Biostomp: A Biocontrol System for Embodied Performance Using Mechanomyography

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ABSTRACT

Biostomp is a new musical interface that relies on the use mechanomyography (MMG) as a biocontrol mechanism in live performance situations. Designed in the form of a stomp box, *Biostomp* translates a performer's muscle movements into control signals. A custom MMG sensor captures the acoustic output of muscle tissue oscillations resulting from contractions. An analog circuit amplifies and filters these signals, and a micro-controller translates the processed signals into pulses. These pulses are used to activate a stepper motor mechanism, which is designed to be mounted on parameter knobs on effects pedals. The primary goal in designing *Biostomp* is to offer a robust, inexpensive, and easy-to-operate platform for integrating biological signals into both traditional and contemporary music performance practices without requiring an intermediary computer software. In this paper, we discuss the design, implementation and evaluation of *Biostomp*. Following an overview of related work on the use of biological signals in artistic projects, we offer a discussion of our approach to conceptualizing and fabricating a biocontrol mechanism as a new musical interface. We then discuss the results of an evaluation study conducted with 21 professional musicians. A video abstract for *Biostomp* can be viewed at `vimeo.com/biostomp/video`.

Author Keywords

Biocontrol systems, mechanomyography, stomp box, embodied performance, user evaluation

ACM Classification

H.5.5 [Information Interfaces and Presentation] Sound and Music Computing, H.5.2 [Information Interfaces and Presentation] User Interfaces

1. INTRODUCTION

Biomonitoring systems offer a vast range of applications for observing various functions of the human body. While most of these applications pertain to medical research, the interpretation of signals internal to the human body has also been used in arts as a control mechanism. In this paper, we discuss the design and implementation of one such application, named *Biostomp*, where we utilize mechanomyography to augment the control space of a musical performer by translating the oscillations from naturally-occurring muscle activity during a performance into control signals that manipulate various effects that are commonly used by musicians.

A mechanomyogram is a low-frequency mechano-acoustic signal generated by contractions in muscle fibres [6, 18]. The monitoring of mechanomyograms, known as mechanomyography (MMG), is most commonly used in medical applications such as prosthetic control, and the study of muscle disorders and fatigue. With *Biostomp*, we exploit the mechanical nature of MMG as a means to extract the unmediated byproduct of muscle activities inherent to a musical performance. We have adopted a stomp box model in our design to alleviate the complexity of a computer-based setup, which is often found in biocontrol systems. Our system is designed as a plug-and-play tool that does not require extra configuration or calibration beyond what is common to stomp box effects pedals.

Biostomp comprises of a custom MMG sensor that is attached to the performer with an armband. The signals from the sensor are passed to the stomp box, which houses a circuitry to amplify, filter, and interpret the MMG signals. The processed signals are then used to activate a motor that controls parameter knobs on effects pedals, such as those for delaying and overdriving an instrument signal. We have designed an adjustable motor mounting system that can easily be attached to knobs on most effects pedals.

Biostomp augments the musician's control over existing parameters of a performance setup in various scenarios. In its primary use, the system listens to the biosignals that occur during a musician's regular performance, and maps these to the control of parameters on effects pedals. But the musician can also engage in an *extended performance* where they actively control these parameters with conscious muscle movements beyond what their usual interaction with their instruments would mandate. In addition to such primary uses of the system, *Biostomp* also provides a separate audio output for the processed biosignals, which facilitates the use of the system as a stand-alone instrument.

We conducted a user evaluation study to explore how augmenting the control space of a performer by interpreting MMG signals affects the performance, to what extent the performer feels in control of the resulting changes, and to what extent these changes are considered to be desirable in a musical context. In doing so, we aimed to evaluate the optimal applications of the proposed system, and delineate a road-map for the future development of our platform.

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2. RELATED WORK

Scientific investigation of signals internal to the human body dates back to the physician Luigi Galvani's discovery of *animal electricity* in 1791; biomonitoring mechanisms has since been a prominent component of medical research [12]. The stethoscope, for instance, is a well-known application in this field.

The use of biosignals in arts, however, has a relatively recent history. In one of the first works to utilize such signals, the composer Alvin Lucier used EEG sensors placed on his scalp to pickup alpha waves that the brain generates under a focused state. Premiered in 1965, his work *Music for Solo Performer* relied on this technique for the control of actuators attached to instruments [8].

In 1980, the artist Stelarc introduced his work *Third Hand*, which used EMG signals captured from his abdominal and leg muscles to control a mechanical hand attached to his right hand. This work was initially intended as a semi-permanent prosthesis but was re-purposed as a performance device due to the discomfort caused by the apparatus. According to the artist, the artwork has "contributed to cyborg discourses on the body".[1]

In the early 1990s, the artist Atau Tanaka drew attention to the use of biosignal interfaces in performance art. He was the first artist to be comissioned to work with *BioMuse*, which is a multi-sensor biocontrol system first developed by R. Benjamin Knapp and Hugh Lusted in 1988. This system was able to monitor and transmit electroencephalogram (EEG), electrooculography (EOG) and electromyography (EMG) signals. A year after the introduction of *BioMuse*, Tanaka co-founded the *Sensorband*, a trio of musicians who use bioelectric sensors, with Zbigniew Karkowski and Edwin van der Heide [2]. The artist describes his work in this medium as a "corporeal activation of sound" that can not only decode experimental performance, but also offer "an entry point to possible intimate spaces created by digital interaction" [15]. *BioMuse* project was later developed into a brand that consisted of various consumer-oriented biocontrol devices.

The artist Marco Donnarumma coined the term "biophysical music" [4] in 2011, following the development of his *Xth Sense* device, which is an MMG-based sensor system that captures biological sounds. Xth sense comprises of an MMG sensor armband and a hardware amplification unit; the hardware is coupled with a custom software that enables mapping, filtering and sound-processing. The artist uses the device in his performance art pieces, where his body becomes the primary sound source.

In 2014, Thelmic Labs released a consumer version of their armband EMG sensor *MYO*, which is a general-purpose gesture controller. Accompanied by a variety of software products, *MYO* is marketed as a cross-platform biocontrol interface. It relies on the use of pre-defined arm and hand gestures to activate certain software commands. For instance, in the MYO Control App, making a fist opens the menu, and spreading fingers launches an application.

3. BIOSTOMP

Biostomp aims to integrate biocontrol into musical performance. Initially developed for guitarists, *Biostomp* can be useful for any performer who utilizes effects pedals in their music. Additionally, the audio output capabilities of our system enables its use as a standalone instrument, in which the muscle sounds themselves act as a sound source.

Stomp boxes often comprise a toggle switch for turning the effect on or off, permanently mapped parameter control knobs, an audio input, and an audio output for the processed signal. Our primary design consideration with *Biostomp* was to capture the simplicity of this model and achieve an unmediated connection between biosignals and the parameters these can be used to control. Most biosignal systems used in artistic projects communicate with a computer software that generates or manipulates sounds. In such cases, the computer can be considered as the sound-producing instrument. The computer can also be used as an intermediary when using biosignals to control external mechanical sound sources. While this approach offers precise monitoring and intricate mapping of biosignals, putting an extra layer between the performer and the instrument can be undesirable in live performance situations.

Biostomp is a self-contained system that does not require a software interface or external calibration beyond what is presented on its physical interface. The system therefore acts as an analogous mediator that is capable of mechanically manipulating hardware signal processing devices, such as effects pedals, with biosignals generated during a musical performance.

Biostomp relies on MMG acquisition for translating muscle activity into control signals. MMG is most commonly compared to electromyogram (EMG), which represents the electrical potential of muscle activity [12]. The hardware and signal processing components of an EMG acquisition system is often technically complicated and expensive to manufacture [1, 6]. Furthermore, EMG sensors have a noisy response under low muscle activity [19], and are sensitive to environmental factors, such as power line interference [7], electro-magnetic pollution [16], and perspiration [11]. Additionally, EMG signals detected by surface electrodes take place prior to muscle activation in the sensorimotor system flow [5] whereas mechanical vibrations picked up by an MMG sensor are generated upon the force production. This implies that control signals acquired with an EMG sensor precede the actual muscle activity. While this makes EMG particularly useful in certain applications, such as prosthetic limb systems, it masks the effect of, for example, physical muscle fatigue, which can be utilized as a meaningful component of a musical performance. Finally, when compared to EMG signals, MMG signals are less sensitive to placement of the sensor over the muscle [17]; this allows MMG sensors to be placed more freely over certain muscle regions and makes them less susceptible to shifts in placement during monitoring. Fig. 1 shows the components and operation scheme of Biostomp.

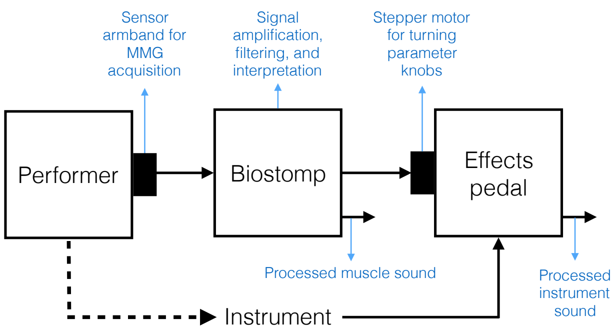


Figure 1: Biostomp components and operation scheme

3.1 Sensor Design

An MMG sensor, an air-chamber that houses this sensor, seen in Fig. 2, and an armband that holds these components in place, seen in Fig. 3, are the principal components of

[1] http://stelarc.org/?catID=20265

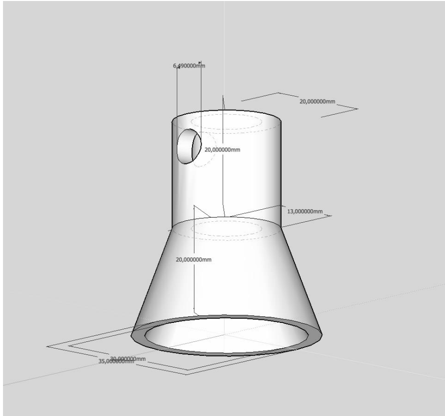


Figure 2: 3D model of the air-chamber housed in the armband

Biostomp's MMG extraction mechanism.

The frequency of core muscle vibrations range from single digit values to approximately 45 Hz [10] with that of superficial muscle contractions go up to 100 Hz [3]. While industrial measurement microphones, such as the Microtech Gefell's MK250, can offer a frequency response of 3.5 Hz to 20 KHz, this is a considerably wider range than that is necessary for our system. Instead, we used a Kingstate KECG2742PBL-A electret condenser microphone, which is suggested as being ideal for MMG applications in a comparative study conducted by Donnarumma et al. [5].

Previous research describes ideal specifications for MMG sensor and air-chamber designs: Watakabe et al. [18] tested several dimensions for cylindrical air-chambers and recommended a diameter of at least 10mm and a height of 15mm, pointing out the correlation between slight changes in this dimension and frequency response. Silva and Chau [14] proposed the use of a microphone-accelerometer composite sensor with a cylindrical air chamber of 1.3cm in diameter and 0.2cm in height, sealed with a silicone membrane, which provides the highest signal-to-noise ratio. Posatsky [13] investigated multiple designs with both cylindrical and conical air chambers and found that cones offer a higher average gain of 6.79 +/-1.06 dB/Hz in low frequencies, in comparison to cylindrical air-chambers.

To achieve flexibility in where the sensor can be placed on the body, instead of a small silicon-based enclosure, we adopted the air-chamber design by the researcher Martin Ma, who proposed the use of wider dimensions for monitoring large muscle regions rather than individual muscles [20]. We modelled this proposal in a 3D design environment (see Fig. 2) and used oil-based plastic acrylonitrile-butadiene styrene (ABS) as our base material. This is a tough-yet-lightweight material appropriate for molding robust objects for everyday use.

Figure 3: The armband that houses the sensor

3.2 Circuit Design

The electret microphone is powered via a 12V regulated circuit; its output is amplified with a 2-gain-staged high-quality audio preamp, designed by Rod Elliot.[2] Note that in our system, the R7 resistor is modified with a 4.7 kOhm resistor to achieve a total gain of 12.9 db.

Based on the frequency range to be monitored with the MMG sensor, a 5th-order low-pass Butterworth filter in a Sallen Key topology with a cut-off frequency at 100 Hz is used. From the filters we experimented with, the cut-off slope and the pass-band characteristics of this design provided us with an optimal noise elimination. OPA27 operational amplifiers were preferred due to their low-noise and high-precision stability characteristics.

The filtered signal is passed to a *Msgeq7* equalizer IC, which is a CMOS chip that provides a DC representation of the amplitudes of 7 fixed frequency bands. In our case, we only use the first band, which has a center frequency of 63 Hz. We also implemented a signal path for the AC signal to allow for the direct monitoring of the audio signal.

Figure 4: *Biostomp* enclosure

Upon detection of a consistent hum in our first prototype, we switched from a plastic enclosure to a metal one, as seen in Fig. 4. The conductive enclosure works as a local earth and offers shielding from electromagnetic interference [9]. A sensitivity knob attached to a 100-kOhm potentiometer enables the control of the preamp's gain. A 3PDT foot-switch is used for switching between motor control or audio output. When the audio output is not used, this foot-switch effectively turns off *Biostomp*.

3.3 Motor System

Envelope following of the band-limited 20Hz-to-63Hz signal is sent to one of the analog inputs on the micro-controller, in this case an *Arduino Nano*. Further smoothing, scaling and mapping is applied to the digital signal. An A4988 driver board is used before the motor for pulse transmission, current adjustments, and over-heating protection. A

[2] `http://sound.whsites.net/project88.htm`

NEMA 14-size bipolar stepper motor is attached to a custom, adjustable motor mounting system, as seen in Fig. 5, which can be attached to stomp boxes with different knob configurations.

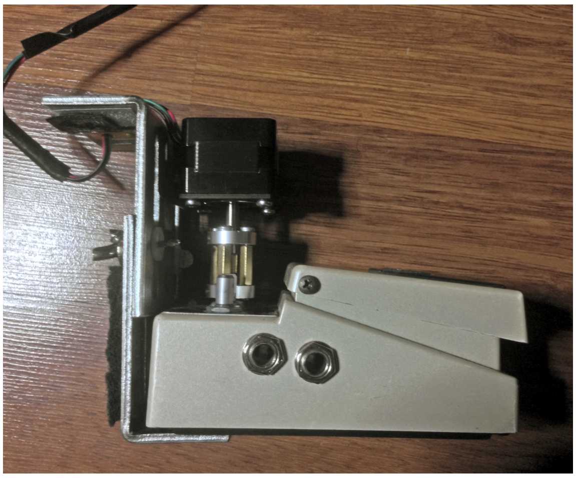


Figure 5: Adjustable motor mounting

4. USER EVALUATION

A user evaluation was conducted to explore the responsiveness of *Biostomp*, and its ease of use for musicians who may or may not be experienced in incorporating digital control interfaces into their performances.

4.1 Preliminary Study

To evaluate our first prototype of *Biostomp*, we conducted a preliminary study with 11 guitar players between the ages of 25 and 45. Two primary issues that surfaced in this study were the lack of ease in mounting the sensors, and the discomfort caused by the armband during performance. Furthermore, the participants reported an inconsistent relationship between their activities and the audible outcome of the device's interpretation of these activities. Such feedback prompted us to revise the wearable components of our system to improve comfort during performance. Furthermore, we revised the grounding and amplification schemes in our circuitry, which helped eliminate some of the noise that impacted the sense of correlation between the bodily movements and the changes in audio effects negatively.

4.2 Method

After revising our system based on the results of the preliminary study, we conducted a primary study with 21 professional musicians, which included 13 guitar players, 1 trumpet player, 1 violinist, 1 keyboard player, 3 percussionists, 1 drummer, and 1 custom electronic instrument player. 11 of the participants reported limited experience with new musical interfaces, with 4 participants reporting no experience whatsoever. The remainder of the participants reported experience with a range of interfaces, such as Arudunio-based sensor systems, MIDI keyboard and controllers, tablets, computer software, and natural interaction devices like the Microsoft Kinect and the Leap Motion. The styles of music performed by the participants included classical, folk, jazz, free improvisation, rock, noise, and ambient.

The study took 30 minutes on average. After a brief verbal description of the system, the users were given a period of time to warm up. The sensitivity of the monitoring was then adjusted for the individual performer. This was followed by a performance, which was recorded audio-visually and lasted 15 minutes on average. Each performer used the system to control the delay time parameter on a delay pedal, and the drive parameter on a fuzz/distortion pedal.

The participants were than asked to fill out a 15-question survey, which consisted of 10 linear scale questions asking users to rate different aspects of their experience using *Biostomp*, as well as 4 open-ended writing prompts, and 1 multiple choice question asking users which of the effects (i.e. delay or drive) was preferred.

4.3 Results & Discussion

Fig. 6 shows the distribution of responses to the 10 linear scale questions about various aspects of their experience performing with *Biostomp*.

While it was left up to the performers to decide whether they would let the system accompany their regular performance, or if they would extend their playing with deliberate muscle movements, users reported the armband gave them an awareness of the system that they wanted to "play into" regardless of their approach. While most users reported switching back and forth between regular and extended performances, one user described that, in addition to his normal guitar playing, he contracted his biceps to the rhythm of the tune; this is an interesting in-between approach that maintains a regular performance but augments it with extra embodied controls. This can be resembled to a performer's tapping of a foot to the rhythm of his or her playing; such an activity is often a natural bodily expression that can serve as a means of timekeeping. While such expressions would not effect the sound output directly, in this case, *Biostomp* translates these expressions into variations in sound, offering a new degree of freedom.

The users reported that they felt a significant potential for improving their control over the system with more practice, implying that the system can be capable of affording varying degrees of virtuosity. In accordance with this, most users indicated that their ability to predict the system's effect has noticeably improved over time. One user stated that once they figured out the limits of the parametric changes enabled by the system, their control over it significantly improved. These results imply an ability to gain expertise with *Biostomp*, which can contribute to its long-term integration into performance practices.

Out of the two effects the participants performed with, there was a preference towards the control of the delay parameter (62%) than that of the drive parameter (38%). Despite this result, multiple users reported feeling more in control of the drive parameter. Other users expressed that the sense of contracting a muscle was more analogous with the audible effect of the drive pedal rather than that of the delay pedal. This indicates an embodied relationship between the variations in physical effort and sound dynamics, which is a rather intuitive relationship that is often observed with acoustic instruments. When asked about which effects parameters they thought would be suitable for controlling with *Biostomp* besides the ones they performed with during the study, users listed size parameter on reverberation effects, cut-off frequency on EQ and WAH pedals, depth and time parameters on flanger and phaser pedals, and pitch value on pitch-shift pedals.

While most of the participants described their movements and the resulting changes in effects to be coherent, they have also suggested that personalizing the experience by using different effects pedals, and attaching the sensor to other limbs could help improve the sense of coherence. One of the users expressed that one of the most engaging aspects of their experience with the system was figuring out its effect on their playing, and added that it wouldn't be as expressive if it was entirely predictable. Another participant noted that the unexpected outcomes have surprisingly affected their performance in a positive way. This is apparent in Fig. 6 (b) and (c), which imply that while most users acknowledged a sense of control over the system, the coherence between their performance and the resulting changes in effects were rated higher with a similar Likert distribution. This could be explained through the unmediated connection the system creates between muscle movements and parameter changes: although the users might not be conscious of their muscle activity when playing their instrument, such activity is nevertheless a part of their performance; *Biostomp* merely maps this to an existing parameter within their control space. By nature of its design, the system is immune to misinterpretations, discontinuities or data loss.

The users reported the armband having a physical effect on the performance to varying degrees. While some users described that the system did not cause any additional physical strain during their performance, others indicated that it could get uncomfortable beyond the 15-20 minutes period they spent with the system during the study. One user noted that the awareness of the device forced them to perform extra movements that might have contributed to their sense of post-performance fatigue. In line with this, another user stated that becoming more experienced with the system would presumably help them be more deliberate with it and therefore reduce the risk of fatigue. Another user suggested that it might be comfortable to play with a smaller armband; the current design of the armband has been resembled to a blood pressure cuff.

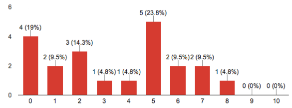
Despite the significant variation of musical styles played by the participants, nearly all of them expressed that playing with *Biostomp* would be compatible with their style. While psychedelic rock, free improvisation and experimental music were the most commonly listed genres considered suitable for performing with this system, the list included more mainstream genres as well. Some users noted that the device would be particularly useful in performances where bodily movements are well-articulated, or more physically expressive. One user mentioned that they would want to compose new pieces with this system in mind, while another felt the device "expanded the playground for the free improviser."

When asked about possible improvements to the system, the participants requested better response times especially with the release stage of the effect; a user noted that it occasionally became hard to decay the effect before a new activation was triggered. Some users indicated that it could be interesting if multiple limbs were monitored to control multiple parameters at once. Given the audio output capability of the system, one user suggested that *Biostomp* could be integrated into a modular synthesizer performance as a CV source. One of the users suggested that the system could be used in an art-form that is more corporeally expressive, such as theatre or performance art.

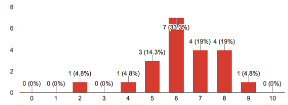
5. CONCLUSIONS

This paper introduces a new interface for augmenting musical performance with biosignals through the use of a self-contained stomp box system that translates muscle activity into changes in parameters on effects pedals. A user study of 21 musicians provides initial validation of the success of *Biostomp* in terms of ease of use, controllability, expressiveness, and fatigue.

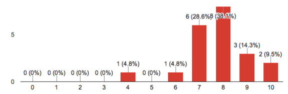
Feedback from our preliminary study guided the fundamental design of our system. The improved comfort and more accurate processing hardware in the new design en-



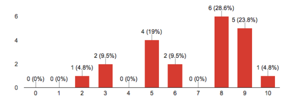
(a) Do you have prior experience with new musical interfaces (e.g. sensor systems, digital control devices)? 0: I have no experience with such interfaces. 10: I have considerable experience with such interfaces.



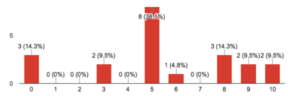
(b) To what extent did you feel in control of the changes in sound effects as you performed with this device? 0: I felt it was totally out of my control. 10: I felt it was completely under my control.



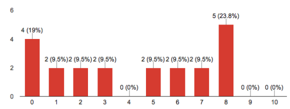
(c) Regardless of the extent of your sense of control over changes in sound effects, how coherent do you think these changes were with your performance? 0: I did not find it coherent at all. 10: I found it very coherent with my playing.



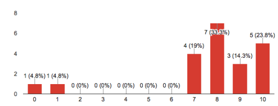
(d) Did you feel you had to contract your muscles deliberately to activate the device, and to what extent? 0: The device acted upon my natural arm movements during performance. 10: I controlled the device entirely with deliberate muscle contractions.



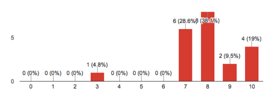
(e) Regarding the two scenarios presented in the previous question, which one do you think is the ideal use of this device? 0: When it changes the effects as a result of my regular performance without deliberate contractions. 10: When it responds my deliberately executed muscle contractions.



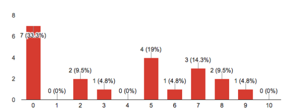
(f) To what extent did the device affect your performance physically? 0: It did not affect my playing physically at all. 10: It significantly affected my playing physically.



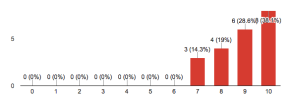
(g) Have you noticed a variation in your sense of control over the changes in sound effects? 0: There was no noticeable difference in my sense of control. 10: I felt my sense of control improved over time.



(h) Have you noticed a variation in your ability to predict the device's effect on sound processing during the course of your performance? 0: The device acted unpredictably throughout my performance. 10: It became easier to predict the effect of the device as the performance progressed.



(i) What is the effect of performing with this device on your overall fatigue after the performance? 0: This device had no effect on my post-performance fatigue. 10: This device increased my post-performance fatigue.



(j) How compatible do you think this device is to your playing style? 0: The function of this device is not compatible with my playing style at all. 10: The function of this device is considerably compatible with my playing style.

Figure 6: The distribution of user responses to our survey, following the performance of multiple musical styles with *Biostomp*.

sured a minimum threshold of musical responsiveness for instrumentalists with a wide range of stylistic backgrounds. In our user study, we observed an ease of adaptation during each participant's experimentation with the system. Some users especially indicated that they appreciated the intimacy that the familiar "effects pedal" presentation of *Biostomp* provided. We observed that users who were introduced to the original sound of the control signal were more easily able to incorporate *Biostomp* into their performances. Users were intrigued by the increased range of expressivity our system enabled, and we will continue to explore and evaluate the use of *Biostomp* to control a wider range of musical effects.

We believe that the overall comfort of the armband will need to be improved for the next iteration of the hardware. In addition to the foot-switch that shifts the signal from motor control to audio output, and the input gain knob, we plan to add extra control knobs (e.g. for adjusting rotation decay time) and switches (e.g. for switching motor rotation polarity) based on the feedback we received from musicians. We also see a great potential in adding a DC output within signal Eurorack standards for the integration of *Biostomp* with modular synthesizers.

We hope that the results discussed here will not only help us improve our own design, but also aid the design of new biosignal interfaces, particularly taking into consideration some of the issues highlighted in this study, such as the effects of mapping strategies on the embodied relationship between the performer and the sound, the benefits of adhering to a performer's existing interaction paradigm, and the need for a range of expressiveness within which the performers can improve their control over the system. Overall, we believe that the integration of biocontrol into music performance opens up a lot of possibilities for both traditional and contemporary performance practices, and that *Biostomp* offers a notable contribution in this area.

6. ACKNOWLEDGMENTS

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