# *ShEMP*: A Mobile Framework for Shared Emotion, Music, and Physiology

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## ABSTRACT

As we continue to strive toward a deeper understanding of human social interaction, the playing field continues to change beneath our feet. Ever swiftly, in even the last decade, the means by which we interact, the frequency in which we do so, even the meaning of interaction within daily life continues to evolve as humans become connected in novel ways—one need only consider the "Twittersphere" or how text messages have come to largely replace paper letters or even email communication. Since 2010, partners in the Social Interaction and Entrainment using Music Performance Experimentation have been investigating the concepts of emotional contagion, leadership, entrainment, and co-creation, and how they support social interaction through a series of studies of music performance and listening. This paper introduces ShEMP, a mobile software framework for Shared Emotion, Music, and Physiology. ShEMP provides a new set of tools for use in the design and execution of experiments that take this investigation of human emotion and interaction further afield into shared music experiences that occur between groups connected via their mobile devices. Here, we provide an overview of the software framework and a description of a series of experiments that have motivated the development of ShEMP.

## Categories and Subject Descriptors

H.5.3 [**Information Interfaces and Presentation**]: Group and Organization Interfaces—*Collaborative computing, Organizational design, Synchronous interaction*; H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*Input devices and strategies*; H.5.1 [**Information Interfaces and Presentation**]: Multimedia Information Systems—*Audio input/output*; H.5.5 [**Information Interfaces and Presentation**]: Sound and Music Computing; C.2.4 [**Computer-Communication Networks**]: Distributed Systems—*Client/server*; J.5 [**Arts and Humanities**]: [Performing arts]

## General Terms

Algorithms, Design, Experimentation, Measurement

## Keywords

Collaborative music, group emotion, mobile computing, physiological interfaces



## 1. INTRODUCTION

How can we measure the quality of a creative experience? In what ways do the emotions of participants affect or are affected by creative collaboration? Is the perception of a musical performance altered depending on whether it is experienced individually or as a member of a group? These are among the questions under consideration by partners, including the authors, in the Social Interaction and Entrainment using Musical Performance Experimentation (SIEMPRE)[1] project. Here we introduce ShEMP—a software framework through which we can explore these questions in greater depth. ShEMP, a mobile software framework for Shared Emotion, Music, and Physiology, in conjunction with MobileMuse, an unobtrusive sensor package for mobile physiological signal acquisition, leverages the distributed yet locative properties of mobile devices to allow the design of ecological experiments outside of the laboratory to investigate collaborative creativity and shared experience of musical performances. This paper provides a brief

[1] http://www.infomus.org/siempre/

introduction to several notable advances made in recent and current SIEMPRE experiments that have been particularly motivating to the development of ShEMP. This is followed by an overview of the design of ShEMP and a discussion of the suite of technologies it employs. We then elaborate on an initial battery of experiments to be executed presently, which motivated the development of ShEMP.

## 2. BACKGROUND

For the last two years, the SIEMPRE project has focused on measuring interpersonal creative interaction on the backdrop of music performance. The experiments designed and executed thus far have focused on this interaction in musical performance and experience in the following three interconnected scenarios [15]:

- Performer/performer interactions
- Conductor/performer interactions
- Performer/audience interactions

Recently a fourth scenario, distributed/mobile music interaction, has been added to SIEMPRE. A new set of experiments will be used to explore this new scenario precipitating the need for ShEMP.

Within these scenarios, our attention is drawn to four foci: *entrainment*, *emotional contagion*, *co-creation*, and *leadership*. The first of these, entrainment, is described by Clayton, Sager, and Will [4] as “a process whereby two rhythmic processes interact with each other in such a way that they adjust towards and eventually ‘lock in’ to a common phase and/or periodicity.” This takes shape on multiple levels and in various situations: from a listener’s foot tapping in tempo with music or their respiration and heart rates coming into synchronization (albeit often much more slowly) with the beat of the music, to the entrainment of the internal physiological processes of two or more organisms within a group. Indeed, as Clayton, Sager, and Will note, humans’ internal rhythmic processes can and do entrain to both other internal rhythms as well as to those of other humans through music performance and shared experience of music. This potential for entrainment through social interaction by way of music is of particular interest to SIEMPRE.

Closely linked to entrainment is emotional contagion. In their seminal work on the subject, Hatfield, Cacioppo, and Rapson [7] describe the phenomenon of emotional contagion as one in which a particular emotional episode in one individual can evoke stimuli that act upon other individuals to bring about similar or complementary emotional responses. While the related phenomenon, empathy, requires cognitive and autonomic facility, Hatfield et al. argue that emotional contagion is an automatic and involuntary process. Converse to empathy, they further define contagion as a process in which humans automatically mimic and synchronize the behaviors of another, and as a result, converge emotionally [6], [8]. Emotional contagion not only strengthens emotional bonds between people, however; the presence and awareness of emotional contagion in interpersonal interaction affects meaning and significance in communication, aids in understanding social interaction, and facilitates empathy and sympathy, for instance. It is this significance that places emotional contagion as the second focus of SIEMPRE’s research into interpersonal interaction.

Several studies under the SIEMPRE umbrella are concerned with musical co-creation. This is not necessarily completely bound up in musical performance by expert musicians, but includes the idea that audience and performer alike work together to shape a performance. On the one hand, the performance process is informed not only by the training and preparation of the musician, for instance, but also by their awareness of and response to input, active or otherwise, from the audience. On the other hand, co-creation also occurs where novice musicians work together to create music for only themselves to experience. In either case, and in all those in between, co-creation serves to bind the group socially and serves as another means for social interaction.

The final focus within interaction that concerns SIEMPRE is leadership. Here again, a common paradigm in musical performance parallels that of everyday human interaction. By manipulating the leadership role, we can examine not only how changes to leadership affect group interaction in general, but also the specific implications these changes may have on such already discussed phenomena as synchronization and entrainment, and the emotional understanding of the audience and performers.

## 3. RECENT WORK AND MOTIVATIONS

With this as the focus, SIEMPRE partners have designed and executed a wide array of experiments both within and without the SIEMPRE umbrella.

### 3.1 Center for Computer Research in Music and Acoustics

A number of research efforts have utilized mobile technologies to examine the role of performers, listeners, and conductors. Wang’s Ocarina broadcasts individual performances of a touchscreen flute-like instrument to a global community of listeners [17]. Here, listener engagement is assessed with three options, “heart” (like), “skip” (dislike), or no response. The locations of the performer and listeners who have “hearted” a given performance are visualized on a rendering of the earth, lending a further degree of interaction among listeners. World Stage [18] provides a different perspective of listener/performer engagement and a greater degree of intimacy by dynamically matching a musical performer with three “judges”. Using a set of predefined emoticons and, optionally, textual feedback, judges assess a performance in real-time. Both the performer and the judges see these responses simultaneously, allowing not only a hermetic appraisal of the music being heard, but potentially also a collaborative, dialectical assessment. Oh’s *Heart* combines musical-emotional data collection/visualization, and musical performance [13]. During a performance of a specifically tailored computer music work, listeners with smartphones self-report their level of excitement, valence in terms of negative/positive, and heart rate (by tapping the screen in synchrony with their observed heart rate) via a smartphone-accessible website. This data is aggregated and displayed for the whole audience to view as the musical work progresses.

### 3.2 Emotion in Motion

Emotion in Motion is an ongoing research project, investigating people’s affective response to musical stimuli in non-laboratory environments. The aim of this study is to explore the relationship between the musical content and changes in the emotional response of the listener (audience), via physiological measurements and self-report questionnaires.

The data capture terminal was designed as an installation that can operate in a public gallery or science centre (Figure 1), where participants can take part in the experiment without external assistance by following on-screen instructions. Even though there have been several iterations and changes to the experimental design, the experiment consists essentially of the participant answering a small number of background and demographic questions (e.g. age, gender, musical expertise, etc.), and then listening to an approximately 90-second long musical excerpt selected randomly from a pool of songs of diverse styles, eras, and emotional intent. While the music is playing, two physiological measurements are recorded simultaneously: electrodermal activity (EDA) and heart rate (HR). EDA and HR were chosen for their acknowledged use as physiological indicators of emotion (PIE) in the psychophysiology literature [14], [3], [8], and [1], as well as for their arguably unobtrusive measurement (both can be captured with sensors worn on one hand). After the excerpt completes, participants are asked to answer a brief self-report questionnaire, indicating how the music made them feel, and their level of engagement and enjoyment, among other questions. This process is repeated for three different excerpts. For a detailed description of the experimental design, please refer to [9].

**Figure 1: Participants at the Eyebeam Gallery in New York City, June 2011.**

The first iteration of the experiment started in the Science Gallery, Dublin, where it ran for a period of three months in the summer of 2010, was later installed in public galleries in New York City and Genoa, and is currently running in Bergen and Singapore. At the time of writing (July 2012), over 6,000 people have participated in the experiment, having more than 18,000 recordings of physiological data associated with a musical excerpt.

Even though the greater part of the work conducted to this point has been focused on improving the data acquisition and feature extraction of signals, preliminary results show significant correlations between physiological features and the self-report questionnaire [9]. A detailed discussion of the experiment's results is beyond the scope of this paper (please see Figure 2 for an example of one such correlation.) Nonetheless, while analyzing the Emotion in Motion database, several mitigating factors were found to influence changes in physiology. We believe that these factors need to be taken into account when designing interfaces that use physiological changes as measures of emotion.

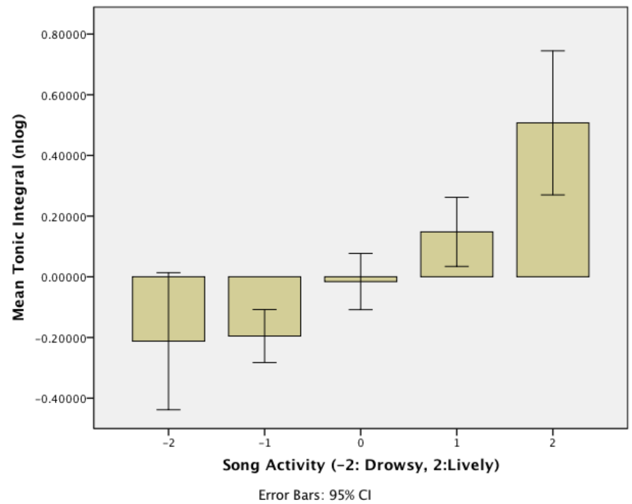


**Figure 2: Example of correlation found between a single feature from the physiology (tonic EDA time integral) and the self-reported answers to the activity question ($r = .190, p < .001, N = 1315$).**

Mitigating factors are mainly associated with the demographic information of the user, as well as physiological characteristics. As expected [10], age and gender have a negative relationship with heart rate variability (HRV) and HR. The electrodermal level (EDL), or the value of the tonic signal before the experiment, also has a negative relationship with the changes in both tonic and phasic signals. Even though this has been addressed in the literature, determining the exact nature of this relationship and any necessary baseline corrections remains problematic [1]. Figure 3 shows a plot of phasic changes of the electrodermal activity versus EDL. A negative relationship between both variables is evident, as well as a reduction in the range of the phasic changes with higher EDL values. The latter can be explained if we consider that the ceiling for skin conductance responses (SCRs), which have a positive onset, lowers with higher EDL values.

Gender has also shown a significant correlation with features related to changes in EDA, as well as age, in a smaller degree. We are currently working on developing a methodology to standardize these mitigating factors, in order to improve the analysis of the physiological response a person has to musical stimuli. The example shown in Figure 2 has been calculated using the residuals of a linear regression using age, gender, and EDL values as factors.

## 3.3 Motivation

Several studies, particularly those with a focus on audience experience of music—be it a live performance, a video recording of a live performance, an audio-only studio recording, or otherwise–note the importance of observing subjects in as ecological a manner as possible (see [9], for example). Furthermore, it is at least presumable that a good deal, if not the majority, of an individual's time spent experiencing music is when they are either alone, or among a small group of people–not in either a concert hall or laboratory. Issues of

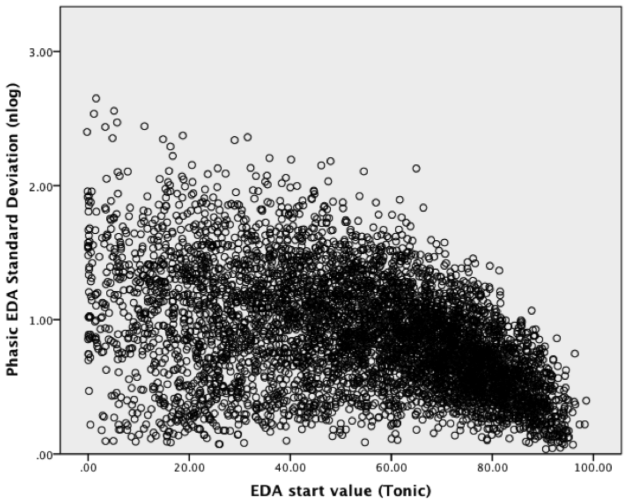


**Figure 3: Scatter plot of Phasic standard deviation versus EDL or tonic start value (measured in reference to the range of the sensor), for 1,744 cases.**

ecological validity aside, it is equally important and interesting to consider implications on the aforementioned research foci when audiences (of one or more) experience music individually.

In 2012, SIEMPRE established an International Cooperation project (SIEMPRE-INCO) to explore these areas in further detail. Specifically, the SIEMPRE-INCO project addresses empathic processes within the aforementioned four areas of interaction, but in the new SIEMPRE scenario of distributed/mobile music. It aims at understanding how emotional contagion and co-creation can and do occur when the individuals or audiences who are participating do not share the same physical environment. How is the experience shaped when two people share a listening experience from two different locations?

To explore these questions, tools are needed for the acquisition of data in mobile environments. As one of our primary scenarios of focus is audience interaction and participation in distributed environments, the existing hardware and software for physiological data acquisition that we have used in other studies is not suitable. A solution that leverages the ubiquity of iOS mobile devices fills our immediate need, and enables further research by ourselves and others on this widely available platform.

# 4. SHEMP DESIGN AND IMPLEMENTATION

Thus, to explore the questions of SIEMPRE-INCO, we have built ShEMP, a software framework upon which we can construct a range of experimental apparatuses. A great deal of the partners' previous work has served to determine the efficacy of a range of measures of audience (interactor) response mechanisms, including self-report questionnaires, input based around the GEMS scale, and dynamic judgement. ShEMP's flexibility allows us to collect voluntary feedback using any or a combination of these models with ease. Coupled with this, the MobileMuse sensor provides ShEMP participant physiological data—pulse oximetry, electrodermal activity, motion, and skin temperature. This section discusses the software and hardware design and implementation of ShEMP.

## 4.1 Software

For ShEMP's mobile software foundation, we heavily leverage the Mobile Music Toolkit (MoMu, [2]). MoMu provides a number of facilities for rapid creation of multimedia mobile applications, integrating touch, real-time audio synthesis and analysis, real-time graphics, and geospatial sensing in a single framework. Using MoMu we can quickly develop mobile applications suitable for the variety of research scenarios we envision with ShEMP.

MoMu offers relatively basic network support, requiring us to develop original software for our network model. As in previous mobile research, we intend to develop both real-time and non-real-time networked musical interactions; these require distinct technical approaches. Furthermore, the nature of research software demands a certain level of flexibility; as such, we anticipate the need to periodically reassess what interactions should or should not occur in real-time. Non-real-time network applications can be easily developed using REST (Representational State Transfer, [5]) or REST-like services over HTTP, using common web framework software. Real-time network interactions are somewhat more difficult to orchestrate, usually requiring custom implementation of ad-hoc network protocols and a server-side management of per-interaction state. We have begun work prototyping both types of interactions using Node.js, a web framework designed both for custom server implementations (ideal for real-time situations) and generalized HTTP/REST web services (for non-real-time situations). From preliminary assessments we find that Node.js adequately addresses both scenarios without pinning the application specifically to one or the other.

### *4.1.1 Digital Signal Processing*

In order to allow the hardware to interface with a variety of devices, signal is passed over a standard 1/8" (3.5mm) TRRS audio plug, as the 1/8" TRRS audio jack has become all but the standard on consumer mobile devices. However, as standard wiring uses only the sleeve of the TRRS plug for input, it was necessary to devise a way to receive multiple input signals over a single channel. On the mobile device (currently, iOS[2] devices are supported), the signal is received as an audio input stream. Within Apple's AudioUnit framework, the signal passes through a DSP chain in order to split the multiplexed signal back into its original constituent signals.

To achieve this, a standard frequency division multiplexing process is used. The signal is first lowpass-filtered ($Fc =$ 7.5kHz) in order to remove noise introduced by pulse-width modulation from the sensor hardware. The signal is then multiplied sample-by-sample with sine waves at the frequencies of the component carrier waves established in frequency-division multiplexing in the sensor circuit. In order to address frequency and phase jitter introduced by pulse-width modulation and timer imprecision in the sensor micro-controller unit, a phase-lock loop is established between the filtered incoming signal and software oscillators controlled by the demodulation routine. These multiplications produce sine waves with a positive DC offset at double the frequency of the initial carrier waves for each component signal. These

[2]http://www.apple.com/ios/

signals are then further lowpass-filtered ($Fc = 25$Hz) to remove said sine waves and leave only the slowly varying DC offset as the final demodulated output for each signal. These demodulated outputs are then exposed to other components of the framework for recording, streaming to an external server, sharing with other devices, or visualization within the user interface.

### 4.2 Hardware

It was decided that the entire sensor system must fit on a single finger. In order to accomplish this, heart rate is measured using standard pulse oximetry techniques rather than a full electrocardiogram. The MobileMuse board (Figure 4) [11] houses four discrete sensors. Upon further consideration, and because of the ease of design, a temperature sensor was also added to the interface. Skin temperature change (in relationship to the environment) has been shown to be indicative of long term mood, and it is thought that this might prove beneficial in assessment of emotional state [12]. A triaxial accelerometer was also added to the circuit for gestural control. While this might seem redundant, independent hand gesture introduces interesting options not presently available with a mobile device's onboard accelerometer or gyroscope. At a minimum this enables two-handed gestural control. Furthermore, an independent accelerometer provides a means of minimizing motion artifacts, an issue to which EDA sensors are particularly susceptible.

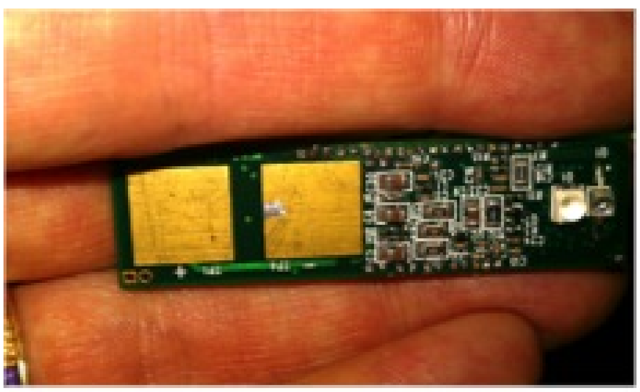

**Figure 4: The MobileMuse sensor board.**

All of the sensor signals are amplified, processed, conditioned and then fed into the ADCs of an ATmega328-PU processor. This choice of processor enables use of the MobileMuse as a custom Arduino[3] board with all of the advantages this creates—most importantly, ubiquitous software availability. The ATmega processor firmware frequency-division multiplexes the sensor signals in order to create one single audio data stream for ease of transmission through the TRRS plug. The signal is then reconverted to an analog stream using the pulse-width modulation (PWM) output of the processor fed through an onboard DAC. Finally, magnetic isolation is used to remove any shock risks and to eliminate line noise.

Initial development of the MobileMuse boards is now complete. The software framework will be complete for use in a first experiment in November 2012. At the completion of the SIEMPRE project, ShEMP will be distributed for public use.

[3]http://www.arduino.cc/

## 5. PROPOSED SERIES OF EXPERIMENTS

Taking the progress made in the Emotion in Motion experiments [9] as a starting point, we propose an initial experiment to explore group emotion, emotional contagion, and co-creation in a distributed mobile environment. In particular, this experiment aims to answer the following questions:

- How does the psychophysiology of a listener as a part of a group differ from when they listen alone?
- What visualizations of distributed collaboration are most conducive to emotional contagion?
- Does a listener's awareness that a listener or creative interaction is a distributed collaborative experience alter their *Quality of Experience* [15], [16] or emotional response?
- Does a participant's awareness of their remote collaborator's emotional state(s) affect the quality of experience of collaborative music making?

To this end, we propose a sequence of iterative experiments that leverage ShEMP. In the first experiment, each participant will be equipped with a mobile phone and MobileMuse sensor. Background (including musical) and demographic information will be gathered from each participant. When a case commences, the participant will be paired with a participant in a geographically separate location. The two participants will be streamed selections of music drawn from the pool of songs with validated emotional content from the Emotion in Motion experiment. Following each song selection, participants will be guided through a self-response questionnaire regarding their emotional response and quality of experience. The design of this questionnaire will be tuned based on recent results from Emotion in Motion and other SIEMPRE work cited herein. Throughout the process, physiological data from each participant will be captured through the attached MobileMuse.

Our initial hypothesis is that a listener's simple awareness that a listening experience is collaborative will affect their emotional response. Assuming that this hypothesis holds, the sequence of experiments will continue to explore ways to improve the collaborators' quality of experience and to make such an interaction further conducive to emotional contagion. This will be explored in successive experiments in the following ways:

- Presentation of collaborator's physiological data streams to the listener in real time
- Presentation of various visualizations of collaborator's emotional response through *shadow media* [20], [19]
- Enablement of interaction with a group of collaborators selected by the participant based on demographic, location, musical selection, etc.

If our initial hypothesis does not hold, we intend to approach the successive experiments with the aim of reshaping our initial hypothesis—seeking ways in which a shared musical experience across remote locations can indeed affect their emotional response, enhancing emotional contagion and improving quality of experience.

# 6. DISCUSSION

Over the past decade, face-to-face human interaction has continued to diminish in favor of ever larger mobile distributed environments. How this will effect the very nature of how we cooperate and create, so called "co-creation", is just now being explored. If empathy, emotion, and affect are critical components of co-creation, then these must somehow be incorporated into mobile environmental communication. Music listening and group performance give us an ideal means for exploring how this might be achieved. In addition, the continued expansion of our social networks places ShEMP and these proposed experiments in an especially exciting position. For one, existing work has noted the need for large-scale data sets for worthwhile analysis of data around human emotion. Secondly, this access to a worldwide population in experimentation allows us to begin to analyze emotional data not just in local interactions, but also on a global scale. This paper has described a new software framework to support mobile music experimentation in just these ways—one that might expand our understanding of co-creation in this ever-prevalent scenario. A novel set of experiments has been introduced as the first steps toward this understanding.

# 7. ACKNOWLEDGMENTS

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