Muscular Interactions

Combining EMG and MMG sensing for musical practice

Marco Donnarumma
Department of Computing
Goldsmiths
University of London
md@goldsmithsdigital.com

Baptiste Caramiaux
Department of Computing
Goldsmiths
University of London
bc@goldsmithsdigital.com

Atau Tanaka
Department of Computing
Goldsmiths
University of London
atau@goldsmithsdigital.com

ABSTRACT

We present the first combined use of the electromyogram (EMG) and mechanomyogram (MMG), two biosignals that result from muscular activity, for interactive music applications. We exploit differences between these two signals, as reported in the biomedical literature, to create bi-modal sonification and sound synthesis mappings that allow performers to distinguish the two components in a single complex arm gesture. We study non-expert players' ability to articulate the different modalities. Results show that purposely designed gestures and mapping techniques enable novices to rapidly learn to independently control the two biosignals.

Keywords

NIME, sensorimotor system, EMG, MMG, biosignal, multimodal, mapping

1. INTRODUCTION

Muscle activity can be detected by using two distinct biosignals, the electromyogram (EMG) and the mechanomyogram (MMG). The former is a series of electrical neuron impulses sent by the brain to cause muscle contraction. The latter is a sound produced by the oscillation of the muscle tissue when it extends and contracts.

Biosignals have been largely adopted in diverse fields, from human-computer interaction, to medical engineering, affective computing, and embodied musical performance. Biosignals have been used in NIME in a diverse range of musical instruments and interface systems ([10]). Different types of biosignals have been used. Some, such as brainwaves (EEG) and galvanic skin response (GSR), are not directly related to movement, but rather to mental and physiological states, and thus fall outside our focus in this paper. The EMG and MMG, are useful in tracking limb movement in performance.

Previous work with EMG in NIME has been presented in [9]. The present authors have separately reported work on use of the EMG [15] and MMG [2] for live musical performance. We have looked at muscle signals in a multimodal context for EMG with ultrasound rangefinders [15] and MMG with accelerometers and motion capture systems [3], but to our knowledge, EMG and MMG have not previously been compared in a musical context.

We present a combined analysis of these two types of muscle sensing. We establish a gesture vocabulary using examples reported in the biomedical literature that describe differences between and complementarities of the signals. With these gestures, we create musical mappings where these differences and similarities are heard through sonification and audio processing. We then study the ability of non-expert users to play this bi-modal biosignal musical interface.

We first give an overview of the sensorimotor system and a brief review of biomedical literature comparing EMG and MMG. We next describe the bi-modal EMG/MMG system, its hardware, gesture vocabulary, and mappings as used in the study. We then present an evaluation of the system followed by results, including interviews conducted with the study participants. We identify tendencies within the group and discuss perspectives for future development.

NIME'13, May 27 – 30, 2013, KAIST, Daejeon, Korea.

2. MUSCLE ACTIVATION MECHANISM

The human sensorimotor system is a chain of interdependent physiological activity that includes: mechanoreceptor stimulation, neural transmission, central nervous system (CNS) integration, transmission of efferent signal (i.e. a neural trigger fired by the CNS), muscle activation, force production, and movement [12]. Figure 1 illustrates the sensorimotor system flow, and indicates when EMG and MMG are produced.

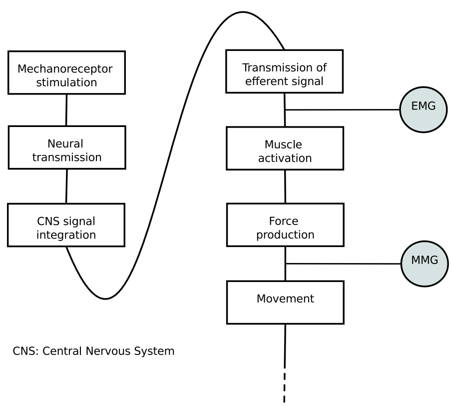

Figure 1: Sensorimotor system information flow.

The EMG is an electrical voltage that results from neuron firing causing muscle contraction. It can be detected using surface electrodes that make electrical contact through the skin. The contraction of a group of muscle fibers (also known as motor unit) results in stochastic bursts of electrical activity [4].

The MMG is an acoustic signal generated by subcutaneous mechanical vibrations resulting from muscle contraction. It can be captured with surface audio microphones [11].

By simultaneously sensing EMG and MMG from the same movement, complementary information on a gesture can be captured. The signals are produced at different points in the execution of gesture. They are interrelated and present several kinds of relationships.

Previous studies have demonstrated EMG and MMG relationships that vary according to the type of contraction and sensor location. Madelein et al. [8] found that EMG and MMG have different *activation* mechanisms depending on the type and force level of muscle contraction. It has been reported that EMG detection is negatively affected by the distance of the EMG sensor from the muscle activation area [1] (*localisation*), whereas the MMG signal is more easily detectable due to its *propagation* qualities, which allows the signal to be transmitted through tissue surrounding the contracting muscle [13]. Gordon et. al showed that, during free-hand forearm rotation, EMG amplitude in the posterior muscles is lower than in the anterior muscle [5] (*relaxation*). Jobe et al. [7] found that, during throwing and pitching gestures, forward arm acceleration in space lacks EMG activity in the deltoid and arm muscles (*acceleration*).

We selected *activation*, *localisation*, *propagation*, *relaxation*, and *acceleration* to design a vocabulary of physical gestures to be performed with a bi-modal, biosignal-based interface created for this study.

3. BI-MODAL EMG/MMG INTERFACE

3.1 Signal acquisition hardware

We used existing musical EMG and MMG sensor systems together in a bi-modal configuration. For the MMG we used the Xth Sense (XS), a biophysical music system[1]. The XS consists of an arm band containing an electret condenser microphone (Kingstate KECG2742PBL-A) where acoustic perturbations from muscle contraction are digitised as sound at a sampling rate of 44100 Hz. For the EMG we used the Infusion Systems BioFlex dry electrode sensor[2]. The EMG signal from the BioFlex was digitized with an Arduino BT-V06 and sent over Bluetooth to the host computer using custom firmware[3]. The EMG signal was sent over Bluetooth connection through a virtual serial port created on a laptop running Linux Ubuntu 10.04. The signal was initially sampled by the Arduino at 500Hz. To create a coherent bi-modal system, we upsampled the EMG in the host computer to match the MMG sampling rate. The XS software was modified to process the two modalities in parallel in equivalent ways. The MMG and EMG were first directly sonified, and then used as control data to enable the user to drive the mapping of 3 gestures.

Arm bands with EMG and MMG sensors were placed on the forearm. One MMG channel and one EMG channel each were acquired from the users' dominant arm over the wrist flexors, a muscle group close to the elbow joint that controls finger movement (Fig. 2).

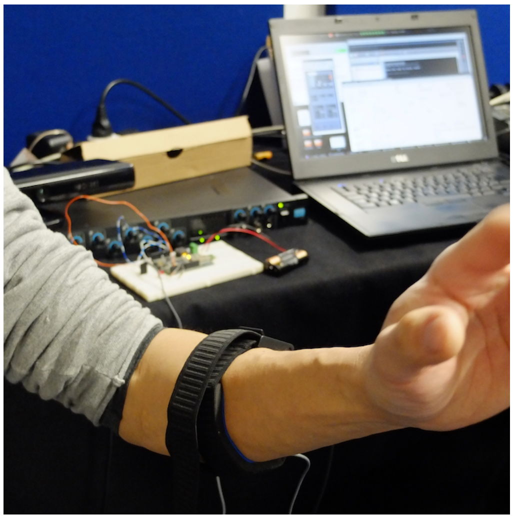

Figure 2: The EMG/MMG armbands.

3.2 Gesture-sound mapping

In order to let non-expert players train with our musical interface, we designed 3 mappings that linked a vocabulary of physical gesture with the production of sound. The gesture vocabulary is described in Table 1. The mapping allowed the production of two different and independent sounds with one gesture. We conceived the mapping by extracting from the medical literature information on the biosignals produced by a varied range of physical gestures.

The EMG was translate into sound and processed into a high pitch musical sound; the MMG was processed into a low pitch one. This aimed to facilitate users in distinguishing the two sounds. The raw EMG data was first normalised, and then converted into audio rate signal. The resulting sound was a cluster of high-pitched, sparse sound grains. In order to give the EMG sound identifiable timbre characteristics, it was further processed. The processing chain included a single side band pitch shifter to lower the frequency, a fuzz distortion to produce a more homogeneous signal, a resonant filter to outline the midrange spectrum partials, and reverberation to widen the stereo field. A similar processing chain using different parameters was used to process the raw MMG sound. The pitch-shifter was used to increase the MMG frequency and thus make it more easily audible through headphones, the fuzz distortion to add textural grains, the resonant filter to make more evident the higher partials (35 Hz and 40 Hz), and the reverberation to simulate a dry room environment.

Gesture 1 exploited the different *activation* mechanisms of EMG and MMG during sustained isometric (i.e. static) contraction [8]. During isometric contractions the EMG is continuously activated, whereas the MMG is a discrete event triggered at the contraction onset and outset. In the sound mapping associated with Gesture 1, the participant could produce a sustained high-pitch sound by clenching continuously the fist, and trigger low frequency reverberated pulses by flicking the clenched fist upward and downward.

Gesture 2 was based on the *localisation* of EMG sensors [1], and the *propagation* feature of MMG [13]. By executing a gentle forearm rotation, the amplitude of the EMG activated at the anterior forearm muscle is too low to be detected by the sensor at the back of the arm (*relaxation*). To produce a higher EMG amplitude and detect the signal, rotation speed and force need to be increased. The MMG meanwhile propagates from the anterior contracting muscle through the surrounding tissues, and is detected by the sensor even when the muscle is contracted gently. The mapping programmed for this gesture enabled the participant to produce low frequency sounds by delicately rotating the forearm, and add high-pitched sounds by increasing speed

[1] http://res.marcodonnarumma.com/projects/xth-sense/
[2] http://infusionsystems.com/catalog/product_info.php/products_id/199
[3] http://www.musicsensorsemotion.com/2010/03/08/sarcduino/

Gesture 1	EMG	MMG
extend arm outward		
strongly clench fist for constant tension	X	
move clenched fist upward/downward		X
Gesture 2		
place elbow on a desk		
slowly rotate horizontally forearm		X
repeat rotation increasing speed	X	
repeat rotation increasing force	X	X
Gesture 3		
lift elbow at shoulder level		
slightly contract wrist upward/downward	+	X
slowly move elbow upward/downward	-	X
repeatedly contract fingertips	X	X

Table 1: The training gesture vocabulary.

and force of the rotary contraction.

Gesture 3 exploited the lack of EMG activity during forward arm *acceleration* [7] and the MMG *propagation* feature. By lifting the elbow to shoulder level and executing a gentle acceleration on two axis (forward/backward, upward/downward) without tensing the hand, only the MMG is activated in the deltoid and biceps. From there, it propagates to the sensor location, where it is detected. At this stage, there is no EMG activation. Iterated finger grasping causes tension in the forearm, and EMG activity is triggered. The participants could use this gesture to produce a continuous low frequency sound by waving the elevated arm, and high-pitched crackles by repeatedly grasping with their fingers. Audio samples produced by the participants for each mapping have been provided for reference[4].

4. EVALUATION

We invited 5 volunteer novices (4 male, 1 female) to take part in a short, individual training session with the instrument. The sound of the EMG and MMG were diffused through headphones on two independent audio channels to facilitate the user understanding when they were controlling one modality independently of the other. The sound created by the EMG was diffused on the left channel, and the MMG sound on the right.

We verbally explained the interactive principle of the instrument by saying that two different sounds could be produced; explaining that one sound would appear on the left, and a second sound on the right. We purposely avoided mentioning the use of EMG and MMG and did not refer to two modalities, only referring to our sensor system as activated by the body.

Exploration First, the participants were allowed to explore the mapping using their own gestures for 1m30s without being given specific information on the gesture mapping. We set a three-step challenge for the participants: *a*) produce sound only from the left channel for 30 seconds; *b*) produce sound only from the right channel for 30 sec.; *c*) produce sound from both channels simultaneously for 30 sec. Timing was kept by the researcher, who signalled the end of the 30s period, so as to help the participants concentrate on the training. We refer to this phase as *exploration.* At the end of the exploration phase, we asked the participants four questions pointing to the type of gesture they performed and its outcome.

1. The type of gesture done to control the left sound
2. Its outcome
3. The type of gesture done to control the right sound
4. Its outcome

Practice Following the interview, we explained to them how to play with the mapping by using the intended designed gesture. We then asked them to perform the same 3 steps from Phase 1 with this knowledge, using the designed gesture for 1m30s . We refer to this phase as *practice.* At the end of the practice phase, we performed a second interview. We asked the participant 3 questions:

1. Difficulty of independently producing the two sounds
2. Difficulty of playing only the left channel sound (EMG)
3. Difficulty of playing only the right channel sound (MMG)
4. Enjoyment of performing these gestures

The protocol was repeated 3 times, once for each gesture-mapping pair. The goal was to understand whether this step-by-step training would help the participants to successfully play the instrument.

5. RESULTS AND DISCUSSION

In this section, we present the results of the training session, looking first at the exploration phase, and then at the practice. The results we report were extracted from the participants' interviews, and validated by analysing the related data from audio, video, and EMG/MMG recordings.

5.1 Exploration

Generally users were not able to independently control EMG or MMG signal with their own gestures. A relevant exception consisted of two participants who were able to produce an isolated MMG signals using Mapping 1. Their gestures were similar in that they executed gentle forearm horizontal movements without tensing their limbs. In this case, they unawarely exploited the propagation feature of MMG signal: by executing light forearm movement the MMG produced by the bicep propagated to the sensor location where it was captured. Given that there was no direct tension in the forearm, the EMG was not activated.

With Mapping 2 there was no user who was able to control the two signals independently. With Mapping 3 only one user was able to isolate the EMG signal for about 10 seconds. He produced strong tension in the muscle proximal to the sensor by opening the palm and contracting his fingers upward. This gesture did not produce MMG as it requires almost no force production by the posterior arm muscles (where the sensors were located), yet demands a strong and continuous tension of the whole arm, which results from continuous EMG firing.

5.2 Practice

Following the gesture instructions, most participants (4 out of 5) were able to produce isolated MMG signals with at least one of the three mappings. In Mapping 1, two users successfully produced an isolated MMG signal. In Mapping 2, in contrast with the exploration phase, two users were able to produce isolated MMG signals. In order to successfully isolate an MMG signal with this mapping one had to perform a very gentle rotation of the forearm, while keeping the elbow and the fingers in a static position; interestingly, during the exploration, most users (4 out of 5) were contracting their fingers without realising that this would trigger EMG and MMG simultaneously. In Mapping 3, only one participant could isolate the MMG. This mapping was based on the most complex gesture, for it required the separate control of two body parts (arm and shoulder). This

[4] http://bit.ly/11IHUDc

points to a specific skill level and "bodily awareness" (as one of the participant stated) that cannot be developed in the short time provided, but requires longer training. None of the participants managed to activate isolated EMG signals in any of the mappings.

5.3 Experienced use

Although not formally studied, it is worth mentioning that, while designing the system, two of the co-authors, one having long experience with EMG-based interface, and the other having an extended practice with MMG-based interface, managed to separate EMG with Mapping 1. This may suggest that although it is generally difficult to produce continuous arm tension without vibrating the muscles, there are factors, such as training and gesture-mapping design, that can facilitate the improvement of this skill. This indicates that the ability of controlling independently the EMG and the MMG signals is not a natural skill in non-expert players, but a skill acquired by training. Indeed, several participants remarked that they might have possibly been able to find strategies for successfully playing the sounds given more time to explore the interaction with the instrument.

5.4 Discussion

The results from the Practice phase indicate that a novice player can learn how to master independently two interrelated modalities and use therefore, a wider range of control variables than those provided by a single modality. This validates the musical adaptation we made of EMG/MMG differences noted in the biomedical literature. By refining the control over specific motor unit, a player could engage in musically compelling ways with a NIME instrument based on bi-modal muscle sensing.

Gestures based on neat contraction onset/outset (as in Mapping 1), and speed of supination/pronation gesture (as in Mapping 2) seem to be easier to understand by novice users and thus more quickly learned. More complex gestures that involve the control of multiple limbs at the same time (as in Mapping 3) proved difficult to perform for first-time users, and might be used only by players with a background in gestural performance.

It might also be interesting to design gestures and mappings that invoke and exploit the simultaneous activation of EMG and MMG. If with a single gesture a performer activates two separate sonic events, then the skill to mediate between the intensities of the two modalities could represent a valuable musical and physical challenge from the viewpoint of corporeal music performance.

Finally, it should be noted that EMG and MMG sensors are subject to noisiness in the respective signals. EMG sensing is affected by several issues, including capacitance build up between the dry electrode and the skin, as well as sensor location and analog signal amplification [6]. MMG sensing suffers in turn, of a too high sensitivity that might result in the capture of other bodily sounds, such as blood flow pulsations. The filtering of the raw EMG and MMG data is therefore often needed, and choosing a given balance between raw and filtered signal is a technical and musical choice [14].

6. CONCLUSIONS

EMG and MMG signals provide a rich bandwidth of information that congruently represents a physical gesture. This information can be used to design musically compelling gestures and sound producing mappings.

We created a bi-modal EMG/MMG music interface using biomedical information on the distinctions between the two signals. Experienced users and designers of the system, were able to distinguish the two modalities. We evaluated the system with novice users who initially were not able to distinguish them without instructions. After brief guided training, our users were successful in controlling the two modes of muscle sensing.

The further development of gesture-sound mappings could benefit of a quantitative analysis of gesture and audio data collected during trials. The mapping used for this training was purposely limited to facilitate distinguishing one modality with respect to the other. Future work towards a more complex musical experience could include deriving mappings from different EMG and MMG gesture representations through the use of machine learning methods.

7. REFERENCES

[1] S. Day. Important factors in surface EMG measurement. *Bortec Biomedical Ltd publishers*, pages 1–17, 2002.

[2] M. Donnarumma. Music for Flesh II: informing interactive music performance with the viscerality of the body system. In *Proceedings of the NIME Conference*, Ann Arbor, MI, USA, 2012.

[3] M. Donnarumma, B. Caramiaux, and A. Tanaka. Body and Space : Combining Modalities for Musical Expression. In *Work in Progress for the TEI Conference*, Barcelona, Spain, 2013.

[4] B. Gerdle, S. Karlsson, S. Day, and M. Djupsjöbacka. Acquisition, Processing and Analysis of the Surface Electromyogram. In U. Windhorst and H. k. Johansson, *Modern Techniques in Neuroscience Research*, pages 705–755. Springer Berlin Heidelberg, 1999.

[5] K. D. Gordon, R. D. Pardo, J. a. Johnson, G. J. W. King, and T. a. Miller. Electromyographic activity and strength during maximum isometric pronation and supination efforts in healthy adults. *Official publication of the Orthopaedic Research Society*, 22(1):208–13, Jan. 2004.

[6] H. J. Hermens, B. Freriks, C. Disselhorst-Klug, and G. Rau. Development of recommendations for SEMG sensors and sensor placement procedures. *Official journal of the International Society of Electrophysiological Kinesiology*, 10(5):361–74, Oct. 2000.

[7] F. W. Jobe, J. E. Tibone, J. Perry, and D. Moynes. An EMG analysis of the shoulder in throwing and pitching. A preliminary report. *The American journal of sports medicine*, 11(1):3–5, 1983.

[8] P. Madeleine, P. Bajaj, K. Sø gaard, and L. Arendt-Nielsen. Mechanomyography and electromyography force relationships during concentric, isometric and eccentric contractions. *Official journal of the International Society of Electrophysiological Kinesiology*, 11(2):113–21, Apr. 2001.

[9] Y. Nagashima. Bio-sensing systems and bio-feedback systems for interactive media arts. In *Proceedings of the NIME Conference*, pages 48–53, Montreal, Canada, 2003.

[10] M. Ortiz. A Brief History of Biosignal-Driven Art From biofeedback to biophysical performance. *eContact! Biotechnological Performance Practice / Pratiques de performance biotechnologique*, 2012.

[11] G. Oster and J. S. Jaffe. Low Frequency Sounds from Sustained Contraction of Human Skeletal Muscle. *Biophysical Journal*, 30(1):119–127, 1980.

[12] B. L. Riemann and S. M. Lephart. The Sensorimotor System , Part I : The Stability. *J Athl Train.*, 37(1):71–79, 2002.

[13] J. Silva, W. Heim, and T. Chau. MMG-based classification of muscle activity for prosthesis control. *Annual International Conference of the IEEE Engineering in Medicine and Biology Society.*, 2:968–71, Jan. 2004.

[14] A. Tanaka. Musical technical issues in using interactive instrument technology with application to the BioMuse. In *Proceedings of the ICMC Conference*, pages 124–126, Tokyo, Japan, 1993.

[15] A. Tanaka and B. Knapp. Multimodal Interaction in Music Using the Electromyogram and Relative Position Sensing. In *Proceedings of the NIME Conference*, pages 171–176, Dublin, Ireland, 2002.