

# Musical Performance Applications of Affective Computing

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## **ABSTRACT**

In this paper, we present several realizations of the Affective Computing philosophy and method in the area of musical performance. We begin with a review of early and important research on music and musicians, describing several projects that have mapped human physiological and affective signals to musical results. We also describe the use of Affective Computing principles in the design of systems for training student musicians, such as the Digital Conducting Laboratory developed by Immersion Music for Arizona State University. We conclude with some thoughts about latest developments in this new and exciting area of work.

## **Keywords**

Affective computing, interactive music, classical music, live performance, computer music, biofeedback.

## **INTRODUCTION**

Affective Computing, a growing area of research established by Rosalind Picard of the MIT Media Laboratory, is computing that “relates to, arises from, or deliberately influences emotions.” [9, 10] Affective Computing has developed a substantial body of research results demonstrating the value of computer-based systems that understand and respond to human internal states. Some of the sensory data streams that have been collected from human users during the course of Affective Computing studies include physiological responses (such as muscle tension, heart rate, galvanic skin response, body temperature) and physical movement cues (gesture, facial expression, pressure).

Musical expression is an area of human behavior that is in many ways mysterious. For example, it is not clear why we enjoy and perform music, and it is not clear why music

evolved as a human behavior. It has been often theorized that music is the one human activity whose primary role is to express and influence human emotion. However, very few quantitative studies have been performed to definitively prove any links between music and emotion. Because so little is known, there are many interesting lines of research that might be conducted by applying Affective Computing methods to questions about music and its abilities to express human emotion.

## **PREVIOUS WORK IN AFFECT AND MUSIC**

The following section provides some background on the work that has been done to explain the relationships between affect and music. Leonard Bernstein, the American conductor, theorized about music based on his extensive performance experience. Manfred Clynes, trained in both neuroscience and music, provided new quantitative research methods and insights. Gerhart Harrer, a psychologist, undertook an unprecedented series of physiological experiments on the German conductor, Herbert von Karajan. Finally, Chris Janney’s “HeartBeat” reflects a growing body of artistic work involving the use of real-time physiological monitoring on-stage.

### **Leonard Bernstein**

The linguistic theorist Noam Chomsky identified a universal, genetically endowed capacity for language among humans; he called this the ‘Innate Expressive Function.’ In his televised Norton Lecture series at Harvard University, Leonard Bernstein borrowed from Chomsky’s ideas and applied them to music, claiming that there is an innate code buried in musical structures that we are biologically endowed to understand. Bernstein thought that the main difference between language and music is that music amplifies the emotions more effectively, thereby making it more universal. “Music is heightened speech,” he said. “In the sense that music may express those affective goings-on, then it must indeed be a universal language.”[11]

### **Manfred Clynes**

Manfred Clynes, a concert pianist and neurophysiologist, found a way to describe musical communication by making

connections between neurophysics, gesture and emotion. In 1977, he presented his theory of Senticity, "the study of genetically programmed dynamic forms of emotional expression." [1] During the 1950s, Clynes invented the term "cyborg" to refer to creatures who have augmented their biological systems with automatic feedback controls. Clynes also adapted cybernetic techniques to the study of physiological regulatory mechanisms, including heart rate, blood pressure, and body temperature. While doing this work he formulated several theories about sensory perception, including his idea about essential forms, precise dynamic forms that are characteristic of each emotion. One of Clynes' big breakthroughs was that emotions are not fixed states, but rather transitions (spatio-temporal curves) with particular trajectories. He related these forms to musical structure through a theory of inner pulse, which he felt was unique to each composer – a kind of personal signature encoded in the shapes of the pulses on many levels simultaneously. For Clynes, the inner experience of music is reflected when the electrical impulses in the brain are mechanically transduced, for example, by the expressive shape of finger pressure. Clynes developed this idea after reading about a German musicologist, Gustav Becking, who did a study showing that when "an experienced musician was asked to follow a musical composition by moving his forefinger in the air – as if to conduct the music – the finger 'drew' shapes that seemed to be consistent among different compositions by the same composer." [1]

During the past fifteen years Manfred Clynes has been working on an extension of the Senticity project more directly focused on music. His Superconductor software package allows users to delve into the deep interpretive issues of a musical score and modify elements such as pulse, predictive amplitude shape, vibrato, and crescendo. The idea is to give the understanding and joy of musical interpretation to people who otherwise would not have the opportunity or musical understanding to experience it.

#### Gerhart Harrer

During the early 1970s, Gerhart Harrer, a professor of Psychology at the University of Salzburg, did an extended, four-part study on the famous German conductor Herbert von Karajan. First he measured the EKG, breathing, and Galvanic Skin Response of Karajan and his student while listening to a recording of Beethoven's Leonore Overture. Certain features emerged in the signals of both Karajan and his student that could be traced to the structure of the music. Then he gave both subjects a tranquilizer and measured the same signals while the subjects listened to music. After the tranquilizer was given, the musically-affected features in the signals were greatly reduced. However, both Karajan and his student did not notice any difference in their experience of the music between their tranquilized and untranquilized states, which suggested to Harrer that their internal experience of the music diverged significantly from their physical experience. These signals are shown below:

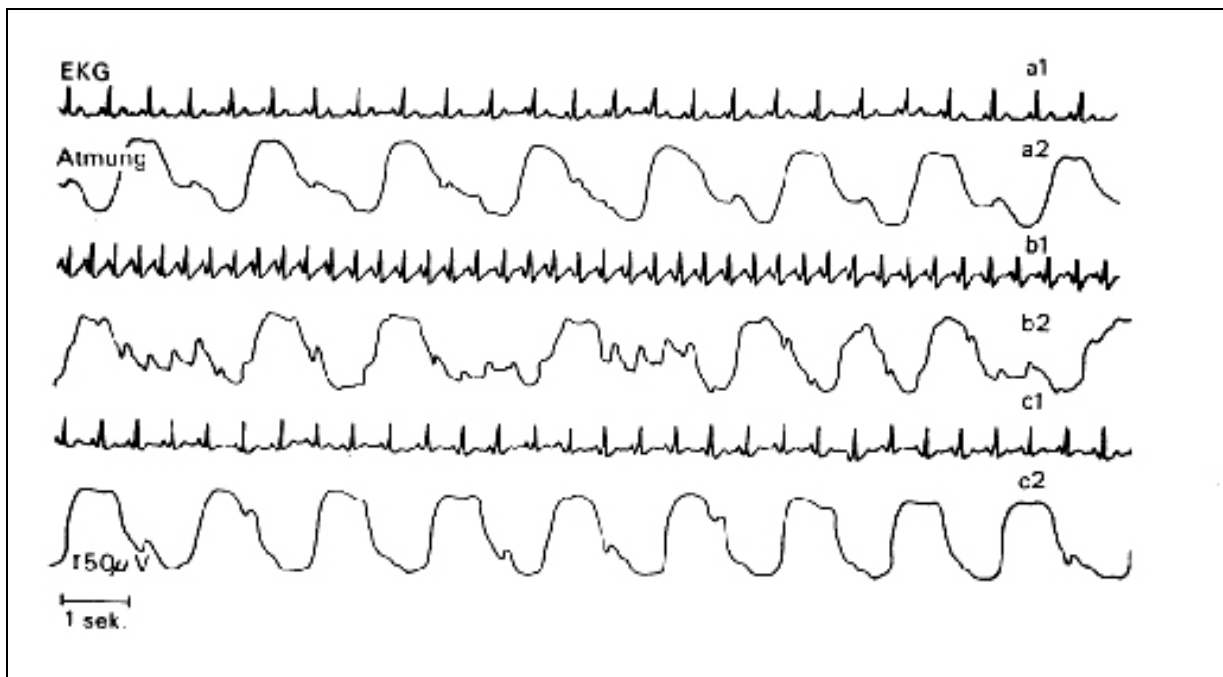


Figure 3. Breathing and EKG signals of Herbert von Karajan[2]

Lines a1 and a2 represent one subject's EKG and breathing signals at rest. Lines b1 and b2 show the same signals while the subject listened to music on headphones, demonstrating irregular features that Harrer attributes to the music. Lines c1 and c2 show the same signals while the subject listened to music, after he had been given tranquilizers.

In a second study, Harrer outfitted Karajan with EKG, pulse frequency, temperature, and breath sensors, which transmitted their data wirelessly to a computer. He measured Karajan's signals during a recording session of the same Beethoven overture with the Berlin Philharmonic for a television film. The strongest changes in those signals correlated with the moments in the music that Karajan said moved him emotionally the most. Thirdly, Harrer played a recording of the Beethoven overture for Karajan while he wore the same sensors. Qualitatively, the sensors yielded similar features at similar points in the music. However, quantitatively, the signal strengths on all the channels were weaker. Finally, Harrer put an EKG sensor on Karajan during two different activities: flying a plane and conducting the Berlin Philharmonic. While piloting, he performed a dangerous maneuver three times in succession; he approached as if to land, and then took off again. He

also accompanied the second one with a roll. Each time he did this, his pulse increased markedly. Also, he was subjected to a second pilot taking over the controls at unannounced times. However, despite all the stresses of flying under such unusual circumstances, his heart rate averaged about 95 beats per minute and never exceeded 115. However, when conducting the Beethoven Leonore overture with the Berlin Philharmonic, his heart rate averaged 115 beats per minute and peaked at 150. The range of variation while conducting is almost double that of the range while piloting. While Harrer acknowledged that the movements are greater for conducting than for piloting, he determined that a great deal of the difference could be attributable to the fact that his piloting heart beat was in reaction to stimuli, whereas in conducting he was specifically and premeditatedly expressing a signal.

The below figure shows the systolic activity in Karajan's EKG signal during both activities. The upper graph gives Karajan's heart rate while conducting, with measure numbers above to show its relation to the musical score. The lower graph shows his heart rate while piloting, with the three risky maneuvers clearly delineated in sharp peaks.

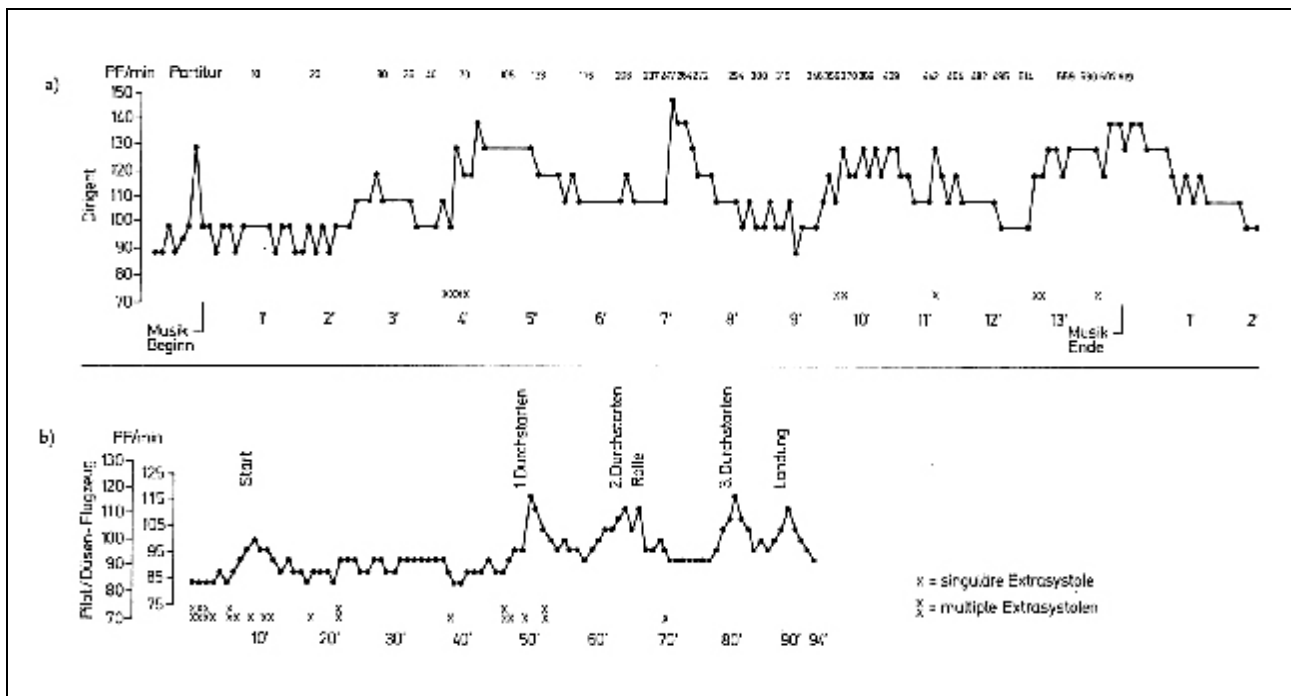


Figure 4. Herbert von Karajan's heart rate while conducting and flying a plane[2]

### Chris Janney

"HeartBeat" began as a collaborative project during the 1980s between Chris Janney, an Artist/Fellow at the MIT Center for Advanced Visual Studies, and dancer/choreographer Sara Rudner. The dance is a solo piece, with choreographic structure within which

improvisation is taken. The dancer wears a wireless device that amplifies and sonifies the natural electrical impulses that stimulate the heart to beat. This forms the basis of the musical score, which is then overlaid with sounds of medical text, jazz scat, and the adagio movement of Samuel Barber's String Quartet. The piece was recently revised for

Mikhail Baryshnikov, who premiered "HeartBeat:mb" in January 1998 at City Center in New York and later took it on a world tour. Janney said about the piece, "it's the easiest tied to the soul because it's the heart. It makes you think about your own heart, your own mortality." [3] This got a lot of attention and the prominence and skill of the artist always helps a lot! However, I have heard first-person accounts of the concerts that much of the excitement in the audience came from the fear that they had at his extremely elevated heartbeat; they were afraid for his health.

### **CONDUCTOR'S JACKET RESEARCH**

In 1997 I began working in the Affective Computing research group of the MIT Media Lab. Motivated by the success of other Affective Computing projects with similar sensors, I began to experiment with various ways to monitor the physiological states of musicians (specifically orchestra conductors) while they were practicing and performing. The key to this work was that the sensors needed to be functional under *real* conditions – that is, that the conductor subjects would have the incentive of a real rehearsal or performance with their regular ensembles and therefore be generating *real*, not simulated, emotion and expression.

The *Conductor's Jacket*, designed and implemented in 1997, was a unique wearable device that measured physiological and gestural signals from sixteen sensors sewn into the cloth of the garment worn by the subject. The system was designed in such a way as to not encumber or interfere with the gestures of a working orchestra conductor. The *Conductor's Jacket* was used to gather conducting data from six subjects, including three professional and three student conductors, during twelve hours of rehearsals and performances. Analyses of the resulting data yielded thirty-five significant features that reflected the intuitive and natural gestural tendencies of the subjects, including context-based hand switching, anticipatory 'flatlining' effects, and correlations between respiration and phrasing. Overall, we found that muscle tension and respiration signals reflected several significant and expressive characteristics of a conductor's gestures. From these results, we presented nine hypotheses about human musical expression and built a model that allowed any user to be able to 'conduct' music while wearing a *Conductor's Jacket*. Users were able to generate real-time expressive musical effects by shaping the beats, tempos, articulations, dynamics, and note lengths in a musical score. [5, 6, 7, 8]

### **"IMMERSION MUSIC" PROJECTS**

In the two years since doctoral research on the *Conductor's Jacket* was completed at MIT, I have continued to work with the device as an interface for artistic and educational projects through a non-profit organization called

Immersion Music ([www.immersionmusic.org](http://www.immersionmusic.org)). One of the applications that we built for the jacket was an educational training system for student conductors, called the Digital Conducting Laboratory. Undertaken at Arizona State University and created in collaboration with Professor Gary Hill, the lab's mission is to provide a system that allows novice students to conduct a virtual orchestra as a supplement to the training that they receive during their conducting classes.

The Digital Conducting Laboratory uses four EMG sensors that are secured to the students' biceps and forearms by special form-fitting sleeves. The sensors detect the muscle tension of the wearer, and feed that data to two PCs running specialized software. The students' arm movements control the way that the computer performs the pre-determined notes of the score, in much the same manner as a conductor directs a live orchestra. The idea is for the students to practice their gestures with aural feedback, to positively reinforce the content of the curriculum. [4]

### **FUTURE WORK**

There is much that remains to be done in this exciting new area of research. The powerful methods of the Affective Computing, when applied to the many unanswered questions in the field of music performance, has yielded a very fruitful area of inquiry and work for Immersion Music. Certainly there is room for many others to contribute to this area, and it would be my sincere hope to have many others join me and my colleagues in this very new field.

### **ACKNOWLEDGMENTS**

I wish to personally thank Dr. Rosalind Picard, my doctoral advisor, whose ground-breaking work in Affective Computing continues to influence and guide my own efforts today. I'd also like to thank Dr. Manfred Clynes, whose advice and support have been helpful and inspirational to me during the past six years.

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