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Haptic Music Generation Based on EEG Analysis

Keio University
Graduate School of Media Design

DI LI

A Master's Thesis
submitted to Keio University Graduate School of Media Design
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Master of Media Design

DI LI

Master's Thesis Advisory Committee:

Professor Kouta MINAMIZAWA	(Main Research Supervisor)
Professor Kai KUNZE	(Sub Research Supervisor)

Master's Thesis Review Committee:

Professor Kouta MINAMIZAWA	(Chair)
Professor Kai KUNZE	(Co-Reviewer)
Professor Matthew WALDMAN	(Co-Reviewer)

Abstract of Master's Thesis of Academic Year 2020

Haptic Music Generation Based on EEG Analysis

Category: Design

Summary

Haptic, the sense of touch is the most real way for us to contact the outside world, and music is also a very important way to regulate emotions. In this paper, we bridge the gap between touch and emotion, and propose a novel system to joint music, haptic and electroencephalogram (EEG). Listeners can create their own somatosensory music through this circle system. The first stage: EEG signal as input to help us to generate music. The second stage: the listener can feel the haptic music while listening to the real music with listener's brain wave signal as the input signal again in the first stage. Meanwhile, it is the first time the silicon pneumatic module as the somatosensory part, which makes it more effective and comfortable for the listener to feel the music expression while listening. And our work verifies the close connection between haptic and EEG. The purpose of this thesis is that using this Emotion, Music and Body Circle to enrich the music experience, to get higher satisfaction(positive emotion) when listening to music. Explore the impact of music directly generated from brainwave data plus haptic performance on human emotions.

Keywords:

haptic music, sense of touch, EEG, emotion, mental health, well-being

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Chapter 1
Introduction

1.1. Introduction

Music is the mediator between the spiritual and the sensual life. - Ludwig van Beethoven

As an indispensable part of our life, music plays a very important role in sociology, psychology, and even medicine. Many ethnographic studies demonstrate that music is a participatory, community-based activity [1]. That is why we go to concerts, we make friends because we like the same type of music or the same singer, and we share our understanding and thoughts about music online. At the same time, we generally believe that music can reflect and affect our emotions to a certain extent in music psychology. Modern music psychology aims to explain and understand musical behavior and experience [2]. Just like listening to cheerful music when we are particularly happy can make us happier, listening to melancholic music when we are sad can make us more empathetic to the sadness that musicians want to express. In medicine, music therapy is applied to issues such as psychiatric disorders, medical problems, physical disabilities, sensory impairments, communication disorders and aging. And therapist uses music and all of its facets—physical, emotional, mental, social, aesthetic, and spiritual—to help people to improve or maintain their health [3].

From the above it can be seen that, the function of music and its influence on emotions have exceeded the functions that an artistic form should have. The role and status of music have been changing. However, from the history of music development, music itself cannot be separated from the physical human body. In ancient times, musical tones and rhythm were used by the half-human progenitors of man, during the season of courtship [4]. It can be speculated that this may be the predecessor of the singing action that controls the vibration of the vocal cords and the resonance of the cavity. In modern history, the development of piano, violin, harmonica and other instruments has enriched the diversity of music. And this kind of musical instrument often needs human hands, feet, mouth and other body parts to control and play [5]. After 2000, with the development of technology, there have been great changes in the way of music creation, the way of music transmission, and the way of feeling music. The creation of electronic music, the dissemination of Internet-based social media, and new forms of music expression using sound and light. We use technology in various ways to enhance the stimulation of the five senses of humans, and accelerate the innovation of music [6].

We can see from paragraph 1 and paragraph 2, that Music and Emotion, Music and Body are deeply related. And between Emotion and Body, there is a study said that human emotions can be easily evoked by different cues, and the sense of touch is one of the most emotionally charged channels [7]. Emotion, Music and Body appear to be closely linked. So as you can see in the figure 1.1, I designed a circle system involved the process of music generation and performance, to clarify the relationship between Emotion, Music and Body. Hearing has always been the most direct way for people to get music. In addition to using vision to enhance music, we try to use other ways to contact the external environment.

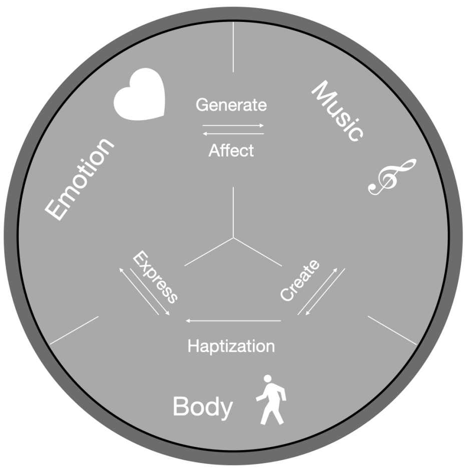


Figure 1.1 Circle system between *Emotion Music and Body*

This paper discusses how sense of touch can be expressed in music appreciation and how emotion can be translated to music. Some previous work has confirmed the influence of music on EEG of human body emotion. If we make people listen to music and increase tactile feeling, then people will get more obvious sensory stimulation when listening to music, thus affecting people's emotion more obviously. We innovatively use silicon material as the vibration body feeling module, and use air pump to adjust the vibration intensity and frequency of silicon. The subjects will feel the comfort brought by music from different dimensions. At the same time, brainwave music is also an intuitive way to express our emotions directly. In the design, we take the listener's brain wave music as the basis of realizing haptic music. At the same time, the listener can create his own haptic music by using this way, which is also helpful to study the relationship between emotional change and somatosensory in psychological research, medical treatment or other fields.

1.2. Research Purpose

My research purpose is that using this "Emotion, Music and Body Circle" to enrich the music experience, to get higher satisfaction(positive emotion) when listening to music and exploring the impact of music directly generated from brainwave data plus haptic performance on human emotions.

1.3. Thesis Structure

This thesis structure is shown as follows:

1. Chapter 1 will introduce the evolution of music and the functions and influence of music in ours daily life. Three elements of emotion, music and body are mentioned, and "Emotion, Music and Body Circle" is created using these three elements.

2. In the chapter 2, related works about the relationship between music, emotion and body will be presented. And the method of music generation from physiological signal will be introduced.

3. Chapter 3 starts to explain the concept of the system of haptic music generation. First the ideation of the ”Emotion, Music and Body Circle” will be introduced. Based on the methods of music generation from EEG and haptic generation from music, the implementation with modular prototypes will be shown.

4. In the chapter 4, we put forward a hypothesis and designed an experiment to test the influence of body(haptic) and EEG music on emotion changes.

5. In the last chapter, the conclusion of the whole thesis will be given.

1.4. Thesis Contributions

1. Providing a simple and quick way to generate music from physiological signal(EEG) data.

2. Exploring differences in emotion changing after listening the haptic music(expressed in haptic way) and EEG generated haptic music.

3. Providing the prototype of haptic music generated from EEG as an example of how to translate EEG data to music naturally and create diversified expression of music.

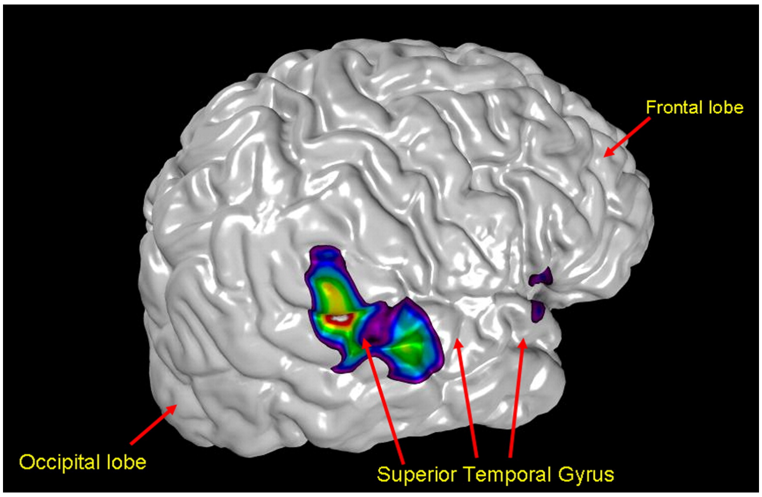
4. Observed and recorded how much can EEG music and classical music affect human emotions with or without haptic expression through the appliance.

Chapter 2
Literature Review

2.1. Music and Emotion

Following the topic of Music and Emotion mentioned in the previous chapter, we need to discuss the relationship between Music and Emotion in this section. Deryck Cooke [8] said that music is often regarded as "a language of the emotions". It expresses emotions that listeners perceive, recognize, or are "moved" by [9]. And the main characteristic of music is that it expresses and evokes emotion and the nature of musical inspiration and the process whereby the notes actually convey emotion from composer to listener [8]. So we believe that music is an affectively activity, both for the creator and the listener. And regarding the definition of emotion, although there is currently no scientific consensus, based on the research of Jaak Panksepp, Paul Ed Ekman and Richard J Davidson [10, 11], we generally think emotions are biological states associated with the nervous system, brought on by neurophysiological changes variously associated with thoughts, feelings, behavioural responses, and a degree of pleasure or displeasure.

From this we can infer that when we appreciate the rhythm, form, melody and harmony of the affective and intellectual complexity of the musical experience, the neural structure like the auditory cortex (figure 2.1) of our brain are activated to help us enjoy and create music. Moreover, some studies believe that emotion is not a phenomenon but a construct, which is systematically produced by cognitive processes, subjective feelings, physiological arousal, motivational tendencies, and behavioral reactions. So for example Jonghwa Kim and Elisabeth Andre [12] used four-channel biosensors were used to measure electromyogram, electrocardiogram, skin conductivity, and respiration changes to collect and analyze physiological signals to record emotional changes in the process of listening to music.



(Source: Mental concerts: musical imagery and auditory cortex [13])

Figure 2.1 Lateral View of Right Cerebral Hemisphere Illustrating Area of Hemodynamic Increase, in Color, during an Auditory Imagery Task

The above is the research on the emotional cognition of music, mostly exploring the source of the listener's emotional changes. In recent years, there have been more and more researches on the possibility of using emotion itself (such as physiological signal data) to make music creation. For example studies of music composition from the brain signal [14] proposed a method to translate the mental signal, the EEG, into music. The goal is to represent the mental state by music. Some similar methods will be introduced in detail in Chapter 2.3.

2.2. Emotion Measurement

2.2.1 General Measurement.

In the previous chapter, we mentioned that some studies used some methods to measure physiological signals like skin conductivity, respiration changes and so on in order to classify emotions. Emotion classification is a controversial issue in emotion research and emotion science. Researchers proceeded with sentiment classification from one of two basic viewpoints:

1. that emotions are discrete and fundamentally different constructs [15].

2. that emotions can be characterized on a dimensional basis in groupings [16].

Among them, the dimensional emotion division can be further divided by dimensionality, such as two-dimensional arousal-valence classification (Circumplex model [17]), three-dimensional pleasure-arousal-dominance classification (PAD emotional state model [18]), and Robert Plutchik's Wheel of Emotions (Figure 2.2) etc.

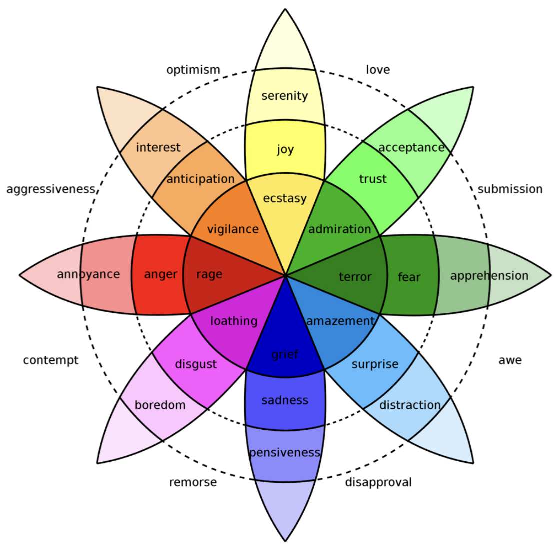
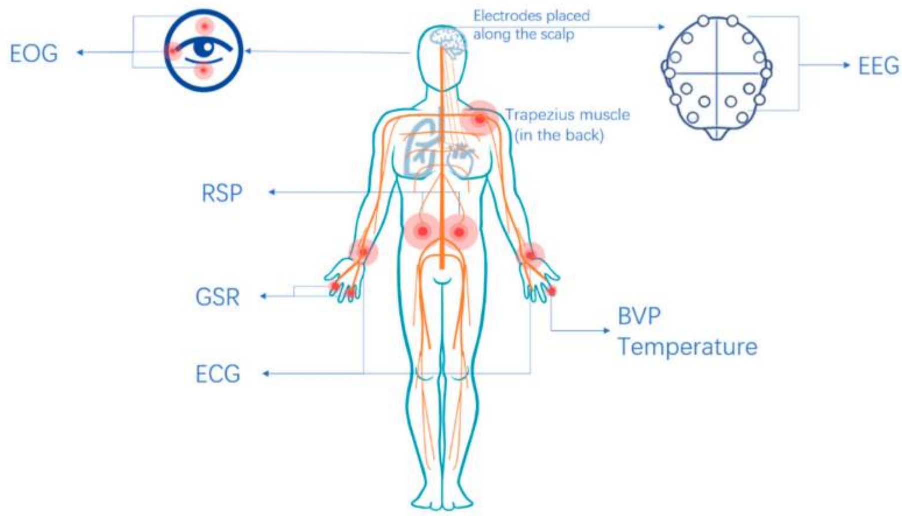


Figure 2.2 Robert Plutchik's Wheel of Emotions

After we know the types of emotion classification mentioned above, we generally use physiological signals for emotion recognition.Compared with the external expressions, such as facial expressions, postures, and voices, which are easily affected by the control of human subjective consciousness, the physiological signals of the human body directly controlled by the autonomic nervous system and endocrine system can reflect human emotional state more truly and objectively.

The physiological signals commonly used in emotion recognition include electroencephalogram(EEG) signals, electrocardiogram(ECG) signals, galvanic skin response(GSR) signals, electromyographic(EMG) signals, and respiration(RSP) signals, etc.



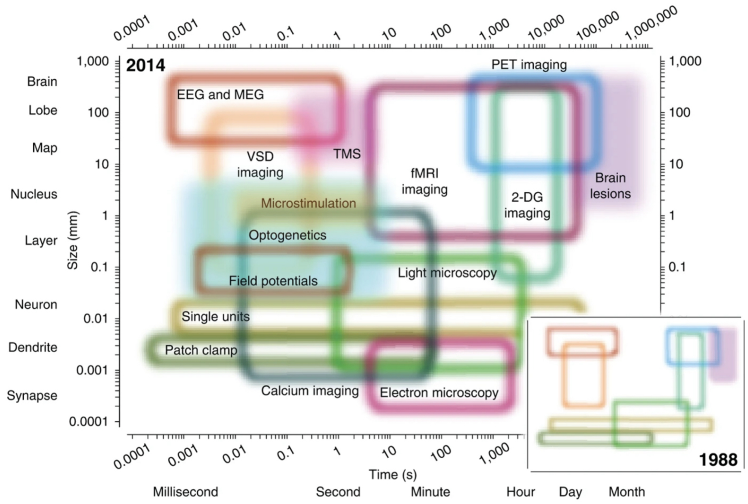
(Source: A Review of Emotion Recognition Using Physiological Signal [19])

Figure 2.3 Position of the bio-sensors to get different physiological signals

2.2.2 EEG and Emotion

According to the research of eeg-based emotion recognition in music listening [20], among the physiological signals introduced above, EEG has the advantages of non-invasive, easy to measure, temporal resolution in milliseconds and has been used in cognitive neuroscience to investigate the regulation and processing of emotion for the past decades.

We can see from the figure2.4 that each colored region represents the useful domain of spatial and temporal resolution for one method available for the study of the brain. Terrence J Sejnowski, Patricia S Churchland, and J Anthony Movshon [21] found that the EEG and MEG have the highest temporal resolution and non-invasive character. And according to Dante Mantini [22] power spectra of the EEG were often assessed in several distinct frequency bands, such as delta (δ : 1–3 Hz), theta (θ: 4–7 Hz), alpha (α: 8–13 Hz), beta (β: 14–30 Hz), and gamma (γ: 31–50 Hz) , to examine their relationship with the emotional states. Each frequency band has different characteristics. The delta wave can show people's fatigue and lethargy; theta wave is obvious in mental patients and adults who feel frustrated; the alpha wave is most obvious when the person is awake, quiet and closed eyes; the beta wave is important for mental tension and anxiety , hyperactivity, high concentration and other states have a strong response; gamma waves will appear when the human body is subjected to multimodal sensory stimulation or tactile short-term memory.



(Source: Putting big data to good use in neuroscience [21])

Figure 2.4 The spatiotemporal domain of neuroscience and of the main methods available for the study of the nervous system

But compared with works based on audiovisual methods, the use of EEG to assess emotional state is still in its infancy. For example, Ishino and Hagiwara [23] proposed a system that estimated subjective feeling using neural networks to classify emotional states based on EEG features measurement. They reported an average accuracy range from 54.5% to 67.7% for each of four emotional states [20]. However, their work only focuses on the EEG spectral power changes in a few specific frequency bands or specific scalp locations. So the study of using EEG signals for emotion recognition and classification need to systematically explore the correspondence between the emotional state of the entire brain and changes in the EEG spectrum in the future.

2.3. Music Generation from Physiological Signal

In the previous section, we know that music is the carrier of emotion, and we also know that when we listen to music, our emotion changes and it can be expressed through some physiological signals to a certain extent. So thinking in reverse , can we use the data of physiological signals to generate music? The answer is Yes. As early as 1934, Adrian and Matthews [24] first studied the connection between brain waves and rhythmic oscillation. With the deepening of brainwave research, in 1990, David Rosenboom [25] provided some specific algorithms for generating self-organizing musical structures in the feedback system, which associate a limited perception model with the occurrence of event-related potentials in the performer's brain. And in 2017, Thomas A. Deuel and his team [26] created a novel musical instrument and biofeedback device using electroencephalogram (EEG) posterior dominant rhythm (PDR) or mu rhythm to control synthesized pianos. From the above research, we can see that it is more feasible to switch from EEG to music generation among various physiological signals.

In order to explain the connection between music and EEG, we introduce a basic concept, scaling properties. It is also known as scale-free, the embodiment of fractal characteristics of complex systems. Spatiotemporal fractal structure indicates that the system does not have characteristic time scales and characteristic space scales in a certain dynamic process. If the scale of the function is an oscillation scale, then the physical scale can be used to measure the physical scale of the function. If X(t) denote the oscillation amplitude deviating from the steady state at time t, then X(t) has a power function distribution:

$$X(t) \propto t^{-\alpha} \tag{2.1}$$

Among them,α is the scaling coefficient, which is the slope of the straight line obtained in double logarithmic coordinates. Because the function is in the form of a power function, this property is usually called a power law, or Power Law. The power spectrum of many phenomena in nature is scaled and can be expressed as:

$$S(f) \propto f^{-\alpha} \tag{2.2}$$

This is an important feature that physical quantities have a scaling property. As for the human nerve center-the brain, the results of functional magnetic resonance (fMRI) research [27] show that when people perform different tasks, such as listening to music, the functional neural connections of the brain have similar scale properties. In terms of electrophysiology, research on sensory neurons has shown that both the firing rate and firing interval of auditory neurons have scale properties, which conform to the Power Law [28]. Studies by Steven B Lowen [29] have also found that both ion channels and neuron firing activities have fractal characteristics, and the power exponent of its Power Law is related to the specific functions of ion channels. Similarly, the nature of scaling also exists in human information communication: According to the observations of Voss and Clarke [30], the power spectrum of signals carrying complex information such as music and radio broadcasts shows a scaling behavior of 1/f, and the index α is at 1 nearby. In practice, the vast majority of music works use music tones by Ambar Chakravarty [31]. Music has four basic properties: pitch, duration, tone strength and timbre, and it is called "Four Elements of Music". Pitch is closely related to frequency. Generally speaking, the higher the frequency, the higher the pitch; the lower the frequency, the lower the pitch. But there is a nonlinear relationship between the two, which roughly conforms to Fechner's law.German physicist Fechner [32] proposed the correlation between the objective stimulus and the subjective perception, namely

$$S = K \log R \tag{2.3}$$

Among them, S represents the subjective sensation, K represents a constant, and R represents the objective stimulus. Currently more recognized. According to Andreas Fink and Mathias Benedek [33], the conclusion is that the alpha wave activity in EEG is related to a variety of creative activities. Therefore, based on the fact that both music and EEG obey the nature of fractal scale, and combined with Fechner's law, we propose from the basic properties of brain waves (amplitude, period and average power) to the basic properties of music

The corresponding relationship between high, pitch and intensity) has established a new fractal brainwave music production method, showing a possible way to use neural information and the inherent laws of music to establish a scientific connection between music and EEG.

2.3.1 Emotion Recognition Methods Based on Physiological Signals

In 2006, Guillaume and others at the University of Geneva, Switzerland, were able to identify signals such as brain electricity, heart rate, blood pressure, and respiration. In the above, the methods of Naive Bayes (NB) and Fisher Discriminant Analysis (FDA) [34] were used to identify the arousal dimension degree of emotion, reaching a recognition accuracy of 50–72%. In 2017, Ruietal [35] used the CNN method to perform emotion recognition on the EEG signal in the DEAP dataset, and achieved an average recognition accuracy of 87.27%. In the same year, Eun Hyeetal [36] respectively compared the use of linear discriminant analysis (LDA), classification and regression trees (CART), neural network self-organizing maps, NB and SVM classification methods to identify sadness, fear, stress and other negative emotions. Among them, SVM's recognition effect is the best, reaching 100%, while the recognition accuracy of LDA is the lowest, only 50.7%. In 2018, Byung Hyung Kim [37]and others of the Korea Academy of Science and Technology used the ConvLSTM (Convolutional-Long Short-Term Memory) model for emotion recognition, and achieved 79.03% and 78.72% emotion recognition accuracy in the arousal dimension and the valence dimension, respectively.

2.4. Embodiment of Music

According to "*Embodied music cognition and mediation technology* [38]", in recent years, the way music interacts with the human mind and the brain have developed rapidly, and multimedia technology has enhanced our way of interacting with music. Between the musical experience and music, the human body can be regarded as a biologically designed mediator that can transfer physical energy up to the level of behavior-oriented meanings, to a mental level of consciousness in experience, value, and the intentions form the basic components of music signification. Therefore, recently most of the application of embodiment of music are in the field of musical visualization and musical haptization.

(Source: Sound Forest: Evaluation of an Accessible Multisensory Music Installation [39])

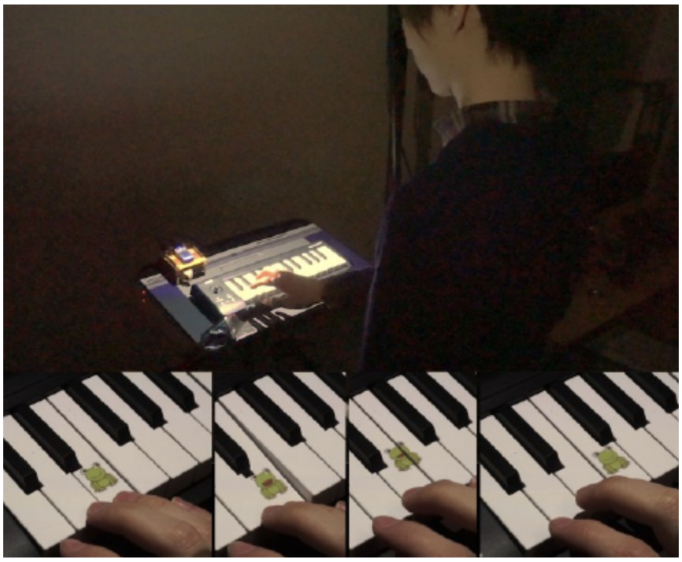
Figure 2.5 Mirrors refecting the lights of the strings in Sound Forest

Sound Forest [39] is a music installation consisting of a room with light-emitting interactive strings, vibrating platforms and speakers, situated at the Swedish Museum of Performing Arts. This work uses a combination of light, sound and tactile vibration to stimulate the five senses of the participants, and increase the interaction between music and the human body.

We can see from the Figure2.6 that synchronized vibration with animation can help people to deepen the memory of music and enhance the musical experience.

2.5. Haptic Technology

As mentioned above. In order to increase interactivity and immersion, more and more music works use visual technology and haptic technology. According to



(Source: HapTONE: haptic instrument for enriched musical play [40])

Figure 2.6 Synchronized vibration with animation helps to teach the melodies of 'frog song'

Gabriel Robles [41], haptic technology refers to any technology that can create an experience of touch by applying forces, vibrations, or motions to the people.

So what is the process of people feeling the sense of touch? When we touch an object, we will feel the interaction on the skin, and these forces convey information and lead to awareness of the physical world. After receiving the perception, the muscles are activated by brain which results in the movement. Therefore, human haptics encircles to a closed loop between humans and the physical environment and all aspects related to sense of touch[1]. For humans, we cannot actively turn off the sense of touch, and when we feel the sense of touch, we often combine it with the surrounding environment and compare it with our own past experience about haptic. Generally we use the technology of electromagnetic force, ultrasound, vibration, pneumatic and so on to create the sense of touch and to create the experience. I will introduce several common haptic technologies below.

1 OpenHaptics Toolkit version 3.0, Programmer's Guide, Sensable Technologies, Inc., 1999-2008.

1. Vibration. According to Shen Ye [42], most electronic devices that provide haptic feedback use vibration, and most use a type of eccentric rotating mass (ERM) actuator consisting of an unbalanced weight attached to a motor shaft. When the shaft rotates, the spinning of this irregular mass causes the actuator and the attached device to shake. Some newer devices vibrate with a linear resonant actuator (LRA), which moves a mass in a reciprocal manner by means of a magnetic voice coil, similar to how AC electrical signals are translated into motion in the cone of a loudspeaker. LRAs are capable of quicker response times than ERMs, and thus can transmit more accurate haptic imagery.

2. Force feedback. Force feedback can be classified into non-contact haptic feedback and contact haptic feedback. According to Ali Shtarbanov and V Michael Bove Jr [43], like air vortex rings are donut-shaped air pockets made up of concentrated gusts of air. Focused air vortices can have the force to blow out a candle or disturb papers from a few yards away. And according to Benjamin Long [44], the focused ultrasound beam can be used to create a local pressure sensation on the finger without touching any physical objects. The pressure-sensitive focal point is generated by individually controlling the phase and intensity of each transducer in an array of ultrasound transducers.

Chapter 3
Concept Design

3.1. Circle System

As mentioned in Chapter 1, in order to clarify the relationship between Emotion, Music and Body, I designed a circle system involved the process of music generation and performance.

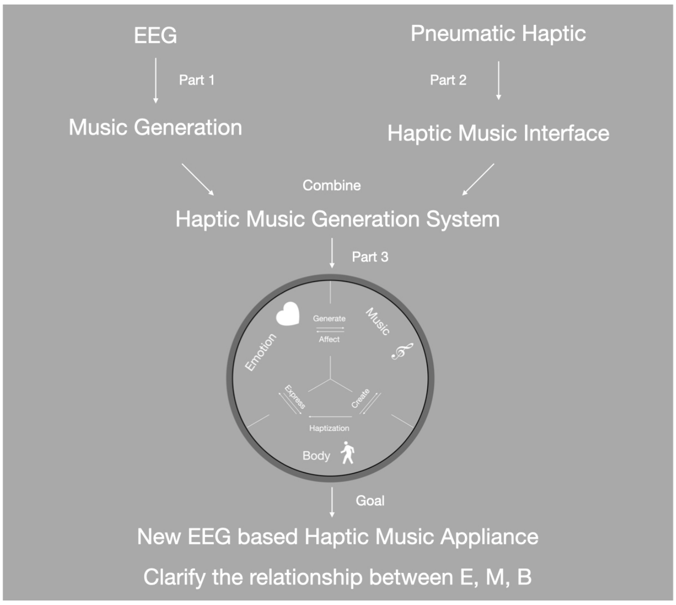


Figure 3.1 The basic structure of the design process of Circle system between *Emotion Music and Body*

According to the chapter 2.2 and 2.3, we know that music is the carrier of emotion, and physiological signals can reflect emotional changes to a certain extent.

Among a variety of physiological signals, EEG has the advantages of non-invasive, easy to measure, temporal resolution in milliseconds, so I consider using human EEG signal data to generate music to complete the first part of the circle system. Then in terms of the performance of the music generated by EEG, I want to increase people's emotion changes when they are listening to music. I chose pneumatic haptic in the haptic technology mentioned in the previous chapter. In order to create a pneumatic haptic interface to express music generated by EEG. This is the second part of the circle system. Then, I collect EEG signal data when people hear music that reflects their emotions and feel the performance of musical haptic. Then use these data to generate new music to complete a complete closed loop of the circle system.

3.2. System Architecture

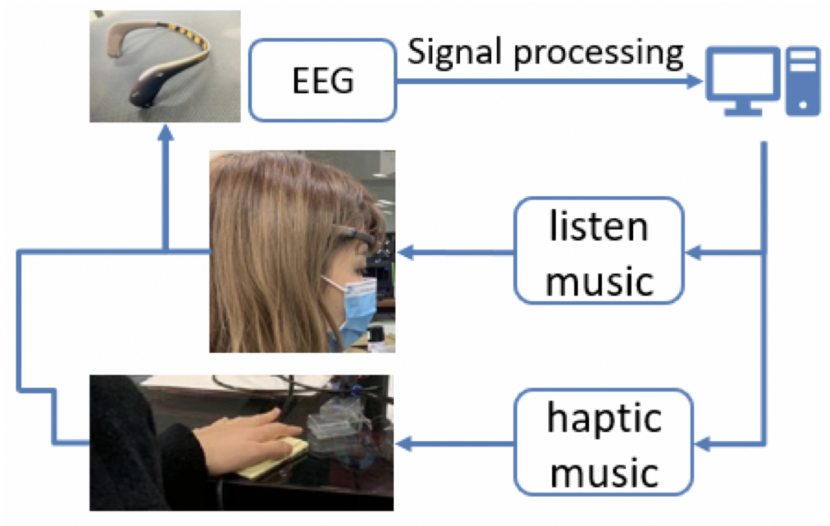


Figure 3.2 The Architecture of Circle System

Figure 3.2 is the architecture of Circle system. For the hardware part, we use the MUSE headband to collect the EEG signal data, and then use the computer to process it. In the part of listening to music, we used ordinary speakers and headphones. In the part of haptic music, we used Arduino MEGA2560, Air Pump, solenoid valves, pressure sensor and sound sensor to build pneumatic control board. For the software part, we used MATLAB to process the EEG data, and use the Cubase and Logic Pro to process the MIDI data. Then use the Arduino to control the pneumatic control board.

3.3. Music Generation from EEG

According to the chapter2.3, we know that music has four basic properties: pitch, duration, tone strength and timbre, and it is called "Four Elements of Music".

3.3.1 EEG to pitch

EEG to pitch. The mapping relationship between EEG amplitude and pitch is a logarithmic relationship with frequency. The range of pitch is called the range. Music with higher range is more cheerful and bright, while music with lower range is deeper and more stable. According to the research results, the amplitude of EEG (Amp) and power spectral density (SP) have a linear correlation [45], namely

$$SP = \mu \bullet Amp \tag{3.1}$$

Where µ is the scale factor, and µ>0. The power spectral density and frequency (Ef) accord with the scale property [46]

$$SP \propto f_E^{\alpha} \tag{3.2}$$

Among them, α is the scaling coefficient, which is the most essential expression of the scaling properties. Usually the range of α is -2 to -1. In the MIDI standard, there are 128 different pitches, and there is a semitone difference between each two pitch values. The relationship between pitch (Pitch, in semitones) and musical instrument oscillation frequency (fM) can be expressed as

$$Pitch = 12 \times \log_2\left(\frac{f_M}{440}\right) + 69 \tag{3.3}$$

Among them, 440 is the international standard pitch (A4, 440Hz), and its corresponding pitch value is 69 in the MIDI standard.We replace the frequency in the formula 3.3 with the power spectrum in the EEG, so we can get relationship between EEG and the pitch of music. In fact, when the brain activity is intense, the consistency of its neuron activity is not high, so it tends to show a lower amplitude. When the brain activity is low, the neurons participating in the activity are consistent, so the amplitude value is generally larger. m is a negative value, which just guarantees that the intense brain activity will be represented by the high pitch, which makes the emotion expressed by the music more enthusiastic. vice versa.

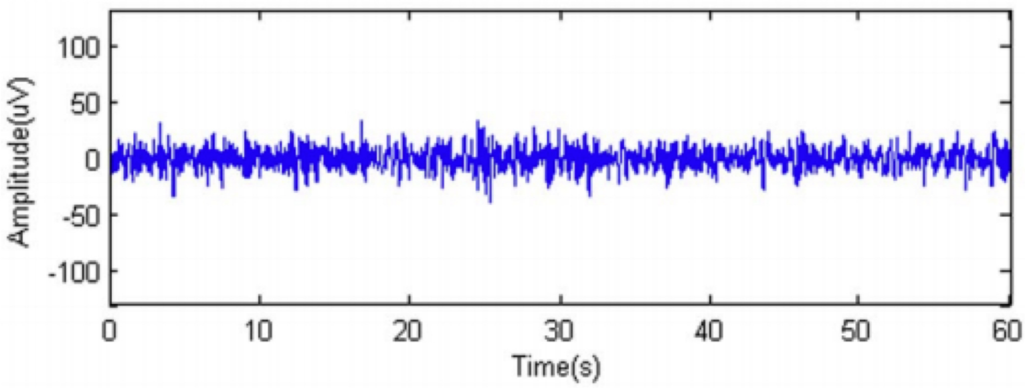


Figure 3.3 The Amplitude Changes of EEG within 1 Minute

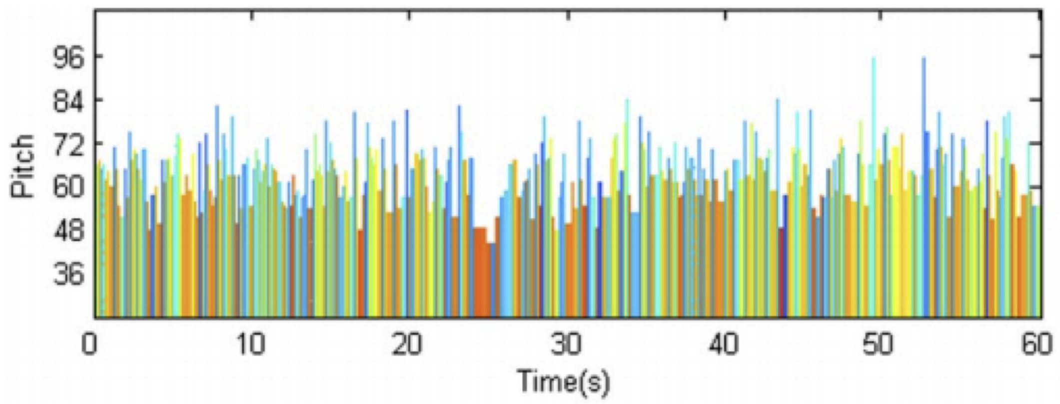


Figure 3.4 Pitch Mapped from Amplitude of EEG

3.3.2 EEG to duration

EEG to duration. In music, the length of the sound indicates the time that the sound continues to sound, which is usually related to the vibration time of the sound source, and is a physical quantity of time nature as the period. Here, we directly correspond to the EEG data period and the sound length. In a certain period of time, the average power of EEG reflects the distribution of energy and expresses the corresponding physiological state. The sound intensity is mainly related to the sound pressure of the sound source and reflects the energy of the sound source. According to Fechner's law, the sound intensity, as a person's psychological quantity, has a logarithmic relationship with the objective stimulus quantity.

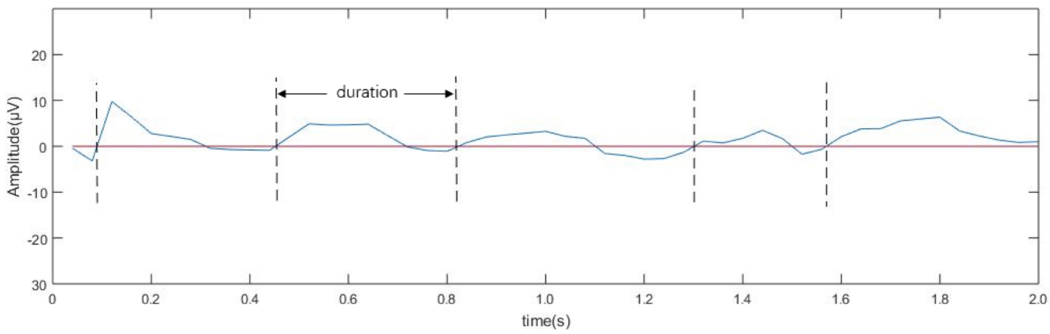


Figure 3.5 Duration from Amplitude of EEG

3.3.3 EEG to tone strength

EEG to tone strength. The volume of music sounds is used to represent the energy of the brain wave data segment, and more intense conscious activities are emphasized. So far, we have established the correspondence from the basic properties of EEG: amplitude, period and average power to the basic elements of musical tone: pitch, pitch and intensity. We use the corresponding relationship to convert the acquired EEG information into the basic elements of music. After adding any selected timbre, it can be made into a MIDI file that can be played directly with the in signals to MIDI music.

3.3.4 Practical operation of conversion from EEG data to MIDI

We use SEED dataset [47, 48] to generate the EEG music. According to the chapter 3.3, we calculate and find the EEG data which is need to generate pitch, duration and tone strength. Then, input these data into our program that generates MIDI music. We use mido and midiutil toolkit in Python to help complete MIDI music production. After getting the MIDI of the main melody, we use Cubase to open the MIDI, and open the Scaler VST as below Figure 3.6, use the Scaler to automatically complete the melody recognition and chord selection including modulation. Finally, we generate two MIDI tracks with the chords like Figure 3.7. We generate MIDI which can become for listening, in order to facilitate our experimentation and simplify music generation, we only use bright piano sounds.

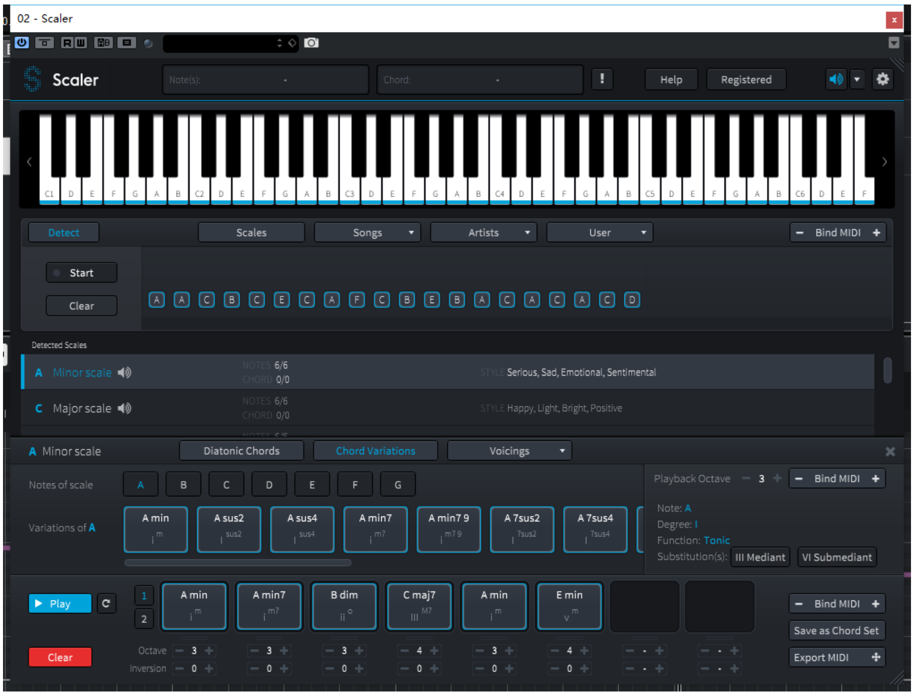


Figure 3.6 Scaler to automatically complete the melody recognition

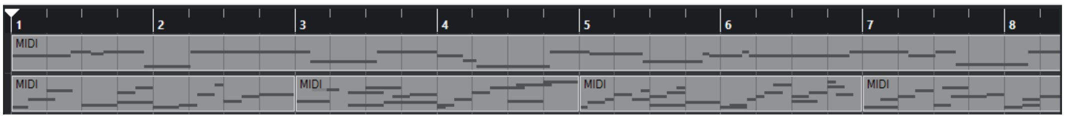


Figure 3.7 2 MIDI Tracks with the Chords

3.4. Haptic Generation from Music

In this part, I will introduce a method to translate music to haptic experience. In order to provide a comfortable haptic experience, I chose the silicon as the material of the actuator and the pneumatic haptic technology to express music.

The silicon air pump module is a new type of haptic somatosensory device created in this article and the structure in Figure 3.8. The prototype of this module is the fluidic control board from the soft robotics toolkit[1].

Compared with the previous haptic player [49, 50], this device is more comfortable and more suitable for the intuitive stimulation of human haptic experience, so that the effect of haptic music can be better expressed. Compared with ordinary haptic music player equipment, the performance of this equipment is better, and the feedback performance of the experiencer is more comfortable. Moreover, the control of the airflow size, strength, and time change of the air pump is more in line with the form of music. Based on the fact that both music and brain waves obey the nature of fractal scale, and combined with Fechner's law, we propose from The relationship between the basic properties (pitch, length and intensity) of the silicon pump to the vibration of the silicone air pump. At the same time, the characteristics of small delay and fast response speed can give the experiencer

1 `https://softroboticstoolkit.com/book/control-board`

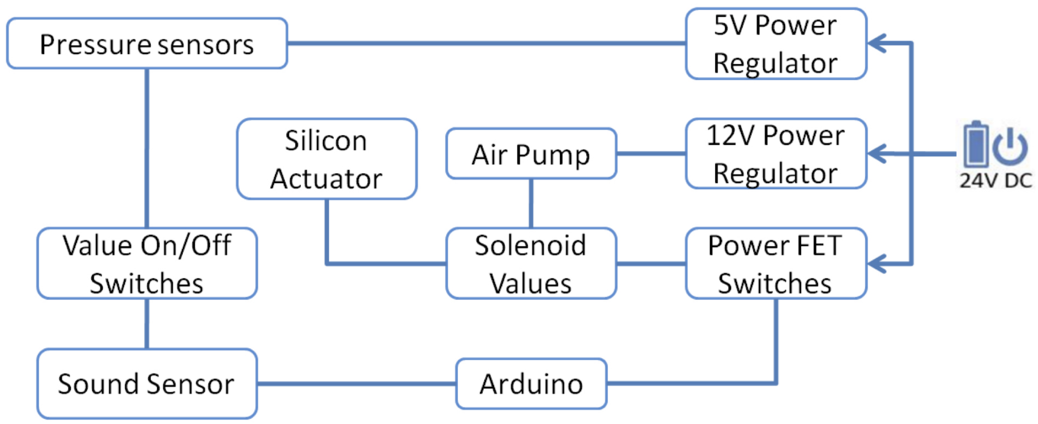


Figure 3.8 The Structure of Pneumatic Control Board and The Silicon Actuator

the best musical experience. Because the design is more suitable for the human sense of touch, it seems to have the function of amplifying sensory nerve information. When using the silicone air pump device, the EEG signal we monitored is more obvious and concentrated than ordinary vibration stimulation. Experiencers are very interested in using the whole set of equipment to create their own haptic music.

3.5. Prototype

3.5.1 Prototype of Haptic Actuator

In the first prototype, as mentioned in the previous section, I first the pneumatic haptic technology to create haptic music. For the actuator, I designed two schemes. One is to use the silicon as the material of the actuator because of the softness and the other one is to use a soft flexible 3D printing material named Tango.

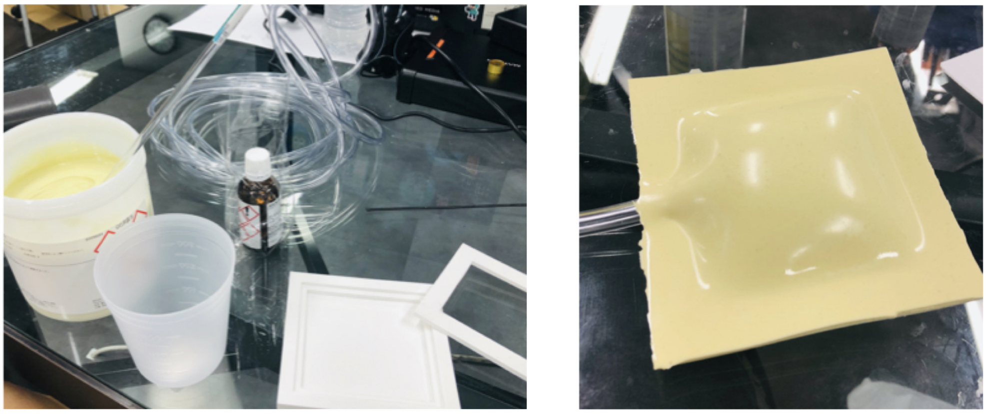


Figure 3.9 Silicon Air Bag as Actuator

I used 3D modeling software to design the silicon air bag mold, and then added the catalyst to the raw material for silicon and poured it into the mold to get the silicon air bag.As we can see from Figure 3.9, actuator 1: silicon air bag's characteristic is that

1. large in size so that the contact area with human skin will be large.

2. Soft to the touch, so that make people not resist contact. Easier to perform melody in music expression.

3. When expressing music, between the inflow and outflow of airflow with the rhythm of the music will be a certain delay.

And I used Fusion 360 to design a air-buttons mold, and 3D printed the Tango actuator directly like in Figure 3.10 and Figure 3.11

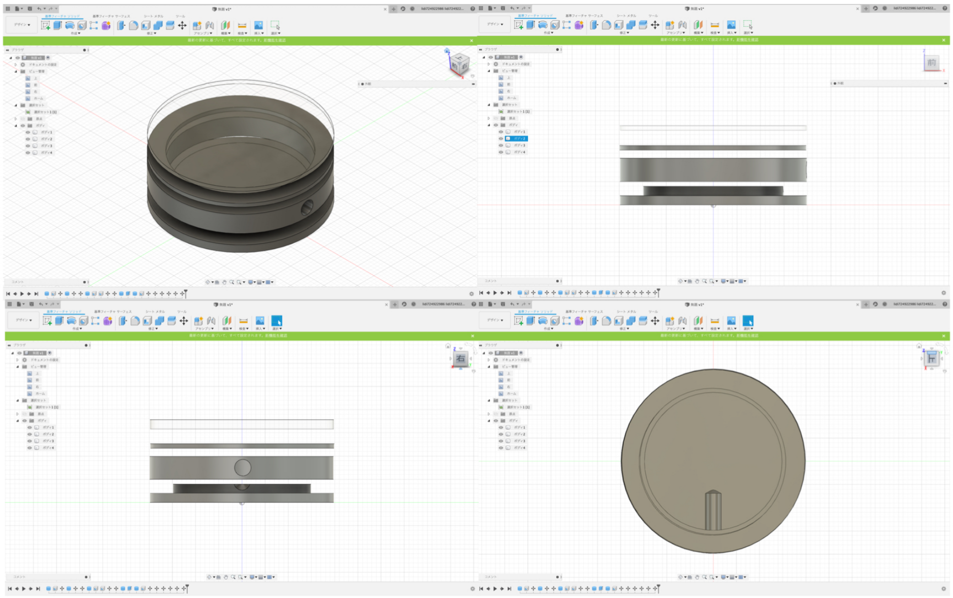


Figure 3.10 Air-Buttons Designed in Fusion360

Actuator 2: Tango air-button's characteristic is that

1. small in size so that the contact area with human skin will be small.
2. Feel harder than silicon. Easier to perform beat but not easy to perform melody in music expression.

3. When expressing music, between the inflow and outflow of airflow with the rhythm of the music will not delay.

After I compared Actuator 1 and Actuator 2, in order to ensure the expressiveness of haptic music, I chose the silicon air bag. It can perform both beat and melody, and it feels more comfortable to the touch. Although there will be a certain delay, it is within an acceptable error range.

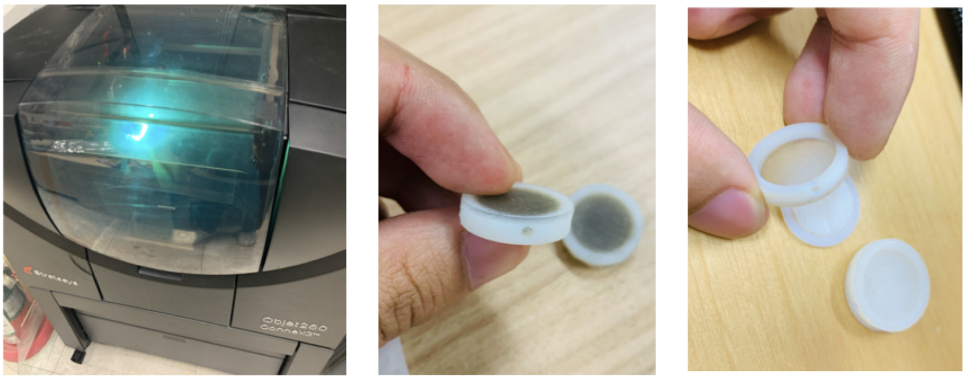


Figure 3.11 Tango Actuator 3D printed by Stratasys Objet260 Connex3

In the prototype 1 stage, I focused on the performance stage of music, the process from music to touch. I used ordinary music and speakers. While letting the participants listen to the music, I used my hand to control the air pump as a motor and inflate the actuator 1: silicon air bag according to the frequency of the music. At this time, if the participant's hand is placed on the silicon air bag, the participant will feel the synchronized haptic feedback while listening to the music. Figure 3.12 is the scene that a participant was feeling haptic music in the pretest.

Figure 3.12 Silicon Actuator Used in Pretest

3.5.2 Prototype of System

In the prototype of system stage, I improved the pneumatic part in prototype of haptic actuator, using a combination of pneumatic control board and silicon, air pump, instead of the manual part.Then added the part of EEG collection and analysis. Specifically, I used the MUSE headband to collect the emotional changes when participants experience haptic music.

We played the MIDI music provided in the previous section to the participants through the player, and at the same time collected the strength and weakness information of the music and provided it to the haptic player, so that the subjects could feel the haptic player while listening to the music. We directly use MIDI data to convert the information of the air pump, because we choose a single tone piano as the music tone, so we use the duration of the pitch as the length of a certain air pump cycle, and then choose the loudness as the vibration strength, so that the experience Feel the specific rhythm of mu-sic while listening to music. At this time, the subject wears a head-mounted EEG monitoring device, monitors brain wave activity while listening to music, and obtains the corresponding EEG

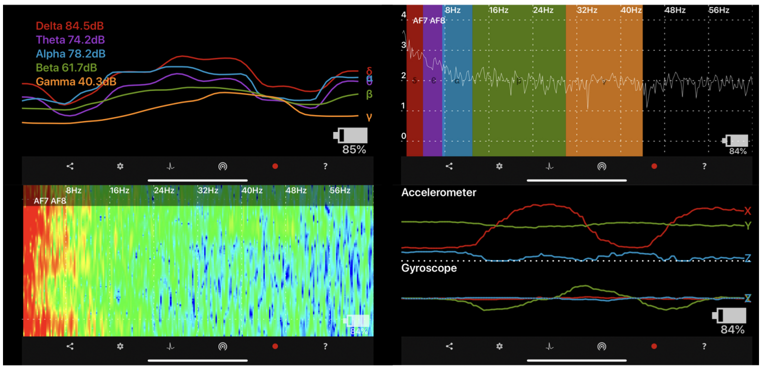


Figure 3.13 Real-time EEG Waveform in Prototype 2 Using Mind Monitor

signal, which is achieved by passing the signal again to the previous module that generates MIDI music files.

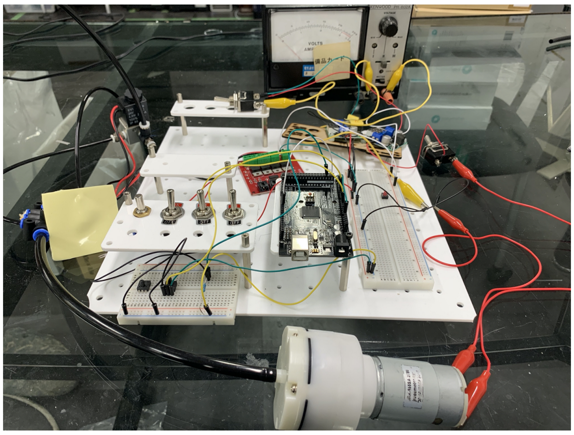


Figure 3.14 Pneumatic Haptic Control Board with A Novel Combine of Air Pump and Arduino

The participant creates haptic music by himself and creates it in real time while listening. The second option: while listening to complete piano music such as Mozart or Beethoven, the participant feels the haptic player and monitors its EEG signal at the same time, and then collects the signal to generate the participant's original haptic music through Listen to my own music again and feel the musical effects created by my own brain waves. The EEG signal monitored while experiencing haptic music has a stronger change intensity than listening to music alone, and can more accurately reflect the participant's EEG changes.

3.6. Interim Findings

From EEG to MIDI part:

1. We can use many tools to convert EEG data into pitch, duration, and strength to generate classical music MIDI signal.
2. We don't know the difference between the influence of EEG music and classical music such as Mozart and Beethoven's music on human emotions.

From Music to Haptic part:

1. When you put the air in silicon air-bag rhythmically with music, you can feel the music by your hand.
2. Pneumatic haptic is easy to express not only beat but also melody.
3. We do get higher satisfaction when we listen to the music through both ears and skin of hand, but we don't know the degree of emotional changes.

Chapter 4
Proof of Concept

In this part, we will explain the experimental design and experimental process, including the analysis and discussion of experimental data.

4.1. Experimental Setup

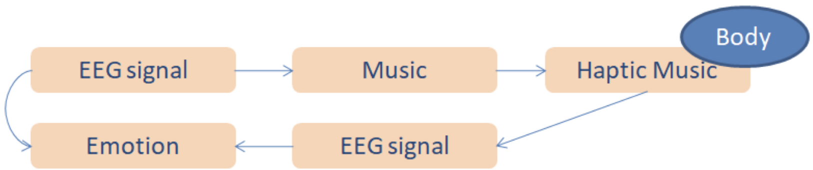


Figure 4.1 A loop of the experiment design

MY hypothesis is that as for music expressing positive emotion, EEG music affects human emotions more than classical music. And the haptic expression enhances the emotional changes. And my purpose is that I want to observe how much can EEG music and Classical Music affect human emotions with or without haptic expression through my appliance. Our experimental design is based on the circle system mentioned in chapter 1, the main purpose is to explore the relationship between emotion, body and music. so our experimental process is also designed as a loop such as Figure 4.1. We can complete the entire experimental process from any starting point to explore whether we can complete the process from emotion to music, body to emotion. The experiment we originally designed was based on EEG music. After generating a piece of music through EEG, we used our novel design to convert to haptic music. While participants listened to music and haptic music, we recorded their changes and emotions at this moment, To explore the connection and mystery between emotion, music and body.

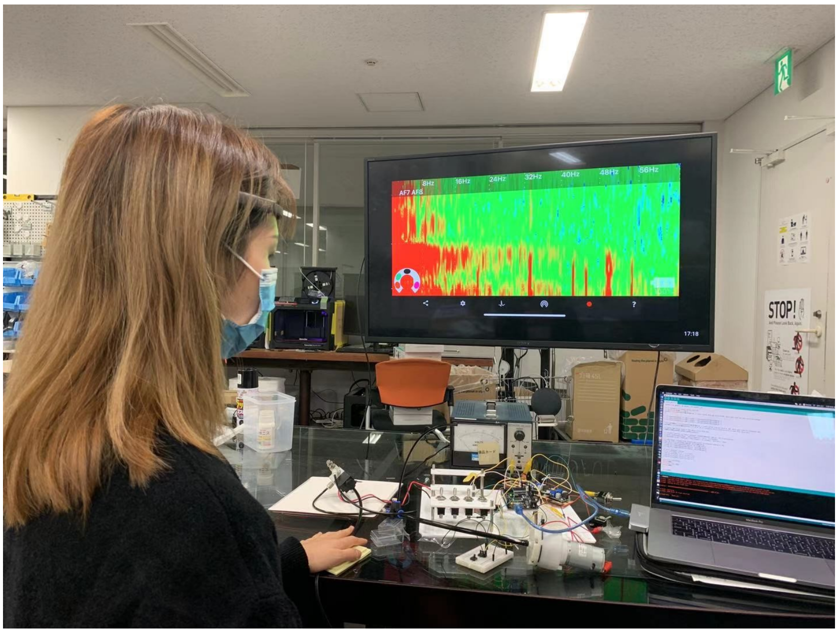


Figure 4.2 Listen to music while 'listening' haptic music and monitoring EEG signal

We gathered 10 participants as experimental subjects, 4 males and 6 females, age range between 23 and 30 years old. By allowing them to listen to different haptic music just like Figure 4.2, collecting subjective and objective information to determine their different reactions to these haptic music. Subjective information is mainly in the form of questionnaires. We set up a unified questionnaire to record subjective information. At the same time, the participants can also express the useless self-feelings in the questionnaire for recording. We first generate music based on EEG signals through EEG music generation. First, let the participants listen to EEG music, add touch in the middle of the way, and collect the participants' brainwave signals. Through experimental comparison, it is determined that music based on EEG signal will affect the participants after adding touch. At the same time, we set non-EEG signals with similar styles of music as a control, gave the participants the same experimental environment, and recorded their brainwave information and listening experience to analyze the connection between EEG music and touch from both subjective and objective aspects.

4.2. Evaluation Procedure

4.2.1 Wilcoxon Rank-sum Test

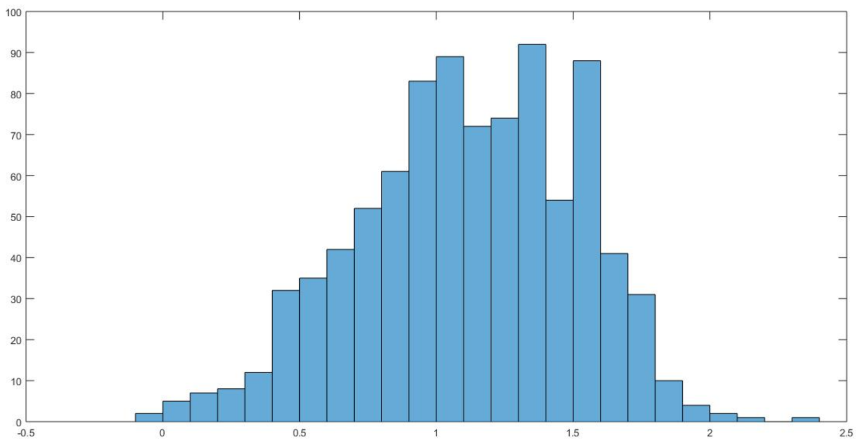


Figure 4.3 The Amplitude Changes of EEG within 1 Minute

From Figure4.3, the overall data obeys the central limit theorem, but the sample data obtained through experiments does not obey a certain normal distribution, but it is close to the normal distribution.

Therefore, we use the rank sum test to verify the significant differences between 10 samples. All data have obvious differences under the 5% confidence level, which

Table 4.1 Wilcoxon Rank-sum Test: the p-value of EEG data we sampled

sample NO.	(H)α=0.05	(H)α=0.01	p value
1 & 2	1	1	0.0089
2 & 3	1	1	$\approx$0
3 & 4	1	1	$\approx$0
4 & 5	1	0	0.041
5 & 6	1	1	0.0014
6 & 7	1	0	0.081
7 & 8	1	1	$\approx$0
8 & 9	1	1	$\approx$0
9 & 10	1	1	0.0065

proves that the data does not come from strong skewness.

From Table 4.1 that there are only two data with p values of 0.04 and 0.08, and there is only less than 8% probability that their distributions are relatively similar, so the EEG data we sampled are universal and reasonable.

4.2.2 Experiment Procedure

The experiment is divided into two steps. The first step is to find the appropriate EEG information to generate EEG music. Using the method in Chapter 3, we get a main melody, then process the music into a piano piece, and then generate the music to become haptic music for the participants to listen to at the same time. Get the brainwave information of the volunteers. Analyze the participants' brain waves to classify the participants' emotions. Let the participants listen to a piece of haptic music similar to EEG music, and the brainwave information is shown in Figure 4.4.

In order to objectively analyze the changes in participants' emotional response when listening to EEG music or haptic music, we collected their brainwave information and used EEGNet neural network to extract and classify the data. EEGNet was proposed by VJ Lawhern in 2018. The sentiment classification model for EEG data has high accuracy in several recent commonly used EEG data set

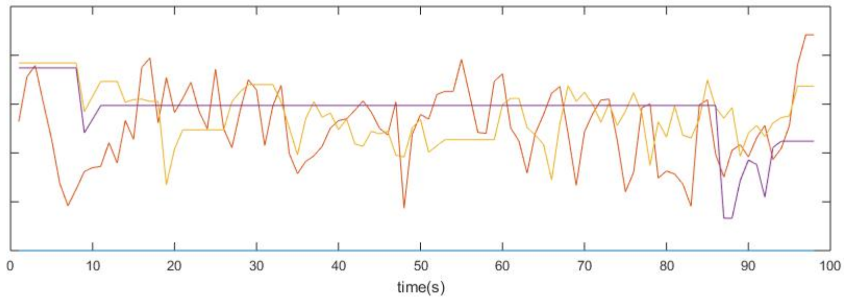


Figure 4.4 Original EEG Data

classification tasks [51]. The structure diagram of EEGNet is shown in Figure 4.5.

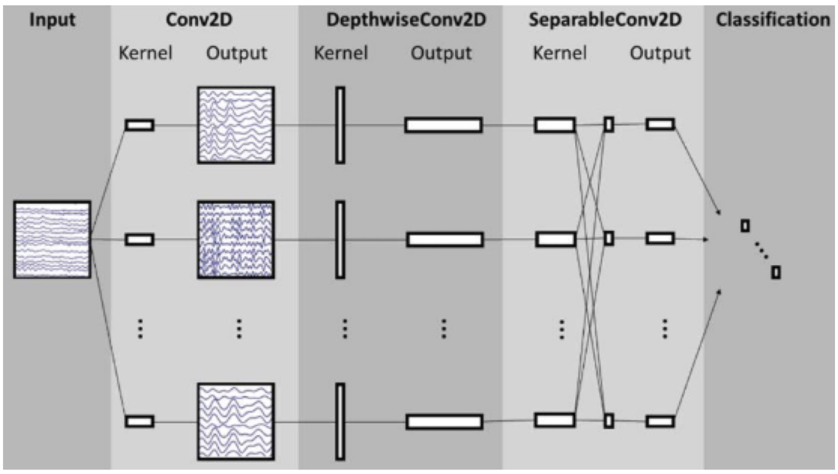


Figure 4.5 Overall visualization of the EEGNet architecture

After we have trained the network model using SEED data set in advance, after getting the participants' EEG data information, perform the classification task. Electroencephalogram data of the original is collected by the five bands electroencephalogram data collected four electrodes, then we need to give the data as shown in Figure 4.6 and Figure 4.7, the filtering process performed.

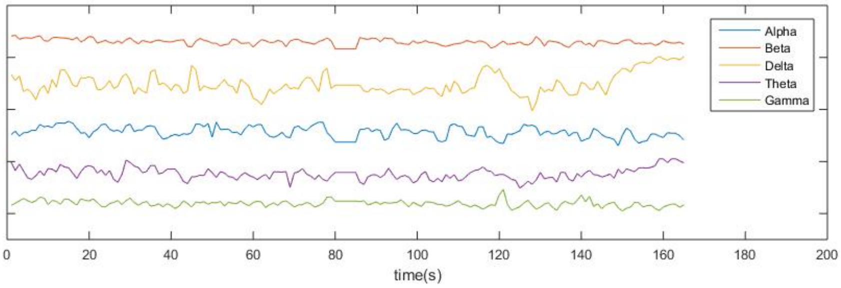


Figure 4.6 Brainwave Data based on Participants from EEG Music

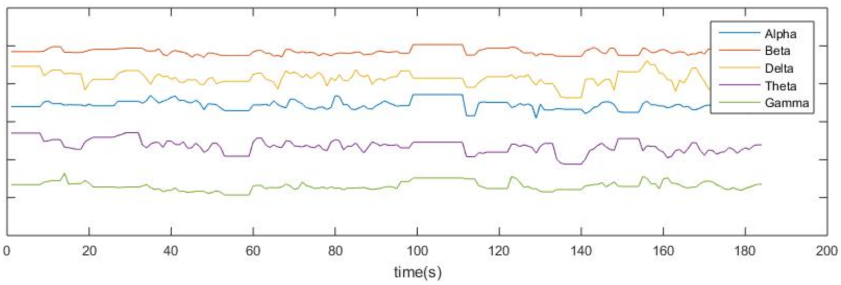


Figure 4.7 Brainwave Data based on Participants from Classical Music

Then we get the emotion classification probability as shown in the figure below. Such as Table 4.2. It shows that the degree of membership of positive emotions based on EEG data.

Regarding the content of the subjective questionnaire, most of the participants said that for contact with haptic music, the material feels comfortable to the touch and has a certain sense of immersion. Compared with our data, their data on emotional classification will increase. The sense of touch has played a positive

Table 4.2 The Degree of Membership of Positive Emotions based on EEG Data

Participant NO.	EEG Music	Classical Music
1	76%	73%
2	65%	62%
3	61%	59%
4	48%	50%
5	71%	60%
6	64%	42%
7	60%	50%
8	62%	55%
9	61%	62%
10	49%	45%

role in helping them. For people who have had haptic experience or are not very interested in haptic music, haptic music will instead cause their mood fluctuations to change without being positively affected and appear random other situations. When possible, it may be negative or positive, or it may be neutral without much change. In this experiment, only one male showed no interest in haptic music. Most of the participants indicated that haptic music has a certain different feeling, which can make them pay more attention to the sense of touch or the music itself. This also proves the rationality and effectiveness of our experiment.

4.2.3 Analysis Procedure

The probability of emotion classification according to EEGNet is not very particularly accurate, but it can still be accurately classified, because for the model, the entire EEG data is classified as neutral or negative emotion The probability is relatively low, and the use of SEED with EEG music with positive emotion generation makes it easier for the model to extract the characteristics of positive emotions. In the 10 analysis samples, 8 of the data have been improved, and there are two data classifications. Not as high as classical music, but the same, as shown in Figure 4.8.

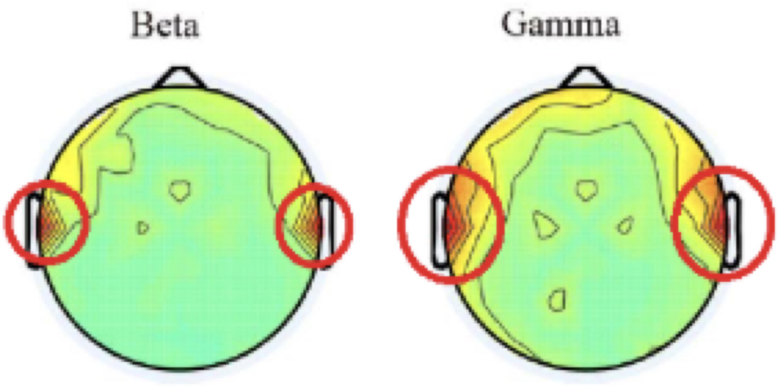


Figure 4.8 EEG brain waves are active

At the same time, we found in experiments that most of the information that can effectively classify emotions, such as the EEG information electrodes TP9/TP10 collected in the equipment we use, comes from Gamma waves and Beta waves, as shown in the figure , which proves that people listen to music When these bands are active.

From the experiment, we can conclude that not only can we express our emotions by playing music through our "body", but we can also express the emotions we want directly through the music generated in reverse by EEG.

In this paper, the brain wave information collected by a certain participant was taken again. In the experiment, we first listened to the experience-takers with normal music without touch, which lasted for about 20 30s. The brain wave information in Figure 4.9 showed that the change and fluctuation of the participant's brain waves began to become obvious after the addition of touch music in the middle.

Part by intercepting our brain wave information, and then compare the whether add touch of participants listen to the music of brainwave mood changes, through the experiment discovered, such as Table 4.3, after add touch part, participants emotion discrimination probability in some participants got bigger, but some par-

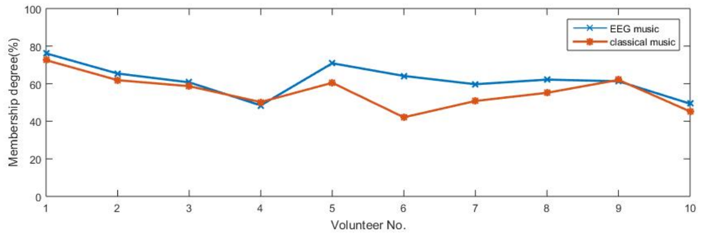


Figure 4.9 The Degree of Membership of Positive Emotions

ticipants brainwaves information does not judge the bigger the probability of ascension, and this may participant itself whether music or contact device for touch sensitive.

Table 4.3 The Degree of Membership of Positive Emotions with Haptic Music

Participant NO.	Listening with Haptic Music	No Haptic Music
1	72%	32%
2	53%	18%
3	67%	42%
4	41%	21%
5	69%	32%
6	45%	20%
7	39%	5%
8	74%	35%
9	54%	55%
10	61%	25%

Based on this, we conclude that for different groups of people, most of them have obvious brain wave response after touching touch, which also reflects that our 'body' can have a direct impact on our emotions. By observing Figure 4.10, it can be found that this influence has a greater change than the way of music.

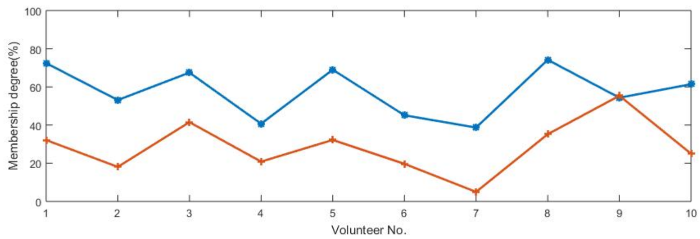


Figure 4.10 The Degree of Membership of Positive Emotions when Haptic Listened as the Same Time

4.3. Evaluation Result and Discussion

Based on the above experimental results and analysis, we make the following summary. The experiment has successfully completed two important tasks in the loop, and we have proved the potential connection between emotion, body and music through experimental realization.

We basically completed two sets of experiments under the experimental design of loop. The experiments show that the changes in the use of haptic music are greater, and the changes in people's brainwave emotions are more than simply listening to music as Figure 4.11.

Moreover, this change is deeper than our use of different music, which is enough to show the importance of the role of touch in affecting people's emotional changes. At the same time, we also confirmed the possibility of achieving emotion through body. Secondly, we use piano music generated based on EEG to stimulate people's inner connection with a certain emotion more than music created by normal composers. Our current work may not have gone deep into quantitative analysis to determine how much EEG-based music can affect People's emotions change, but it resonates in the brainwave information we collect. We have thus realized the feasibility of emotion to music. It's just that further research requires us to have a deeper understanding of the role of emotion in generating music.

Through experiments, we found the potential interconnection between body, music, and emotion. At the same time, we analyzed the difference in the degree of

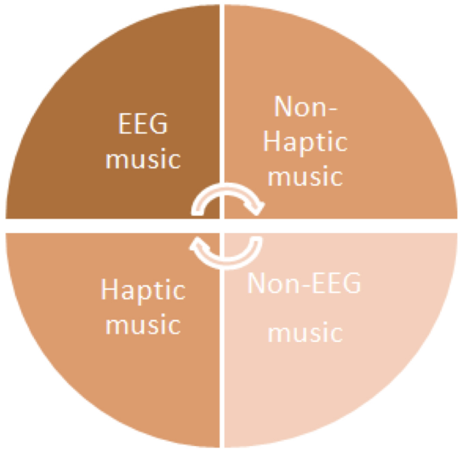


Figure 4.11 Increase of Haptic and EEG Information in Music Affects the Expression of Emotion in Music

influence. For a piece of creative music we generated, we added EEG components to it and realized the sense of touch. Music, the combination of the two has the greatest impact on people's emotions. If there is no sense of touch and no EEG information is added, the impact of music on people's emotions will be reduced.

4.4. Other Related Issues and Future Work

Finally, we discuss some other issues during the experiment, and at the same time explain the future work.

We review Table 4.4, which indicates whether the participants are male or female. We summarize and analyze the experimental results of different genders. There are 4 males and 6 females in the experiment. Participants' genders are relatively uniform. We use the average probability of emotion classification obtained when they listen to the same haptic music, which is 47.88%, but for men, it is

55.55%. Through the analysis of the results, men are more sensitive to touch than women. Although the amount of data is not very large, it is obvious that for men, the impact of touch may be higher than for women.

Table 4.4 The Degree of Membership of Positive Emotions (Distinct Gender)

Participant NO.	Listening with Haptic Music	No Haptic Music
1(female)	72%	32%
2(male)	53%	18%
3(female)	67%	42%
4(female)	41%	21%
5(male)	69%	32%
6(female)	45%	20%
7(male)	39%	5%
8(female)	74%	35%
9(female)	54%	55%
10(male)	61%	25%

Next, let's look at Table 4.5 below. We also marked whether the participants were male or female, and analyzed the influence of EEG-generated music on males or females. After comparison and calculation, when listening to EEG music, there is an average of 62.15% probability for women to distinguish female emotions as positive emotions through brain waves. For men, this probability is 61.35%, which is slightly lower than that for women, but the difference between the two values is not big. It can be analyzed that for EEG music, there is no big difference between men and women. Emotional changes may be more susceptible to EEG music.

In the future research work, we will focus on studying how EEG affects people after joining music, and how we should use EEG to enrich our emotional expression in music. Secondly, we will consider increasing the subjects and groups of the experiment. In this experiment, we have 10 participants with 4 men and 6 women. Our next experiment will increase the number of subjects while ensuring a balanced gender ratio to obtain a more universal Sexual conclusion. In the future work, we will expand our tactile range, such as in the whole body, or adjust the

Table 4.5 The Degree of Membership of Positive Emotions based on EEG Data (Distinct Gender)

Participant NO.	EEG Music	Classical Music
1(female)	76%	73%
2(male)	65%	62%
3(female)	61%	59%
4(female)	48%	50%
5(male)	71%	60%
6(female)	64%	42%
7(male)	60%	51%
8(female)	62%	55%
9(female)	61%	62%
10(male)	49%	45%

haptic stimulation experience, to achieve a diversified haptic music experience.

Chapter 5
Conclusions

The goal of this thesis is that using this Emotion, Music and Body Circle to enrich the music experience, to get higher satisfaction(positive emotion) when listening to music. Explore the impact of music directly generated from brainwave data plus haptic performance on human emotions. This article proposes an EEG-based haptic appliance that collects the participants' EEG information to enable subjects to create their own EEG music. At the same time, we propose a new type of silicon air pump device, which can experience haptic music experience.

In the chapter 1, 2 and chapter 3, we know that

1. We basically completed two sets of experiments under the experimental design of loop between Emotion, Music and Body.
2. The changes when participant listen to the haptic music generated from EEG in people's brainwave emotions are more than simply listening to music or haptic music. And this change is deeper than our use of different music, which is enough to show the importance of the role of haptic in affecting people's emotional changes.
3. This current work may not have gone deep into quantitative analysis to determine how much EEG-based music can affect People's emotions change, but it resonates in the brainwave information we collect. We have thus realized the feasibility of emotion to music.

From the experiment in chapter 4, we know that

1. In the process of generating 60 seconds of music from EEG data and expressing it in pneumatic haptic, listening to EEG music increased the positive emotion of 8 out of 10 people by about 10% on average rather than listening

to classical music. Compared with classical music, EEG music has a less obvious impact on positive emotions. According to the experimental results, it only increased by 8%.

2. In both EEG music and Classical music, Haptic express increased the positive emotion of 9 out of 10 people by about 30% on average compared to non-haptic. Compared with non-haptic, music haptic expression has an obvious effect on positive emotions, which is increased by 30% according to the experimental results.

In the future work, we will consider how to miniaturize the device, while connecting the device to the network and a dedicated APP, so that users can directly listen to the created haptic music. And then apply in the field of music entertainment(like immersive music) or make the deaf who can not hear the music feel the haptic music. As motion monitor applied to music therapy is also a potential application.

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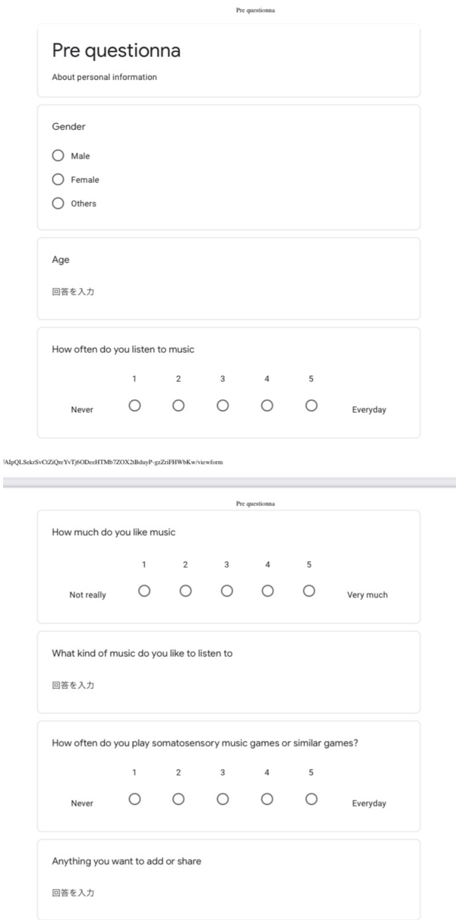
Appendices

A. Form


Pre questionna

Pre questionna

About personal information

Gender

Male

Female

Others

Age

回答を入力

How often do you listen to music

	1	2	3	4	5	
Never	○	○	○	○	○	Everyday

AIpQLSekrSvCtZiQreYvTj6ODeeHTMb7ZOX2tBduyP-gzZriFHWbKw/viewform

Pre questionna

How much do you like music

	1	2	3	4	5	
Not really	○	○	○	○	○	Very much

What kind of music do you like to listen to

回答を入力

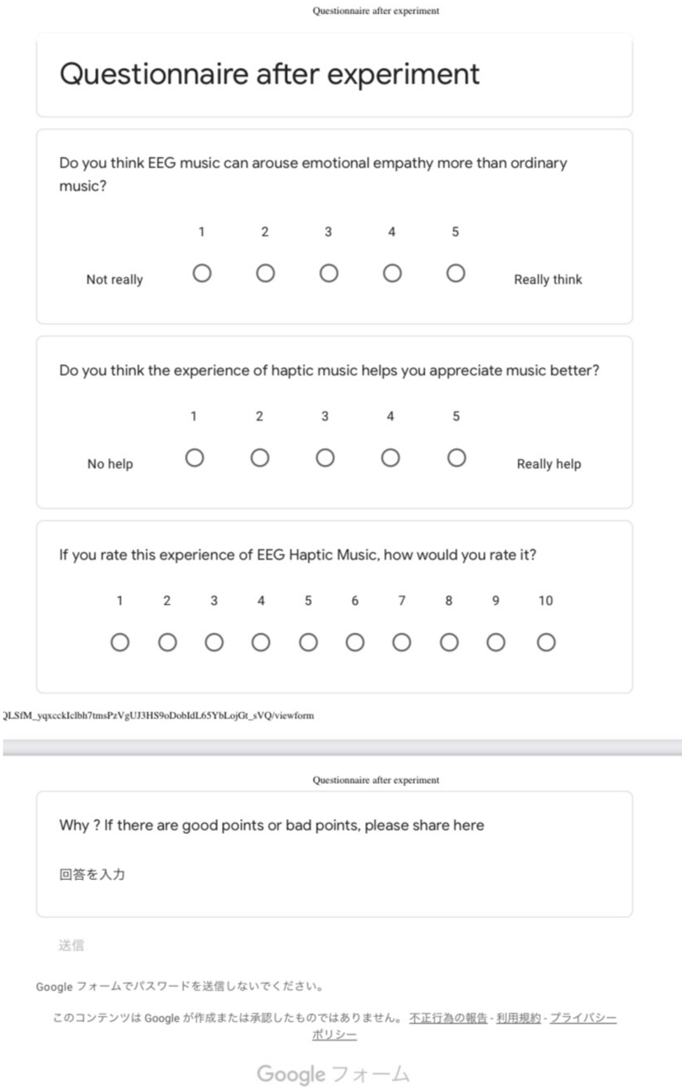
How often do you play somatosensory music games or similar games?

	1	2	3	4	5	
Never	○	○	○	○	○	Everyday

Anything you want to add or share

回答を入力

Figure A.1 Pre Questionnaire Form before Experiment



Questionnaire after experiment

Questionnaire after experiment

Do you think EEG music can arouse emotional empathy more than ordinary music?

Not really 1 2 3 4 5 Really think

Do you think the experience of haptic music helps you appreciate music better?

No help 1 2 3 4 5 Really help

If you rate this experience of EEG Haptic Music, how would you rate it?

1 2 3 4 5 6 7 8 9 10

QLSfM_yqxcckIclbh7tmsPzVgUJ3HS9oDobIdL65YbLojGt_sVQ/viewform

Questionnaire after experiment

Why ? If there are good points or bad points, please share here

回答を入力

送信

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Figure A.2 Questionnaire Form after Experiment