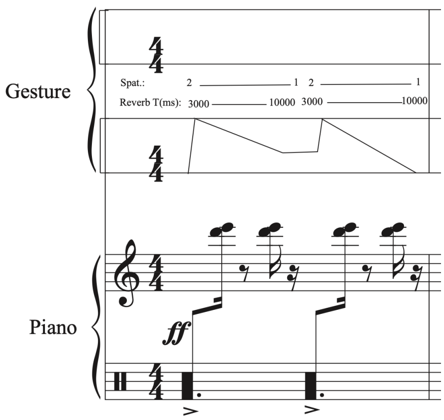

Figure 4: Score for Demo 1

The performer's gesture involves the use of a slap board, which is mapped to spatialization and reverb effects. The way to mapping is regression.

Regarding spatialization, the parameter changes are inversely proportional to the signal values. The EMG signals control the variations in panning. As muscular dynamics increase, the panning values decrease, resulting in a stronger directional bias towards the left. Conversely, diminished muscular activity shifts the panning to the right.

In terms of reverb, the parameter changes are directly proportional to the signal values. The EMG signals govern the variations in total time. As muscular dynamics intensify, the total time increases, resulting in a longer reverberation duration. Conversely, a decrease in muscular engagement leads to a shorter total time. Figure 4 presents the notation for Demo 1, illustrating this relationship.

As a composer and performer in the BBDMI project, the following observations can be made: From a compositional perspective, BBDMI represents a completely new instrument, offering a fresh dimension for musical creation. Since it requires the performer to use natural performance gestures, the process begins by observing the muscle signal characteristics produced during natural movements. Sound is then constructed based on these gestures, which contrasts significantly with traditional instruments, where musical material is typically constructed first. From a performance perspective, once BBDMI is properly worn and adjusted, it is very convenient to use. It allows effective real-time sound

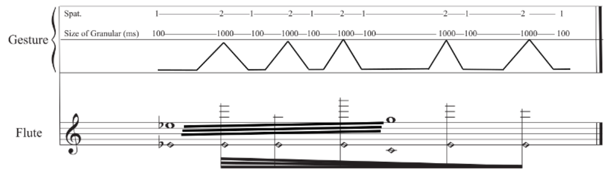

Figure 5: Score for flute

processing without requiring performers to learn additional gestures beyond their natural playing movements.

5.2.2 Flute Demonstration: Demo 2. [3]

This demonstration employs a direct mapping, where the parameter variations are proportional to the magnitude of the signal values. The gestures utilized by the performer include timbral trills and whistle tones, which are respectively mapped to spatialization and granular synthesis effects.

In terms of spatialization, the EMG signals govern the variations in panning. As muscular dynamics increase, the panning values also escalate, resulting in a greater directional bias towards the right. Conversely, reduced muscular activity shifts the panning towards the left.

In granular synthesis, the EMG signals control the grain size[4] parameter parameter of the Granulator module. The technique of timbral trills interacts synergistically with the granular effects processor, enhancing the overall auditory experience.

6 BBDMI in Perfomance

As an interactive system that translates muscle activity into musical expression, BBDMI introduces new possibilities for performance while also presenting unique challenges. This section explores how performers engage with BBDMI in a musical context, focusing on the integration of muscle-based control into score reading and real-time performance. Additionally, it examines the challenges encountered during practice, including the refinement of muscle control, adaptation to real-time feedback, and the complexities of expressive execution. This discussion highlights both the creative potential and the technical demands of incorporating BBDMI into contemporary performance practices.[14]

6.1 Score Reading

For performers using BBDMI, the traditional approach to score reading must be integrated with new performance techniques. As shown in Figure 5, performers not only need to read the notes and rhythms provided in the score but also pay attention to the notation related to muscle strength. Effectively combining the musical notes and rhythms indicated in the score with the electromyographic (EMG) signals collected by the BBDMI sensor is crucial for achieving a creative performance.

While reading the score, performers must understand the relationship between the production of each musical note and their muscle activity. Therefore, performers familiar with the BBDMI mapping parameters must develop an in-depth understanding of how each note corresponds to muscle movement. This process involves not only comprehending the score but also integrating

[3]Video link for Demo 2: https://vimeo.com/1053605930/f9849b1fdb

[4]Modulating grain size dynamically (instead of keeping it constant) enables the creation of evolving textures and directional microstructures in sound, especially when combined with grain waveform, envelope, and spatial position changes. [11]

the body's natural movements with the expression of the musical notes, enhancing both the expressive quality and technical efficacy of the performance. This introduces new challenges, making the practice more complex.

6.2 Challenges During Practice

During the practice process, the subtlety of muscle control directly affects the quality of EMG signals, which in turn impacts the output. To achieve precise control over sound variations, performers need to engage in intensive practice to enhance their sensitivity to muscle signals. Moreover, the BBDMI integrates the performer's tactile and visual feedback systems into the sound generation process, creating a novel yet complex relationship in performance. This requires performers to constantly adjust and optimize their gestures while playing to respond to the changes brought about by real-time feedback. Such demands not only test their comprehension of the score but also challenge their physical coordination and expressiveness. Consequently, adapting to these dynamic changes becomes a core task in the practice process.These challenges echo earlier findings on the complexity of tactile gesture-based sound interactions [12].

7 Discussion

The integration of the BBDMI (Body-Based Digital Musical Instrument) into musical practice provides composers with a novel perspective on sonic possibilities and significantly expands the methods available for real-time sound processing. By translating muscle activity into controllable musical parameters, the BBDMI system opens new avenues for performer-instrument interaction and expressive creativity. However, several technical and compositional issues were encountered during the course of the project, which this report aims to summarize. Similar technical obstacles were documented in early DMI performances such as with the Karlax and T-Stick instruments [8].

7.1 Technical Issues

One of the main challenges encountered in the implementation of the system is ensuring connectivity and stability between the microcontroller and the computer. Establishing a reliable connection has proven cumbersome and prone to instability, occasionally resulting in noticeable latency. This, in turn, hinders the responsiveness and immediacy required for effective live performance control.

In addition to connection issues, signal transmission limitations present another obstacle. While the BITalino system can currently transmit up to eight signals, which is sufficient for certain parameter control tasks, this capacity becomes restrictive when a more comprehensive analysis of the performer's overall EMG activity is needed. The limited number of signals may not provide enough detail or flexibility when selecting optimal muscle areas for mapping.

Furthermore, the lengthy setup and adjustment process adds to the complexity of using the system. Setting up the sensors, calibrating their values, and fine-tuning the data processing parameters require a significant amount of time. This can be particularly challenging for performers and composers working under the time constraints of rehearsals or live performances, potentially discouraging its practical adoption.

Finally, the reliance on single-use sensor patches raises both economic and environmental concerns. Since each performance requires frequent replacement of these patches, the system's sustainability for long-term or large-scale use is questionable. The recurring costs and waste generated by disposable patches pose logistical challenges, making it necessary to explore more cost-effective and reusable alternatives.

These issues collectively highlight the need for improvements in stability, transmission capacity, setup efficiency, and sustainability to make the system more practical and accessible for musical applications.

7.2 Compositional Considerations

Beyond technical constraints, performer movement and notation pose additional challenges in the practical use of BBDMI. The limited range of motion caused by the short length of sensor cables restricts performers from moving naturally, which can hinder their ability to fully explore expressive gestures. This limitation reduces the fluidity of performance and may constrain the ways in which BBDMI can be incorporated into dynamic musical interactions.

Moreover, a more structured bodily notation system is necessary for effectively integrating BBDMI into various musical contexts. Such a system should provide performers with a clear and intuitive way to interpret physical movements, ensuring that their gestures align seamlessly with musical output. Without an adequate notation framework, performers may find it difficult to navigate the system, potentially leading to confusion or misinterpretation of movement-based controls.

Overcoming these challenges will be key to optimizing BBDMI for artistic applications. Extending the length of the sensor cable and refining the notation strategies will allow performers to interact with the system more naturally and efficiently, making it a more viable tool for expressive and creative musical performance.

8 Conclusion and future work

This study highlights the creative and technical potential of Brain-Body Digital Musical Instruments (BBDMI) in expanding real-time musical expression using physiological signals. By capturing, calibrating, and mapping EMG data, BBDMI enables an innovative form of interaction between the performer and sound synthesis processes. The integration of BBDMI in flute, shakuhachi, and piano demonstrations showcased its versatility and effectiveness in shaping sound through gestural control, while enhancing the expressive and dynamic capabilities of each instrument.

Key advancements include the development of a robust signal workflow, reduction of signal latency, and the implementation of a modular system for real-time sound processing. These achievements underscore the potential of BBDMI for professional use in both compositional and performance settings.

However, challenges such as unstable connectivity, signal limitations, lengthy setup times, and the reliance on single-use sensor patches must be addressed to enhance usability. Similarly, compositional challenges like limited performer movement and the need for a clearer bodily notation system highlight areas for further exploration and development.

Future work will focus on refining the system's stability, optimizing adjustment, and improving the performer's creative experience by addressing technical and compositional limitations. With continued research and innovation, BBDMI has the potential to become an integral tool in contemporary music, offering composers and performers new avenues for artistic exploration and expression.

9 Acknowledgments

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10 Ethical Standards

The authors do not recognize any potential conflicts of interest in this research project. They recognize that all BBDMIs require the utilization of electronic materials and resources and acknowledge the lasting environmental and social impacts associated with their production.

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