The Space Between Us: A Live Performance with Musical Score Generated via Affective Correlates Measured in EEG of One Performer and an Audience Member

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ABSTRACT

The Space Between Us is a performance piece for vocals, piano and live electronics using a Brain-Computer Music Interface system currently in development. The brainwaves of one performer and one audience member are measured throughout the performance and the system generates a real-time score mapped to emotional features associated with the brain signals. The system not only aims to portray emotional states through music but also to direct and induce emotional states through the real-time generation of the score, highlighting the potential of direct neural-emotional manipulation by live performance. Two accepted emotional descriptors, valence and arousal, are measured via electroencephalogram (EEG) recordings and the two-dimensional correlates of averaged windows are then mapped to musical phrases. These pre-composed phrases contain associated emotional content based on the KTH Performance Rules System (Director Musices). The piece is in three movements, the first two are led by the emotions of each subject respectively, whilst the third movement interpolates the combined response of the performer and audience member. The system not only aims to reflect the individuals' emotional states but also attempts to induce a shared emotional experience by drawing the two responses together. This work highlights the potential available in effecting neural-emotional manipulation within live performance and demonstrates a new approach to real-time, affectively-driven composition.

Keywords

NIME, BCI, brain-computer music interfacing, live performance, real-time composition, affective states, emotions and music.

1. INTRODUCTION

The Space Between Us is an 18-minute long live performance for a singer and pianist, and with electronic sounds generated by a computer. During the performance both the singer and an audience member who is positioned in the front of the auditorium wear a brain cap. The caps are connected to the system and are fitted with electrodes that detect emotional readings in their brain signals. At regular intervals during the performance the system measures the emotions of the performer and audience member and uses these readings to select the next musical phrase. An electronic score is presented to the singer and pianist via computer screens and the system also controls a processed piano feedback system with microphones and speakers positioned inside the piano, as well as computer generated electronic sounds. The piece aims to explore and influence the emotional connection between both parties; performer and audience member.

Emotion has long been considered an intangible *condicio sine qua non* for human interactions with music, be it whilst listening, performing, or composing. Mood induction in a multimodal environment is not a straightforward task, with a wide range of influential factors to take into account. The affective influence of music when combined with visual stimuli (for example, as signifiers and cues for emotion in film), suggest that utilising multimodality can increase affective responses in the listener [3]. Furthermore, there is some evidence that the range of affective responses in existing EEG/BCI (Brain-Computer Interface) systems can be increased by utilising multimodal stimuli [17]. *The Space Between Us* uses the medium of live performance with emphasis on emotional communication and induction through music and text alongside stage production dramaturgy.

Using brainwave control outside of laboratory environments in performance settings has become more feasible in recent years, helped by low-cost EEG [1] headsets that can interface with consumer-grade computers. Brainwaves have been used for a range of musical applications including therapeutic uses [19], collaborative composition [11] and real-time performance [5].

In 1962 Joe Kamaya reported that it was possible to train subjects to perform voluntary control over alpha waves (8-13Hz) with 100% accuracy [13]. The most common method of control was relaxing and activating mental processes (which can be considered basic meditative emotional descriptors within EEG patterns). The subsequent piece *Music for Solo Performer* (1965) by Alvin Lucier pioneered this approach of alpha control [18]..

In 2013 Giraldo and Ramirez conducted experiments using an EEG based system for mapping valence and arousal (the emotional indicators within EEG) to synthesise parameters providing emotional feedback through music [9]. In the same year Kirke and Miranda report on a system that composes generative music in response to subjects' emotional levels that were recorded whilst listening to emotionally charged music [14]. The system for *The Space Between Us* uses affective response to arrange a composition in real-time, but aims to add an additional dimension; employing an adaptive feedback loop for affective induction to manipulate musical parameters. In turn, this creates a new compositional arrangement with every performance. By incorporating both the audience member's and the performer's emotional perspective the system also

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[1] The electroencephalogram (EEG) is the measurement of electrical activity in the brain by electrodes placed on the scalp.

provides a platform for observing and analysing embodied emotional relationships between the two

2. PASSIVE BRAINWAVE CONTROL

BCI control for music commonly falls under one of two categories, those with *active* or *passive* control. Active systems are designed for explicit user control of brainwaves mapped to musical parameters [10, 21]. Passive systems utilise implicit control of brainwaves where control is not governed by user decision-making [8]. Natural shifts of emotion are not generally achieved through explicit choice and the system is designed to feedback the changes in affective states to the participants through music. It is hoped this may help reflect the uncontrollable emotional interactions people encounter when engaged in active listening, re-enforcing these through live performance (Figure 1). However, as the system listens to the emotions of the users it adapts to the responses based on certain mapping rules. For example, we hypothesise that it is possible to produce music for enhancing a specific mood or to maintain a state, such as 'relaxed'. This could be extended to provide therapeutic benefits or to help design more complex emotional 'experiences' within performances and other real-time applications such as composing or collaborating.

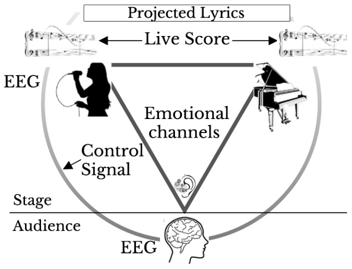

Figure 1. Conceptual diagram of the performance

3. Measuring emotion in EEG

Research is still in in the early stages of interpreting emotional language within EEG, and the information that can be detected is at best generalised descriptors of complex phenomena. Russell's model of affect [23] provides a way of parameterising emotional responses to musical stimuli in two dimensions: valence (positivity) and arousal (energy or activation). Other models of music and emotion have been used in the past but the 2-dimensional model was implemented in this work as it has been well documented in respect to music and to neurophysical measurement by means of EEG [9, 24]. There are a number of known methods reported to measure levels of valence (scale of attraction) and arousal (alertness) within EEG. Aftanas and Golocheikine have measured levels of theta and alpha bands across the scalp to successfully determine synchronicity in the brain. This symmetry across the hemispheres of the brain, observed during meditation, is associated with positive emotions and can be used to provide a scale for valence [1]. In 2001 Schmitt and Trainor proposed a means of categorising emotional responses to music in EEG through measuring levels of valence and arousal in the alpha band via electrodes places on the frontal lobe. Here the level of arousal correlates to the spectral power of the band [23]. Their experiments indicated that during active listening (attentive focusing or *feeling the music*) music with known emotional qualities can induce predictive EEG patterns. In 2010 Lin et al. [16] monitored levels across three bands, delta (1 - 3Hz), beta (4 – 7Hz), alpha and gamma (31 – 50Hz) to discern relative levels of emotion recorded in response to music listening between self-reported emotions from subjects.

To measure brainwaves unobtrusively in a live performance environment a minimal number of electrodes is appropriate. The system presented here adopts Ramirez and Vamvakuosis' approach of measuring valence and arousal across the alpha and beta bands at the AF3, AF4, A3 and A4 electrode positions [22]. EEG is sampled at a frequency of 256Hz and pre-processed using a notch filter to reduce mains power interference. To handle interference from blinking, muscle activity or movement related artifacts we adopt Tenke and Kaysers method of segmenting incoming EEG into epochs of 1 second (50% overlap; Hanning window) and rejecting those that are clipped above a threshold of +100 μv [25]. The raw EEG passes through butterworth bandpass filters to isolate the spectral power of each frequency band. Mean values of spectral power are normalised across the last 20 seconds of one and a half minute windows to gauge subjects' response to the previously selected window of music. This method is designed to account for the previously documented effect of diminishing arousal over time as subjects familiarise themselves with the stimulus set and the test environment [4]. This would also be present in any additional bio-sensors we may add to the system in the future to help improve measuring affective responses [7]. We are then able to extract values for the four quadrants of the 2-Dimensional arousal/valence model, broadly speaking; joy (positive valence and high arousal), anger (negative valence and high arousal), sadness (negative valence and low arousal) and relaxation (positive valence and low arousal) through the equations shown below.

$$\text{Arousal} = \frac{bF3+bF4}{aF3+aF4} \qquad \text{Valence} = \left(\frac{aF4}{bF4}\right) - \left(\frac{aF3}{bF3}\right)$$

The resulting emotional trajectory is plotted across 2 dimensions on Russell's [23] circumplex model of affect. The model is further bisected to create 12 regions of emotional intensity with associated values (*e-values)* used for mapping to the musical engine of the system (Figure 2).

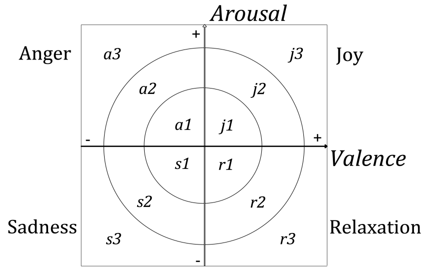

Figure 2. Russell's 2-d model of valence and arousal [19] combined with e-values (a1, j1 and so on) of emotional feature and intensity.

3.1 System design

In the past developing musical systems with brainwave control has been a costly endeavour. In the current climate of more affordable EEG headsets we are looking to design systems using more accessible platforms. Unfortunately with cheaper components comes a trade-off in signal quality; a major concern when measuring and interpreting brain wave signals in real-time, especially in noisy and unpredictable environments away from the laboratory. With this in mind *The Space Between Us* provides an interoperable platform for format agnostic BCI hardware. In a bid to incorporate open source platforms calibrated EEG Signals from other proprietary or open source hardware can be connected to the performance software, as long as the pre-processed data can be sent via the OSC protocol. The system has been designed and tested with g.tec Sahara electrodes and MOBIlab+ amplifiers.

There are two elements to the system for *The Space Between Us* (Figure 3). The first element (made up of grey boxes) handles the incoming raw EEG signal before passing the pre-processed signal to the second element (made up of the white boxes), a musical engine that extracts the emotional features used as a control signal to generate the musical score and live electronic control. The music is comprised of phrases of pre-composed notation for voice and piano, and adaptable live electronics including real-time control over a live piano feedback processing unit.

The EEG of one performer (the singer) and one audience member is sent wirelessly from the amplifiers to nearby laptop computers. A third laptop receives the pre-processed signal over a network connection. Once the emotional features are extracted a mapping algorithm selects the next musical phrase. This is sent to the electronic music processing algorithm and presented as a score on computer monitors to both the pianist and vocalist who are synchronised via a visual metronome.

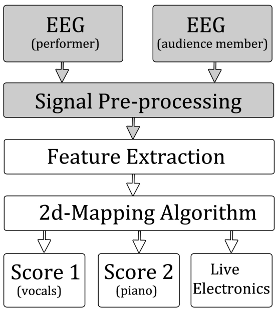

Figure 3. System overview.

4. EEG CLASSIFICATION

In order to obtain accurate measurements of valence and arousal classification of the incoming EEG is required. Popular methods used to determine a meaningful hyperplane to distinguish values of valence and arousal include SVM [17] and CSP [15], but both require an involved course of training unsuitable for live performance environments. Therefore the musical phrases need to be built such that they elicit the desired emotional responses, using classification, in both the performer and the audience member for the system to function as desired. Matching music to one individual's affective response is challenging – however, initial tests have indicated that profiles can be matched to achieve an approximately level playing field across a subset of listeners. This highlights a particular issue with a system of this kind, (creating music that can elicit similar affective responses across individuals) which should be the subject for further investigation.

As levels of valence and arousal differ for each individual our system adopts a simplified approach to determine basic calibration prior to performance. Previous studies have demonstrated that it is possible to measure affective responses to music in EEG [16, 24], and initial system tests have shown that the system is capable of reflecting states in subjects' response to previously heard music. There are a number of factors that make eliciting desired affective states on–the-fly extremely difficult to achieve. Initial tests have indicated that individuals can elicit unpredictable responses to music, especially across a high-resolution model. This is likely to be dependent on a range of factors including mood, taste, age, as well as social and cultural interpretations. Where standardised libraries such as the Affective Digitized Sounds database (IADS) of audio stimuli for emotion induction [2] exist to form a baseline against a range of subjects, it is clear that the calibration of a system should be relative to the stimuli itself to make sure that stimuli can elicit the desired states during performance.

We determine valence as a relative ratio of asymmetry in the frontal region for which no training is necessary, but which we calibrate against the pre-composed musical phrases. [6].

5. MAPPING EMOTIONS TO MUSIC

The piece is performed in three movements, the first two are led by the emotions of each subject in turn, and the third movement is based on the correlated response of both subjects.

The calculated 2-D coordinate values are converted to *e-values* based upon their location within the 2-D space. The *e-values* represent a scale of emotional feature and intensity. The performance is split into twelve 90 second windows and the calculated e-value of each window is used to determine the outcome of the musical mapping for the next window. The e-value is derived from the last 20 seconds of the window in order to capture the effect of the previous musical phrase. An added offset is used to present the beginning of the next phrase to the musicians before the current has ended, akin to reading a traditional musical score. Each window has an associated 12 element array of pre-composed musical scores for each part, and these are categorised by corresponding e-values. In total there are 48 possible musical variations for each element (voice, piano, electronics) over each movement (12 e-values x 4 windows). Movement 1 records the initial emotional state of the performer and attempts to direct their emotion towards the opposing e-value in the 2-d plane. The score for window 1 is selected at random and the resulting 2-d coordinate (x = v, y = a) recorded at the end of the window is saved as the initial state. A target coordinate is determined from:

$$\begin{gathered}(1 - v(init)),\\ (1 - a(init))\end{gathered}$$

which reflects the opposite emotion within the plane. Multiplying the target co-ordinate by 0.33, 0.63 and 1 respectively sets a trajectory across the next three windows. Associated *e-values* are selected that span the projected path and select the corresponding musical phrase from the array. Movement 2 then follows a similar procedure for the audience member. The mapping for movement 3 uses the coordinates of each subject from the fourth window of movement 2 as initial values, *p* (performer) and *a* (audience member). The difference between each individuals' emotional sate, calculated as:

$$\sum \frac{p + a}{2}$$

becomes the target value for movement 3's third window, again with multiplication factors of 0.33, 0.66 for the preceding two windows, plotting a trajectory. The final window in movement 3 selects a target value of positive valence, at the closest e-value to the difference between *p* and *a* to induce a positive emotional ending to the performance experience.

6. MUSICAL PARAMETERS

The Director Musices system [7] is a well established model for deriving emotional features in music. Changes in mode, tempo, dynamics and articulation are known qualitative factors for influencing the emotional state. For example, it is widely accepted that a change from a major key to a minor key is well correlated to a change in perceived mood [18]**.** Additional factors, scales of lyrical content and performative dramaturgy, have been constructed. The lyrics are adapted from the (public domain) prose of the romantic poet Percy Bysshe Shelley, a writer well known for his emotional language. For the text to be communicated clearly to the audience, it is projected at the rear of the stage.

Secondly, we have designed, through pre-production rehearsals, a key representing the 12 *e-values* which are presented on screen to each performer. Varying the intensity of the score's background colours provides a symbolic prompt for each performer to add their own interpretation of feeling to the performance. Facial expressions, physical gesture and subtle performance deliveries are semi-improvised by each performer in response, which help provide a more humanised input to the otherwise automated system.

7. DISCUSSION

As an artistic application of real-time composition using affective states this system demonstrates a work in progress proof of concept. The system and associated performance touch upon a wide range of areas that are open for deeper investigation, crucially the psychological effects of EEG mood induction and emotional perception in multimodal environments.

The system aims to highlight the potentials of mapping affective states to associated music with a simple method for plotting trajectories to move an individual from one state to another, as well as drawing the affective states of towards each other across a 2-dimensional model.

This is, to the best of the authors' knowledge, the first time such a system has been proposed; specifically for emotion-based collaborative real-time composition in a performance setting, although sonifying emotional characteristics of EEG and measuring brain responses to music are areas investigated by a number of researchers over the last ten or so years [12, 22].

From a technical perspective we acknowledge that greater resolution in converting emotional features into musical mappings could be higher and more expressive. An automated generative musical system may be more suitable for this, or a more complex hybrid of this with our approach, but our wish was to integrate known emotion based features with human composition. We acknowledge the need for more user testing in order to understand the process of shifting a user's state as this process is currently under researched.

Currently EEG is extremely problematic to measure during physical activities. In order to bypass the inherent artefacts created by the act of singing and performing EEG is recorded for 20 seconds at the end of each 1 minute 30 second window whilst the singer is instructed to remain still and focus on their emotions at that time in response to the previous window's music. Until this issue is resolved our approach appears to be a simple and effective solution.

The importance of examining the outcomes of performance as experimental data should not be overlooked, both in terms of EEG readings and user experience. We hope to use the information recorded from upcoming performances to feed into future work.

Work towards manipulating emotions through a responsive musical system, as well as the synchronisation of the emotional levels of more than one person engaged in acts of music making, is an exciting prospect. This concept has further potential in a wider range of interactive media applications where designers, composers and artists who wish to explore emotional links to develop shared emotional experiences in response to art have a working foundation upon which to build.

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