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Master's Thesis
Academic Year 2021

Frisson Waves: Sharing Frisson to Create Collective Empathetic Experiences for Music Performances

Keio University
Graduate School of Media Design

Yan He

A Master's Thesis
submitted to Keio University Graduate School of Media Design
in partial fulfillment of the requirements for the degree of
Master of Media Design

Yan He

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Abstract of Master's Thesis of Academic Year 2021

Frisson Waves: Sharing Frisson to Create Collective Empathetic Experiences for Music Performances

Category: Design

Summary

Frisson is a feeling and a mental experience of body reactions such as shivers, tingling skin, goosebumps. This research proposes Frisson Waves, a real-time system to detect, trigger and share frisson in a wave-like pattern during music performances. The system consists of a physiological sensing wristband for detecting frisson and a thermo-haptic neckband for inducing frisson. This project aims to improve the connectedness of audience members and performers during music performances by sharing frisson. In this thesis, we described thoroughly the literature and works related to exteroception and interoception interaction, emotion contagion, concept design process, and system development process. Results of studies proved a significant effect of triggering frisson, detecting frisson and capability of sharing frisson and primitive enhancement of connectedness in a live performance context.

Keywords:

frisson haptic, physiological sensing, interactive music performance, interoceptive interaction, empathy

Keio University Graduate School of Media Design

Yan He

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Chapter 1
Introduction

1.1. Motivation

I went to classical concerts quite often after I came to Japan. Every time they felt like an enjoyable sound bath. But during the pandemic time, concerts were all canceled, those weird but amazing sensations in the concert were also gone consequentially. After almost one year since the pandemic, I went to a live concert again. I suddenly realized those long-lost feelings are what my body is responding to the strong emotions the music brings to me. I felt goosebumps, shivers, I have a lump in my throat, I have tears in my eyes. These feelings of sudden excitement are called frisson. After the concert, I asked my friend, "that piece gives me frisson, can you feel it?" Not only because I want my friend to feel frisson but also my feelings. In traditional music concerts, people usually do not communicate with the one sitting with them, also people don't have connection with performers, performers don ' t know what the audience are thinking about.

Also in the pandemic quarantine time, we need to stay home and everything is online. Social contact gradually became less frequent and people were more distant. When I stay at home, except for online courses, I spend quite a lot of time playing piano. After playing piano alone for a long time, I get in contact with people who are also playing music by themselves and try to overcome the quarantine life. Then we started to play together once a week and discuss holding a concert together, so we can have something to look forward to. I would say to some extent that music and the chances of social communication brings us hope in the lifeless gray of the pandemic.

Before the Frisson Waves project, I investigated the hedgehog dilemma metaphor which created an experience for how people who are afraid of social interpersonal communications are going back and forth to seek for social warmth. In Frisson

Waves research, I am not only trying to combine art and technology to create new experiences for live music performances, finding out the contagious embodied aesthetic emotions, but also trying to create implicit chances for people including this research project team and myself to communicate more with others, getting social connections.

1.2. Overview and Goals

This research project aims to create new experiences for live music performances. Frisson Waves describes a novel way of sharing frisson through a haptic metasomatic interaction system based on physiological sensing and thermal haptic feedback. There are two main goals to achieve.

- The first goal is to detect frisson automatically and induce frisson among the audience during music performances in a way that music performers can perceive it and be reactive to the audience.
- The second goal is to explore whether frisson sharing can enhance connectedness of the audience and performers or not. If yes, to what extent we can enhance the co-presence and empathy between all participants in concerts.

The Frisson Waves system consists of a smart wristband measuring heart and electrodermal activity to detect sudden changes related to frisson, and a neckband with Peltier thermoelectric modules to induce frisson. This system enables us to detect and transmit the sensation of frisson throughout the audience in wave-like patterns, like ripples on the water.

To evaluate this system, there were three experiments related to triggering and detecting frisson. Two experimental concerts were held to evaluate this research concept, the first one one for recording frisson live, the second one for sharing frisson in real time. Later on, on October 3rd, this research project will collaborate with Karuizawa International Youth Concert. In this thesis, the planning and designing of the collaborative concert will also be introduced.

Through sharing frisson, this research also wants to show how we can share things that are usually limited to a person and look into how we can augment our sensations by sharing experiences.

1.3. Thesis Outline

This thesis has six chapters in total.

The first chapter will give an introduction about my motivation, general goal and overview of Frisson Waves research project.

In the second chapter, literature review and related work on how experiencing emotions triggers body reactions, how embodied sensations generate emotion, how people influence each other when they feel or feel others' emotions or body sensations. Then the embodied aesthetics experience "Frisson" will be introduced with appropriate scientific background of frisson, the psycho-physiological responses of frisson, causation, detecting, triggering, sharing of frisson.

In the third chapter, the design and the concept of Frisson Waves will be introduced based on field work including classical music concerts observations, performance observations and different tryouts including visually interactive piano performance, also with the inspiration of previous hedgehog work. Then this thesis will talk about an overview of Frisson Waves, concept design, prototype iteration design, system design methodology.

In the fourth chapter, the development process and experimental validation of how frisson is detected, generated and shared with the developed system will be introduced which will give readers the information of the developing framework and details.

The fifth chapter will introduce three studies of triggering frisson, detecting frisson, and two experimental concerts of recording frisson, sharing frisson. They are aiming to serve as proof the concept of frisson sharing.

In the last sixth chapter, conclusion and future work will be discussed.

All the study materials including questionnaires are in the appendix.

Chapter 2
Literature Review

This chapter will cover the literature review and related works. Literature will introduce the overview of aesthetic emotions and the neurobiological mechanism of how we feel from our mind to our body, how we feel from our body to mind and the blurry boundary between mind and body. Then this chapter will talk how individual feelings affect each other and the effect it can bring to people. Based on the three parts of previous literature and works, Frisson, the psycho-physical response will be introduced.

2.1. Mind to Body: Embodied Aesthetics

2.1.1 Aesthetic Emotions

Emotions

Human emotions are rich and complicated. Perlovsky et al. [9] stated that we can experience the multiplicity of emotions fragmentally or continuously which is beyond words like feeling happy, sad, peace, etc.

Aesthetic Emotions and Assessment

Embodied aesthetics means embodied responses and resonance of aesthetic emotions and experiences. Perlovsky et al. [9] proposed that aesthetic emotions are emotions that we feel when we are in aesthetic activities such as such as dancing, painting and gymnastics, which has elements related to pure beauty or when we appreciate things. "Measuring the Aesthetic Emotions" research from Schindler et al. [10] provides a comprehensive literature review about aesthetic emotions and an assessment tool for it. The AESTHEMOS subscale from Schindler et al. [10]

covers prototypical aesthetic emotions [11] which include feeling of beauty, liking, fascination, being moved, and awe. Besides, the AESTHEMOS Subscale from Pelowski et al. [12] accesses the pleasing emotions with positive affect valence such as joy, humor, vitality, energy, and relaxation as well as epistemic emotions such as surprise, interest, intellectual challenge, and insight, etc, negative emotions such as anger, sadness, confusion, etc.

Emotions that are induced by music are diverse and rich where we can experience a huge variety of emotions, most of which are aesthetic emotions. Zentner et al. [13] characterized the music-induced emotions and the paper provided the measurement tool of music-induced emotion.

Aesthetic emotions cover rich ranges of emotions which differentiate in valence, arousal and dominance , and aesthetic emotions happen in the context of aesthetic activities. In order to measure audience ' s aesthetic emotions in live music performance, this thesis uses the Self-Assessment Manikin Scale [14] which is more intuitive for audience to report compared with the previous two aesthetic emotions measurement tools from Schindler et al. [10].

2.1.2 Embodied Aesthetics

Mind to Body Model

Our bodies are always responding to our minds in some ways. Some body responses are obvious for us to perceive. For example when we feel sad while watching movies or listening to music, we can clearly perceive that our body is responding with difficult breathing, feeling a lump in the throat, or crying, etc. Jain et al. [6] proposed some body responses are always hidden to the perception that they are so subliminal that we could not even notice the changing, for example when we are watching movies we can't tell how our glucose levels are changing.

Body to Mind Model figure(see Figure.2.1) is excerpted from the research "The nature of feelings" of Damasio et al. [15]. Since the next sections of Body to Mind, Individual to Individual Mechanisms Framework are based on Body to Mind Model figure (see Figure.2.1), so this thesis made this editable version. Body to Mind Model figure(see Figure.2.1) will introduce the mechanism of how

aesthetics emotions are generated from exteroception to our mind.

In the Mind to Body Model, external changes such as aesthetic stimuli are displayed in the exteroceptive system which are vision, hearing, touch, taste and smell, then minds generate feelings, drives, emotions. Damasio et al. [15] proposed that feelings means mental experiences of body states, drives which are an innate physiological action aimed at satisfying basic physiological needs such as hunger, libido. Emotions are innate physiological actions that are triggered by perceiving or recalling external stimuli.

The Psycho-Physical Responses of Aesthetic Experiences

Scarinzi et al. [16] proposed that aesthetics experiences are as known as artistic experiences that arise in response to works of art or other aesthetic objects. Shelley et al. [17] proposed that aesthetic experience aims first at understanding and appreciation, at taking in the aesthetic properties of the object. Stecker et al. [18] proposes that aesthetic pleasure is pleasure taken in finding something valuable or in admiring it. Human artistic experiences have diverse manifestations such as associated various feelings, emotions, body reactions, physiological responses. There are various psychological responses to emotion and affect in Physiologica Responses to Aesthetic Experiences Figure(see Figure.2.2). Inside the affect-space framework for aesthetic experience, awe, chills, frisson, moves, thrills, transcendence, etc. are indices of aesthetic experience when humans are in a deep hedonic tone of positive affect valence.

Towards the psychological responses of aesthetic experience, there are various corresponding body responses like Psycho-physical responses to Aesthetic Experiences (see Figure.2.2). For example, the tingling sensation, goosebumps, shivers are the correlated body reactions to mental experience of frisson or chills. Physiological Responses to Aesthetic Experiences figure(see Figure.2.2) is excerpted from the research from Schubert et al. [1]. From the summary of physiological responses(see Figure.2.3), Armony et al. [2] proposed that heart rate, heart rate variability, blood pressure, electrodermal activity, respiratory rate are associated with each emotion.

Physiological Responses to Aesthetic Experiences figure(see Figure.2.2) is excerpted from the research from Armony et al. [2]. Since physiological responses

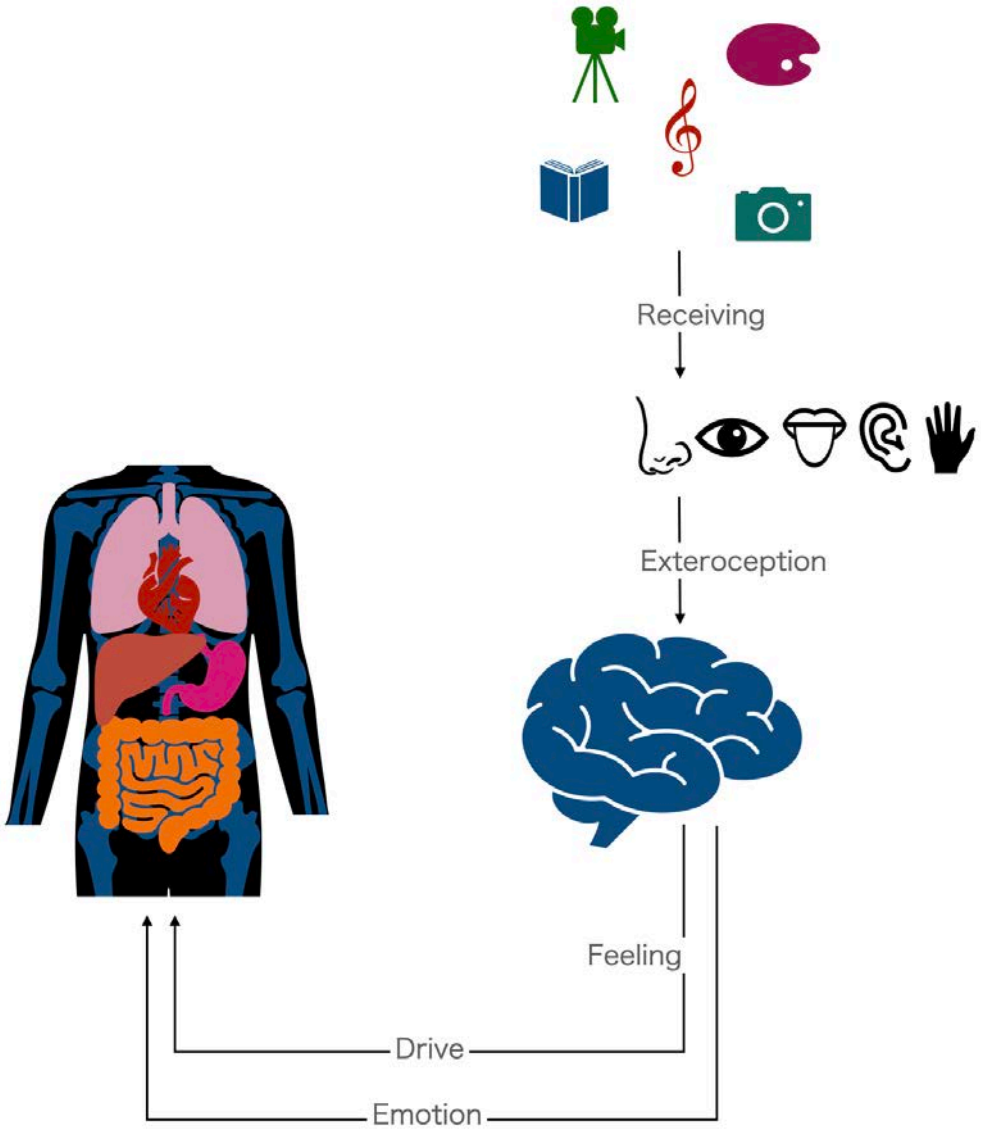


Figure 2.1 Mind to Body Model

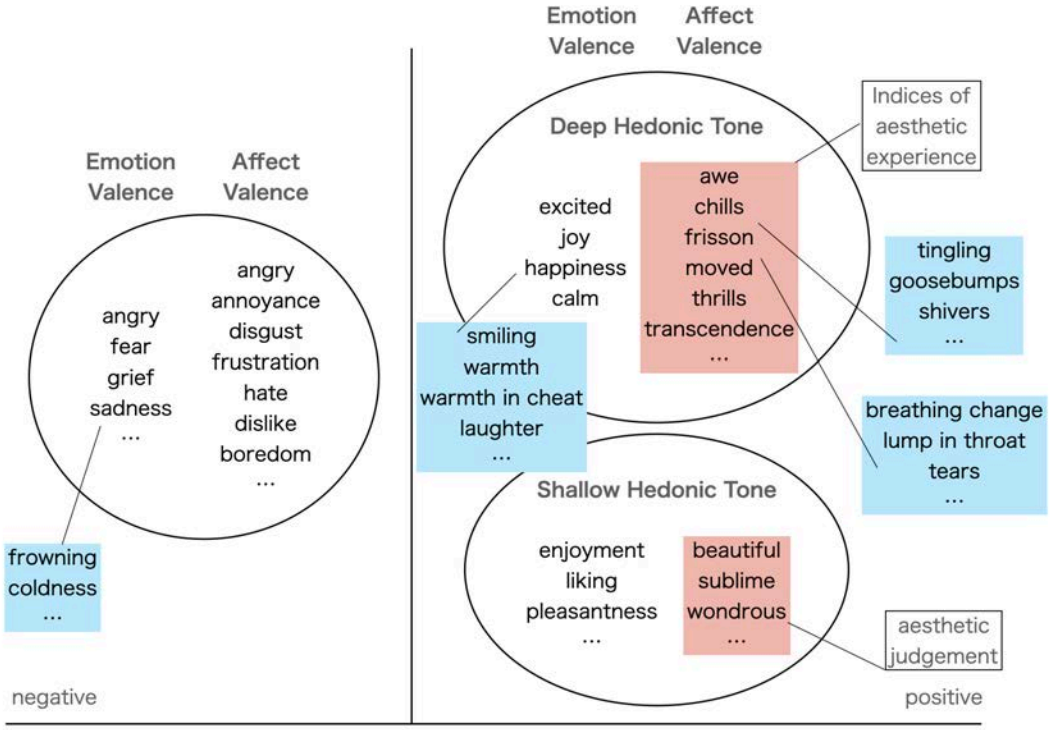


Figure 2.2 Psycho-physical responses to Aesthetic Experiences [1]

Organ	Fear	Anger	Disgust	Sadness	Happines	Frisson
Heart	↑HR ↓HRV ↑Blood pressure	↑HR ↓HRV ↑Blood pressure	↓HR ↑HRV ↑Blood pressure	↓HR ↑HRV ↓Blood pressure	↑HR ↓HRV ↑Blood pressure	↑HR ↓HRV ↑Blood pressure
Sweat Glands	↑EDA	↑EDA	↑EDA	↓EDA	↑EDA	↑EDA
Lungs	↑Respiratory rate	↑Respiratory rate	↑Respiratory rate	↑Respiratory rate	↑Respiratory rate	↑Respiratory rate

Figure 2.3 Physiological responses to Aesthetic Experiences [2]

of frisson is added in the chart to compare with other feelings and emotions. HR is heart rate which means the time of hearts beats every minute. HRV means high frequency components of heart rate variability. When HR is low, the difference between every two R-R intervals(calculated based on the interval between the peak R and the R point in the ECG signal complex) is big, HRV is higher. When HR is high, the difference between every two R-R intervals is small, HRV is lower(see Figure.2.4). Ramachandran et al. [19] proposed that EDA which means electrodermal activities is a direct measure of the amount of limbic (emotional) activation, EDA is also called as GSR (galvanic skin response), or SCR(skin conductance responses). EDA allows us to access a human's unconscious mental process. In the thesis, HR, HRV, EDA changes of frisson feeling will be mainly discussed.

Figure 2.4 Heart Rate, Heart Rate Variability, R-R intervals

Mind to body model explained the mechanism of receiving external aesthetic stimulus through exteroception system generated drives, emotions, or feelings and then drive the body to occur various reactions. Mind to body model also provided solid literature results of embodied aesthetic emotions occurring context which is a footstone of triggering frisson for this thesis.

2.1.3 Related Works of Neurological Aesthetics

These sections will mainly introduce the aesthetic works that are explored with neuroscience cognition especially in performing arts.

From the research of Peacock et al. [20] that before human interaction technology has been applied to aesthetic works, artists were already exploring art works with psychology experiments. Research of Berman et al. [21] shows that Alexander Nikolayevich Scriabin (Russian composer, pianist, 1871 - 1915) proposed his synesthetic perception of color hearing. Scriabin's color symbolism of synesthesia experiences[1] different colorful vision sensations and moods in response to different music chord stimuli. For instance, "yellow" are not assigned for chords of D, G Sharp, C, F Sharp, B, E, but also aims to convey the mood of joy or happiness.

The Boiling Mind [22] project showed a novel way of choreography stage production which enhances performer-audience connection through sonification and visualization of physiological sensing data. Boiling Mind also inspired this research a lot by blurring the boundaries between performers and audience and bringing the audience to the stage.

Un-Sychronized Orchestra[2] is a series of concerts which are created by Media artist Yoichi Ochiai cooperated with Japan Philharmonic Orchestra. This projecte reconstructs orchestra performances in the pandemic time with various technology such as synesthesia arousal, haptic interactions, visualizations to bring novel experiences and liveness to live music performances.

NEUROLIVE[3] is a research collaboration project between artists and scientists in European Research Council. This project started from 2020 which aims to investigate, practice, conceptualize, and measure the liveness of performances. In NEUROLIVE project's proposal, when performers and spectators are experiencing liveness, the psycho-physiological responses and neural involvement between

1 Interlude
`https://interlude.hk/scriabins-color-symbolism-music/`

2 Un Synchronized Orchestra
`https://www.w0w.co.jp/works/un_synchronized_orchestra`

3 NEUROLIVE
`https://neurolive.info/About`

performers and spectators' minds and bodies are quantitatively. This thesis is also trying to measure and quantify frisson in liveness of music performances through generating mind-body unison responses, and explore more about neuroscience and aesthetics.

ADVANCED ART DESIGN LAB [4] is established from 2021 in The University of Tokyo. This lab focuses on nature-centered, human-centered, inclusive design associated with art. Their music performance works, "BEATITUDES", "Nature-Centered Concert", "Hospital Concert" shifted more attention to the environment and their audiences which explored harmonious ways of expressing music, connecting nature and humans also enhancing the empathy and co-presences.

2.2. Body to Mind: Interoceptive Technologies

2.2.1 Interoception Interaction and Body to Mind Model

"We cry because we feel sad, or we feel sad because we cry?" This question from James-Lange theory of emotion [23] about the expression and experience of emotion can be regarded as that phenomenon of an body action could also evoke the associated emotion. Jain et al. [6] proposed that interoceptive technologies means inducing emotions from the body to mind. For example, the project from Fukushima et al. [24] showed that moving the muscles on the face to generate a smile may lead to the emotion of happiness in the mind. Interoception means we perceive through internal body states which cognition level could be from subliminal to metaconscious. Interoceptors are also called visceroceptors that detect stimuli in human internal organs as well as visceras: heart, kidneys, bladder, skin, hormones, lungs, stomach, intestines, bone, immune cells.

Body to Mind Model figure(see Figure.2.5) is excerpted from the research "The nature of feelings" of Damasio et al. [15]. Since the previous sections of body to mind, and the next section of individual to individual mechanisms framework is based on this Body to Mind Model figure, so this thesis made this editable version.

Traditionally, human computer interaction technologies stimulate conscious sen-

4 ADVANCED ART DESIGN LAB
https://www.aad.rcast.u-tokyo.ac.jp

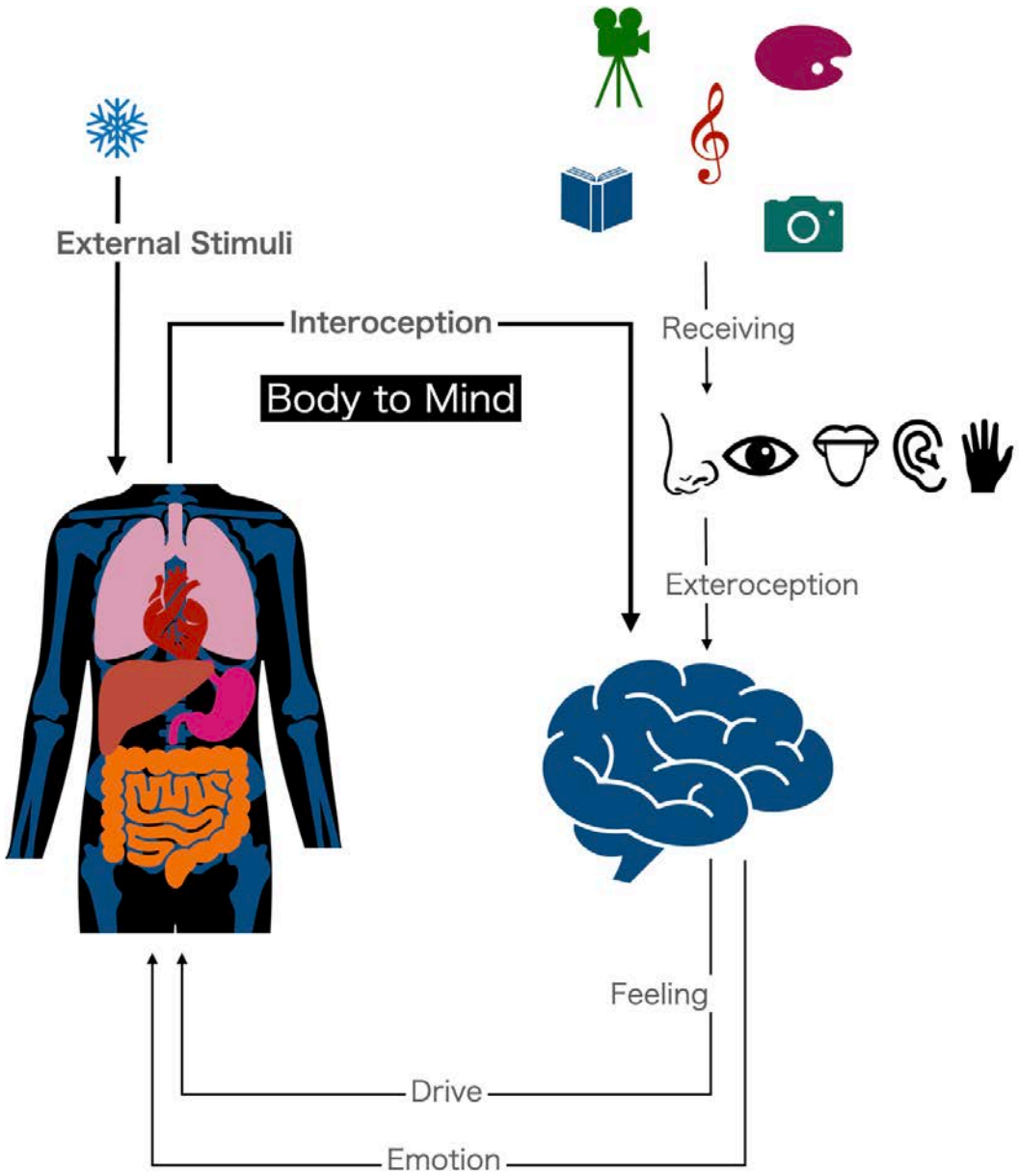


Figure 2.5 Body to Mind Model

sations in exteroceptive systems such as vision, hearing, smelling, gustation,and haptic. The body-mind model which utilizes interoceptive technologies to process body to mind pathways affects cognitive processes such as behavior and emotion. Body to Mind model helps in decreasing the information processing working load of memory through branching the perception and conscious information processing situations which creates more implicit interactions than exteroceptive interactions. Price et al. [25] proposed that interoceptive awareness is the ability to identify, access, understand, and respond appropriately to the patterns of internal signals. For example, interoception is when people find out pen is destroyed by someone intentionally, and people recognize their muscle tight end, fist clench, heartbeat quicker, face get warmer. People may interpret this sensation of feeling the emotion of anger. Craig et al. [26] proposed that interoception provides a distinct advantage to engage in life challenges and on-going adjustments.

Body to mind model which explained the mechanism of receiving external thermal stimulus through interoception system generated body responses and then drives minds to feel various drives, feelings, emotions. The body to mind model also provided a solid basis of interoceptive interaction technology and the utilization possibility for this thesis to trigger frisson.

2.2.2 Related Works of Interoceptive Interactions

Interoceptive interventions and interactions works usually used for behavioral, cognitive and affective interventions and regulations. Related works are embodying feelings through metasomatic interactions which aim to drive cognition or emotion by driving physical sensation. In the "Emotion Check" project [27], provides that false feedback of a slow heartbeat when people are detected to feel anxious. In the project from Nishimura et al. [28] shows that facilitating affection through haptic false feedback of quicker heartbeat. "Interactonia Balloon" [29] explores creating the feeling of tension and releasing of tension by simulating the respiratory status consciously through an interactive balloon art work. The work from Ban et al. [30] regulates the level of relaxation by controlling the rhythm of somatic sensation of breathing.

2.3. Individual to Individual: Contagious Embodied Responses

2.3.1 Emotional Contagion and Empathy

Emotional Contagion

"Say, cheese", people usually also start to smile when taking a photo of other people smiling. Laughing is contagious, crying, frowning, yawning and so on are also contagious. Prochazkova et al. [31] proposed that emotion contagion is the phenomenon of having one person ' s emotions and related behaviors directly trigger similar emotions and behaviors in other people, which takes on the sensory, motor, physiological ,affective states of others.

From the theory from Prochazkova et al. [31] that there are three-step processes in emotional contagion: mimicry, feedback, and sharing. The first step is mimicrying of motor sensory functions such as facial muscle movement, eye contact, or mimicrying of autonomic systems such as pupil diameter changing, blushing physiological synchrony. The second step is feedback which means the brain interprets the physical actions we mimic into associated feelings and switches on the feelings inside our brain. The third step is sharing which means we share the emotional experience with people we mimic until behaviors and emotions become synchronized. For instance, In the sample scenario, person A feels sleepy and tired so person A yawns. Person B saw A yawns, B also unconsciously yawned. B is yawning and B ' s brain correlates yawning with tired and sleepy, B starts to feel tired and sleepy. Now A and B are both tired and sleepy.

Empathy

Prochazkova et al [31] states that empathy is a mental process that enables humans to take another's perspective and relate to other people's emotions, thoughts and intentions. It is actually not an ability people are purely born with as perceptive thinking does not develop in our brain before the age of four. Certain aspects of empathy are developed later in life and learned through interactions.From Preston et al. [32] that emotion contagion is also the primitive form of empathy according to the perception-action model. Cognitive empathy is a more sophisticated

process and extension of emotion contagion. Empathy multilayered in firstly, emotional contagion, secondly, sympathetic activation and concern which occurs when experiencing excitement or stress and thirdly perspective-taking ability. De et al. [33] suggested that the basic development of empathy, emotional contagion matches the state of self and others, sympathetic concern usually companies with consolation, perspective-taking will target help objects.

2.3.2 Individual to Individual Model

In the social interaction context, people are not separated emotional islands. Rather, they continuously spread their own moods and receive and are influenced by others' moods. When they are together, they literally could catch each other's emotions like viruses, a phenomenon known as emotional contagion. This thesis is mainly trying to explore interoceptive interactions to create emotion contagion so as to arouse empathy in the context of performing art.

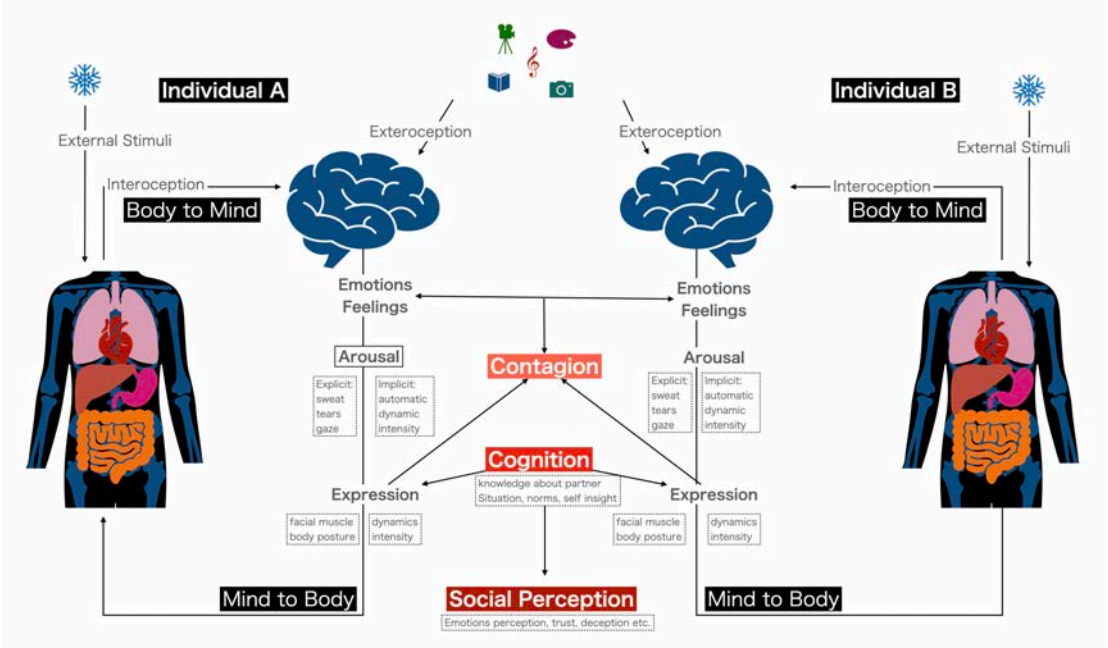


Figure 2.6 Individual to Individual Emotion Contagion Model

Individual to Individual Emotion Contagion Model figure(see Figure.2.1) is

modified from the research "The nature of feelings" of Damasio et al. [15] and "A neurocognitive model of emotional contagion" of Prochazkova et al. [31]. Individual to individual contagion model combined mind to body model and body to mind model and emotion contagion process to explain the mechanism of sharing body responses or emotions to create a contagion emotion of body reactions effect between individuals. The individual to individual contagion model also provided a solid basis for sharing frisson to create collective experiences and share personal psychological or physiological to have an effect on social significance.

2.4. Embodied Aesthetics Feeling: Frisson

2.4.1 Scientific Background

Frisson is a feeling, which is the mental experience of body states like goosebumps, shivers, skin tingling. Frisson is described as a sudden strong feeling of excitement often together with so-called goosebumps. It ' s known as aesthetic chills or musical chills which refer to a set of bodily sensations, such as shivers, or piloerection (goosebumps), transient paresthesia (skin tingling), sometimes along with mydriasis (pupil dilation). From the defination of Schoeller et al. [34] that the embodied feeling of frisson induced body sensations that it ' s a physical feeling of shivers down your spine and tingling on the nape of your neck and the back of your arms. Having goosebumps is a physiological phenomenon that small bumps appear on the skin surface as the hairs stand up. Frisson can be caused by cold, fear or a strong emotional stimulus. Frisson or "having goosebumps" is strictly personal with highly individual differences rather than a shareable experience among people. However, while some people have a strong frisson response, not all people perceive these moments of mind-body dualism naturally that are not shareable with others.

2.4.2 The Psycho-Physical Response of Frisson

In daily life or in the context of a musical performance or a concert ,when live performances deeply resonate with us, our bodies respond with physiological reactions - we call this phenomenon "frisson". Frisson is not a shareable experience

among people. Some people are more likely to feel frissons while others are less. For example, some people will feel goosebumps when they listen to a musical performance, while others do not. Even when we are together with others, feeling goosebumps is a strictly personal experience. This thesis aims to understand, augment and share how we experience frisson in live music performances to free our body and brain to try more distinctive experiences. People can have goosebumps as a reaction to coldness, but goosebumps can also be a physiological response to an emotional experience.

Frisson is a reappraisal response since we feel frisson because of fear or cold so as to take actions to survive[5]. Nowadays frisson is shifting from response to danger to aesthetic emotions. Feeling frissons or aesthetic chills frequently is considered a sign of enjoyment and pleasure. Frisson has universality that across cultural and context boundaries, humans could feel frisson, other species such as cats, porcupines can feel piloerection (goosebumps). Mccrae et al. [35] and Panksepp et al. [36] states that frisson is a strong emotional indicator as well which is usually triggered by intense and discrete emotion. Silvia et al. [37] states that risson is a somatic maker which refers to a physically felt signature of an emotion.Haar et al. [38] states that frisson or chills have been related to various complex emotional states such as awe, insight, prosocial emotions, and being moved such as the emotions in the Distinct Varieties of Aesthetic Chills diagram2.7.

2.4.3 Causing, Detecting, Triggering, Sharing of Frisson

Causing of Frisson

The cause of frisson could be mainly concluded in four factors like in the formula below. Pgoosebumps = Cf(Sc + Id + Ap)[6] Pgoosebumps means the percentage chance of getting goosebumps. Cf refers to cognitive factors. Sc means social and environmental context. Id means individual differences. Ap means acoustic

5 GooseLab
http://www.goosecam.de/index.html

6 Barclaycard
https://home.barclaycard/insights/2018/09/giving-goosebumps---the-importance-of-customer-experience/

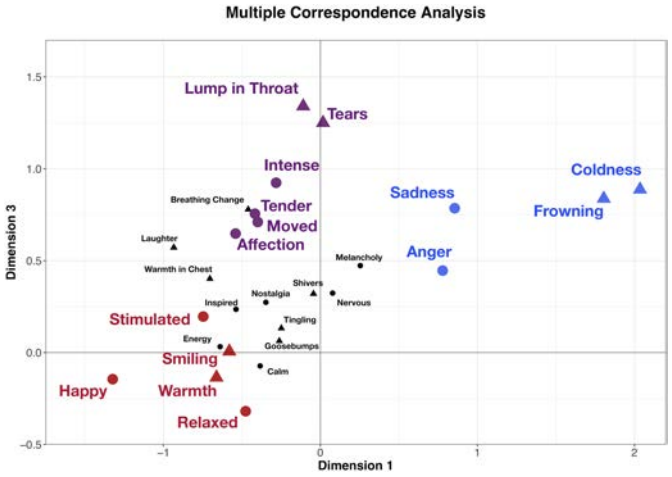


Figure 2.7 Distinct Varieties of Aesthetic Chills [3]

properties. From this formula, Pgoosebumps = Cf(Sc + Id + Ap), the percentage chance of getting goosebumps are caused by Cognitive factors (Cf), Social and environmental context (Sc), Individual differences (Id), Acoustic properties (Ap). Cognitive factors mean personal attachment to certain music. Social and environmental context means being alone or being with a group of people. Individual differences mean individual characters or openness toward things and experiences. Acoustic properties mean features of the music such as volumes, rhythms. From this, the scenario of live music performance could cover the four of the factors.

Measuring of Frisson

There are many ways of measuring chills or goosebumps including physiological sensing, optical measure, self assessment. In order to find the way of automatic detection of frisson in live music performances context, unobtrusive and unconscious measurements are the main methods to be discussed in this section. The existing method of frisson recordings are as fellows: The methodology of utilizing visible topological states to objectively detect piloerection was developed at

(a) *GooseCam*

(b) *CapacitivePiloerectionSensor*

Figure 2.8 Measuring Goosebumps Methods [4] [5]

this research[7](See as2.8a). Through recording the spatial frequency changes in the visible domain, this goosecam is able to accurately detect the happening of goosebumps. Research from Benedek et al. [4] combined the goosecam(see Figure.2.8a) for continuous measurement of piloerection and self-report method to record goosebumps which provided a reliable mapping of emotion and occurrences of visible piloerection. However, the recording of frisson needs a bigger recording zone on the body skin since the area of feelings frisson differs in individuals, this goosecam will not be suitable for various areas of frisson detection. In the context of live music performance, lighter and convenient wearable devices are vital for the better experience of performances.

Kim et al. [5] proposed measuring mechanical changes in the skin to detect goosebumps through a capacitive skin piloerection sensor(see Figure.2.8b) is the method developed by this research. This is a consistent and convenient measurement though it's not applicable for live concerts due to the limited area and cost, and difficult disinfection methods limitation in this pandemic time.

In the work of Grewe et al. [39] that revealed the correlationships with physiological responses between emotions and chills. The two physiological signals of SCR(Skin Conductance Response , is also called Electrodermal activity) and HR (Heart Rate) reported peaks during the chills sections of music. Electrodermal activity (EDA) is an authoritative indicator of emotional arousal associated with

7 GooseLab
`http://www.goosecam.de/index.html`

human behavior. EDA is also often referred to as galvanic skin response or GSR and EDA reflects the sympathetic nervous system activities which are affected by the activation of the psychological system and emotion. The well-standardized EDA output is for peak detection. Heart rate (HR) is a reliable indicator of emotional valence. EDA Explorer[8] from MIT Media Lab tool is effiencient as well Benedek et al. [40] also found out the increase of phasic electrodermal activity and increased respiration depth are primarily associated with piloerection. Data set from Zhang et al. [41] included 457 people ' s simultaneous electrodermal activity responses to music emotion recognition. The research from Grewe et al. [42] looked into electrodermal activity of chills stimulated from four different sensory domains that are tactile, aural, visual, gustatory. In their experiment setup, participants were asked to press the button of a computer mouse whenever they perceived a feeling of frisson or chill during a stimulus with an explanation of chills. They also provided a control group to excerpt the possible effect on physiological data from motor action when pressing the button. In summary of the measurements of frisson mentioned above, Frisson could assess via a combined self-report and physiological (galvanic skin response) measurement. Detecting physiological signals such as electrodermal activity, respiratory rate and heart rate combined with self-report are the most efficient and common ways. Though the physiological response patterns of piloerection is also under discussion in the research mentioned above, it provided an insight and possibility to detect frisson based on the specific model or pattern of frisson. In order to detect frisson automatically in the live concerts context, collecting frisson data and the training model of frisson is necessary. The research, "Suppressing the Chills" [43] suggests using an analog slider for continuous self-report measurement along with skin conductance measurement. Compared with button pressing, it might be easier to find the frisson EDA pattern.

In order to get an overview of the training model of physiological data of a phenomenon, this related work about convulsive seizure detection. Poh et al. [44] provides a concrete workflow from observing phenomenon to recording physiological responses data and motor actions data, automatic detecting convulsive

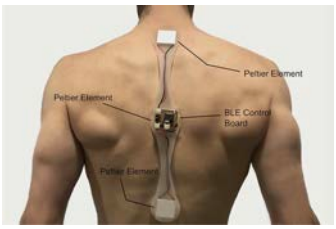
8 EDA Explorer
`https://eda-explorer.media.mit.edu`

seizure through machine learning, and applying the model into medical concrete practice with over 96 percent accuracy. Poh et al. [45] analyzed electrodermal activity(EDA) and accelerometry using a sliding window of 10 seconds to reduce data error from non-motor and non-rhythmic epochs and then extract various features. By utilizing the SVM (support vector machine) algorithm. SVM classifierswere constructed to produce posterior probability estimates for each feature vector. A decision threshold was applied to the posterior probability estimates to assign each epoch to a seizure or non-seizure class.

This framework is appropriate to frisson model training as well except frisson responses are more instantaneous and interindividual different.

Triggering of Frisson

Based on the factors that cause frisson, there are a lot of related works exploring triggering frisson from external stimulus. Grewe et al. [42] proved that among different sensory domains, tactile feedback is the most frisson-tending trigger such as moving feathers around the neck. In the "The Thermal Feedback Influencer" [46] project that sudden cold thermal feedback in the context of listening to music is also proved to be the obvious trigger of frisson and could enhance music listening experience. The project "Frisson" [6] created a spine-attached thermal band as an aesthetic prosthesis(see Figure.2.9a)to induce emotions from the body up through interoceptive technologies. Work from Fukushima et al. [7](see Figure.2.9b) and "MAGHair" [47] project controls and stimulate body hair to augment the feeling of surprises and awe. Kato et al. [48] simulated the feeling of bugs climbing on the skin through tactile haptic feedback to create a sensing of disgusting. Colver et al. [49] proposed aural stimuli such as aesthetic work of music or sound are also relatively easy to trigger frisson. To trigger frisson, not only through different pitch, rhythm, volume of the music and sound itself which create various abundant music expressions and approaches matters for triggering people to feel frisson, but also spatial sound technologies could have influence on generating frisson. For example, Miyazaki et al. [50] explored enhancing goosebump binaural recording sound technology in ASMR triggers.



(a)
FrissonWearableProsthesis

(b)
SimulatingBodyHairtoCreateEmotion

Figure 2.9 Interoceptive Technology of Enhancing Frisson and Awe [6] [7]

Sharing of Frisson

Previous works related to frisson sharing exist, Neidlinger et al. [8] have explored externalizing and sharing the feeling of goosebumps with color visualizations and inflatable textiles in the work "AWElectric"(see Figure.2.10). However evaluation on the user experience is not accessible yet. So far no attempts have been made to share frisson collectively during music performances. To bridge this gap, this thesis introduces Frisson Waves: a haptic metasomatic interaction system based on physiological sensing that detects, generates, and shares frisson.

Figure 2.10 AWElectric: Share Goosebumps [8]

Chapter 3
Concept Design

3.1. Overview

Sharing and experiencing unshareable sensations such as frisson in realtime is the primitive attempt of freeing our bodies and minds. In addition, the loss of liveness and sensations because of the pandemic led to recessive influence on current society and human living situation. In order to overcome the difficulty of real time sensations sharing and the situation of the pandemic as well as to bring back and share the feeling from liveness, this research explored multiple tryouts of somatosensory interactions works and formed the current concept of sharing frisson in live music performances with physiological sensing technology and interoceptive haptic technology.

3.2. Observation of Classical Music Performances

This session will talk about how the concept design is developed from the initial idea of augmenting music performances' expressiveness to somatosensory sharing in live music performances. Initially, through the field work of going to classical concerts which are held by the Tokyo Philharmonic Orchestra every month, the idea is mainly triggered by noticing that traditional music performances are usually one-way expressions by the artist and expressed from the artist to the listeners. Therefore, this research aims to design and develop an interactive music performance based on musical perception of the performer. For example, through a pre-interview, the interpreted and sensory perception of the music piece will be designed into real time visualization during performance. Through the augmented performance, this research aims to express the performer's feeling and enhance the

empathy and connection between listeners and performers. This research aimed to find out how the mediation technology augments the performances. Then this research plans to narrow down the research range of music performances into classical piano performances. Before the performer plays, the performer will be interviewed about their feeling and understating of music pieces like their personal memory and emotion or imagination through a designed toolkit. The content of the interview and the real-time physiological data of the performer and the listeners will be visualized during the performance through projection mapping. After the performance, feedback from the experiment subjects will be collected to evaluate the research. Therefore, the field work of live piano performances observation and physiological data recording is conducted with the help of Xuan He(Piano Performance Major of Graduate Student of Tokyo University of the Arts).

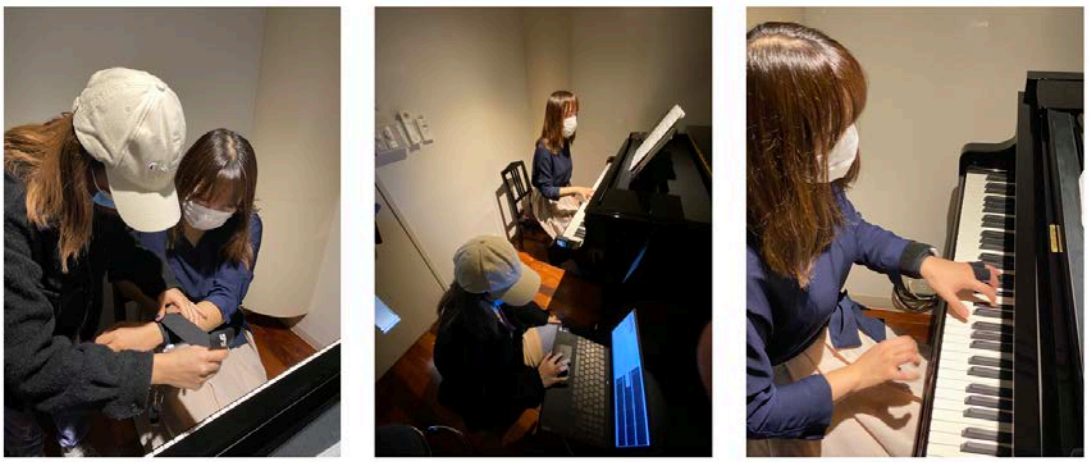


Figure 3.1 Piano Performance Field Work

During the piano playing, the physiological sensing wristband [51] is worn on the hand. Due to the fast movement of the hands and fingers, the recording of electrodermal activity and blood volume pulse data are unsteady and not accurate. Also from the feedback of the pianist, wearable devices on the fingers caused a distinct influence on the performing experience. Due to this feedback, the wristband's electrodermal activity mental sensor is adjusted to two conductive silicone patch which could be attached on the neck.

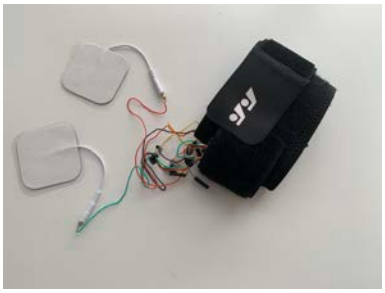


Figure 3.2 Conductive Patch of Wristband Electrodermal Activity Sensor

3.2.1 Iteration Zero: Visual Interactive Piano

Based on the field work and observation, the goal of sharing performers ' feeling and imagination are designed through real-time visualization of music and physiological data with projection mapping. The visualization of MIDI interaction piano performance implementation is conducted as depicted in the Visual Interactive Piano Performance Setup(see Figure.3.3). 88 keys are assigned mapped in a color lamp from blue to red, the force of hitting piano keys is mapped as the size of the objects. Objects are designed before the playing which the player thinks is more close to the imagination. For example, pieces from Bach are represented with symmetrical circles, pieces from Debussy are represented with abstract lines.

This prototype aimed to make a demo of the augmented classical piano performance. Based on this experiment, this prototype wanted to look into how the mediation techniques can be applied to performances in general. However, there were two main obstacles of this version of prototype to realize the goal of sharing feelings. Firstly, the visualization is not triggering the audience's similar feeling or imagination real time from performers such as feelings of frisson or imagination when playing. Back to 1997, artists such as Sakamoto Ryuichi, Iwa toshio already did a lot of experiments with visual interactive music playing[1]. It becomes difficult to find novel and interesting research questions. Secondly, the modified physiological sensing wristband was not working for putting on the ear for performer,

1 Divertimento for an Image Playing Piano Sakamoto Ryuichi and Iwai Toshio's Experiment InterCommunication No.20
https://www.ntticc.or.jp/pub/ic_mag/ic020/intercity/asada_E.html

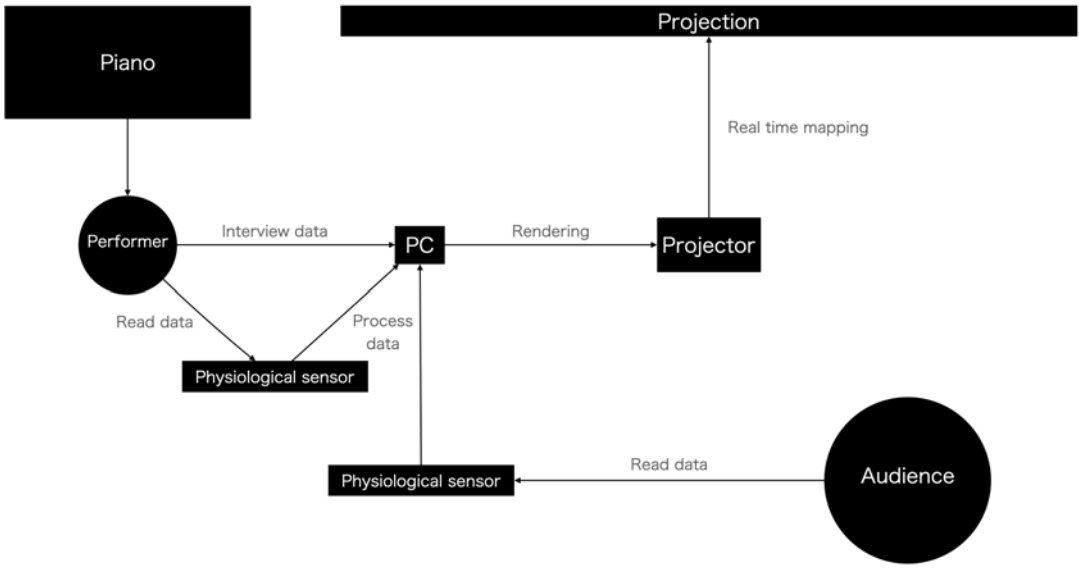


Figure 3.3 Visual Interactive Piano Performance Setup

Figure 3.4 Visual Interactive Piano Performance

so it was hard to streaming piano music performers real time physiological data.

3.3. Frisson Waves Design Concept

3.3.1 Overview

When music deeply resonates with us, we may experience a sudden feeling of excitement. Frisson is a psycho-physiological phenomenon commonly described as having goosebumps, or feeling shivers down one's spine. Frisson can happen to some people frequently while others may never experience it [52]. As a personal experience, it's also difficult to share with others. Frisson Waves describes a novel way of sharing frisson through a haptic metasomatic interaction system based on physiological sensing and thermal-haptic feedback. The goals of this research are: Firstly, to detect and induce frisson so as to share among audience and performers during live music performances; Secondly, to explore to what extent is frisson shareable through our system and how can frisson sharing augment live music performances.

3.3.2 Concept Design

Frisson is a psycho-physiological response that can be triggered from external stimuli such as music or intense emotions. It is akin to goosebumps or shivers, a skin tingling sensation, yet there have been few works that leverage this phenomena.

This research aims to make the personal feeling of frisson a shareable experience through thermal-haptic technology and physiological sensing so as to augment music performance. Frisson Waves system consists of two devices: The first device is a wristband which is embedded with an electrodermal activity sensor and blood volume pulse sensor to detect physiological changes of sudden changes in skin properties and heart rate variability related to frisson [51], The second device is a neckband with haptic actuators and Peltier thermoelectric modules to induce frisson.

Using this described setup(see Figure3.5), this system enables us to detect and transmit the sensation of feeling frisson to the nearby spectators and then throughout the audience in designed macroscopical patterns like a wave or ripples. During

Figure 3.5 Neckband and Wristband Setup

the musical performance, each of the Frisson Waves devices are associated with a seat, allowing us to know their relative positions. Once a feeling of frisson is detected from one audience member, the neckband will try to generate more frissons on nearby audiences to create a empatic propagating experience effect akin to waves flowing or a water droplet where the nearby audience receives stronger haptic feedback. In the performances, not only music and sound waves are flowing, but also people ' s feelings and emotions are surging and sharing like how waves moving up-down in a circular motion and flowing away to transfer energy. That ' s also why the project is called Frisson Waves.

This research is aimed to design real-time body feeling "frisson" sharing and aiming to enhance live music performance experience, evoking connectedness and increase the awareness of accompaniment in live concerts.

There are three experimental live music performances in total scheduled for this concept ' s user test, Frisson Waves Concert I.(see Figure.B.11). and II. (See as figureC.5).and Karuizawa International Youth Concert in 2021 (see Figure.D.1). The Frisson Waves Concert.I performance happened on April 9th,2021 with 20 audiences which aimed to observe, understand, and record the audience and performers ' frisson feeling. The collaboration with Karuizawa International Youth Concert which is scheduled on Oct.3th, 2021 with 100 audiences.

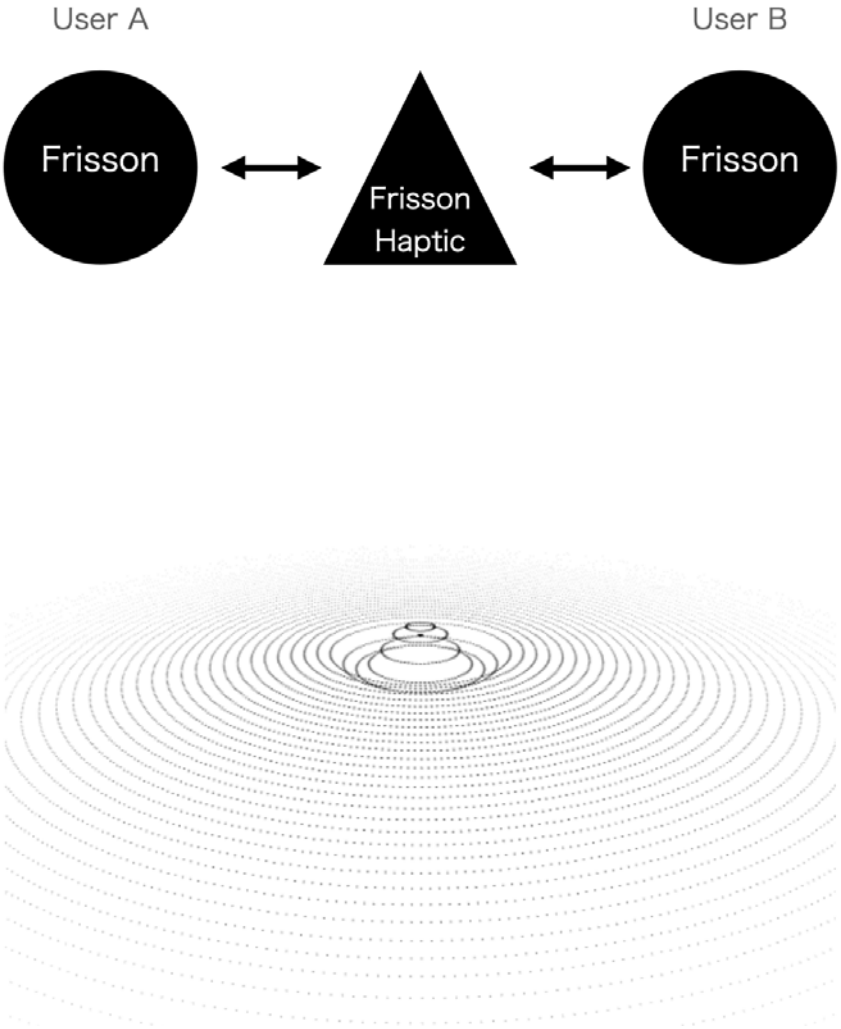


Figure 3.6 Frisson Sharing Concept

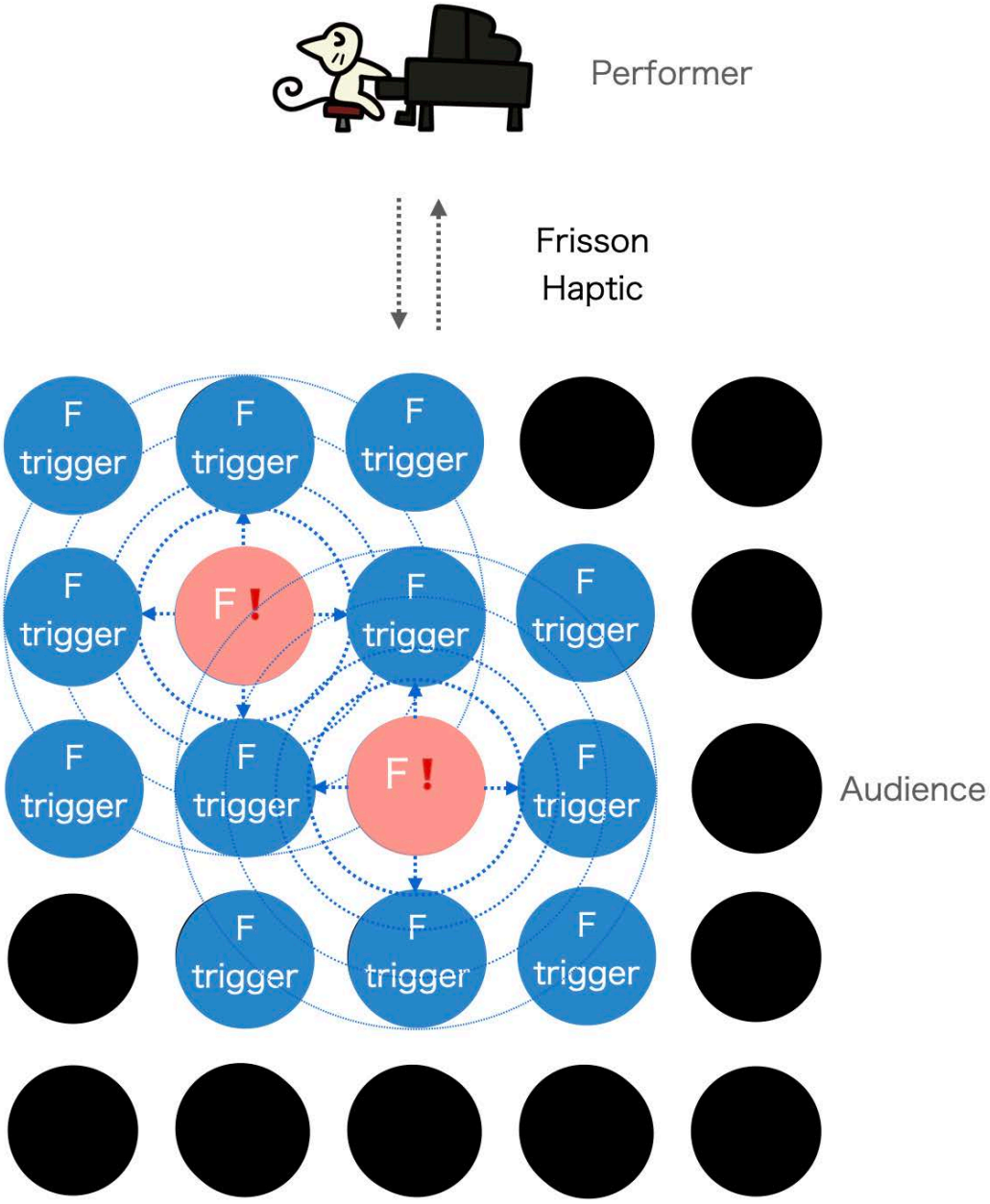


Figure 3.7 Frisson Sharing in a Pattern of Wave of Ripple

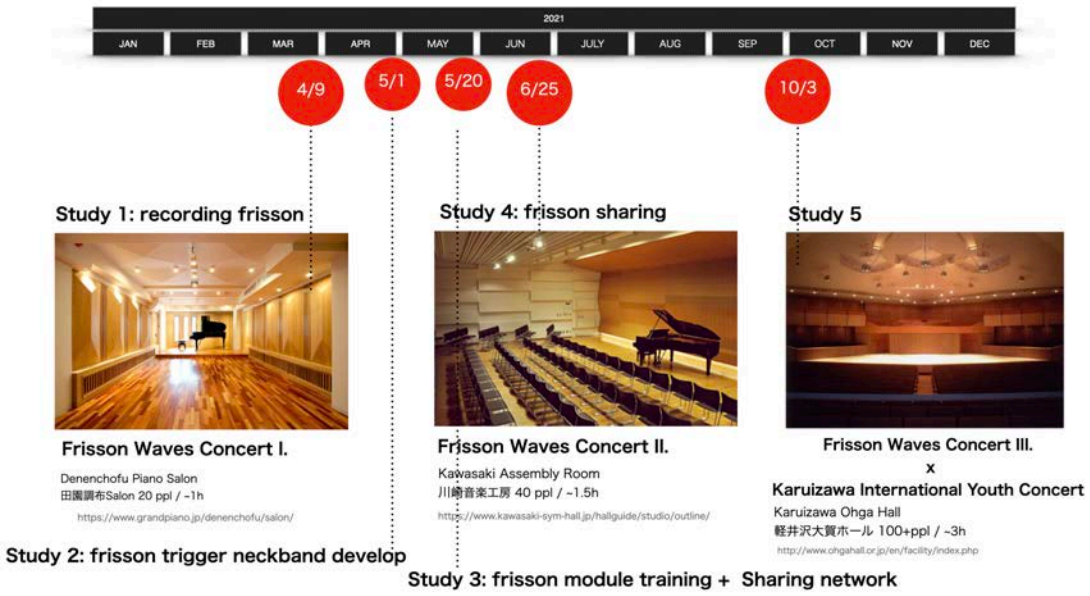


Figure 3.8 Timeline of Studies

3.4. Prototype Design

3.4.1 Iteration One: Frisson Waves Carpet with Servos Actuators

The primitive idea is inspired by my previous work of hedgehog which aims to create fear to trigger frisson through simulation of spiky thorns or spines erection. The idea is about designing a tangible carpet with spikes that simulates people ' s frisson feeling. When one person is detected to feel frisson, the spikes correlated with the location of the person will stand up and move sequentially to all other directions like waves. So people ' s frisson feelings will be simulated as spikes fluctuate in a motion of waves on the giant carpet. However, the visualization, tangibility, and inflation of goose bumps usually don ' t actually trigger frisson and may cause danger to people in live concerts. It will cost incredibly high to build and need and space to to make a giant tangible carpet to cover everyone in the concert and it is nearly impossible for current concert context under pandemic situation. The futurablity of the giant carpet will be difficult to match the cost

of it.

3.4.2 Iteration Two: Thermo-Haptic Neckband with Directional Hint

The second frisson triggering device is designed like a neckband with six haptic actuators to generate wave flowing direction from one side to another and two Peltier thermoelectric modules on the sides to generate cold sensation feedback.

In this case, when users are in a live concert, they can sense others ' frisson through the direction. For example, if the vibrotactile actuators vibrate sequentially from left to right on the user ' s neck, this direction cue provides the information that the person sitting left from the user is feeling frisson. Some feedback from people who test it feels like the cold sensation is flowing from one side to another and reported feeling interesting, some people reported the neckband ' s cold sensations with the direction from vibrotactile actuators feels like water flowing on the neck which matches with the concept of waves.

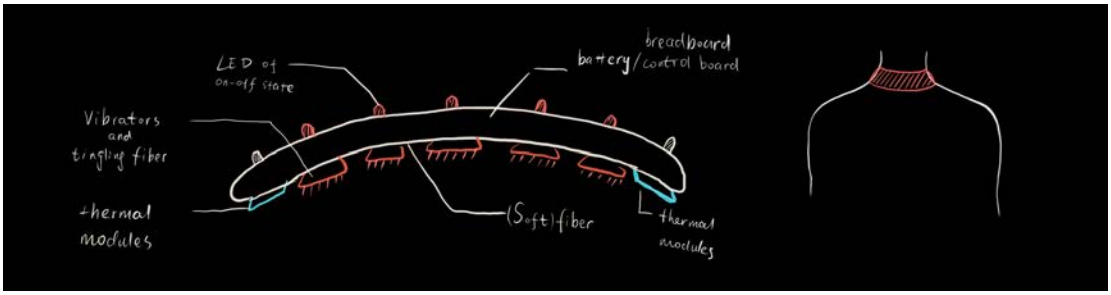


Figure 3.9 Initial Design of Neckband

3.4.3 Iteration Three: Thermo-Haptic Neckband with Direction and Heartbeat

This version of the neckband is the same setup with the iteration two but provides real time heartbeat feedback streamed from a wristband. In this version, the four haptic actuators of the neckband are designed to generate wave flowing direction on the neck, two haptic actuators are designed to generate heartbeat-like rhythm

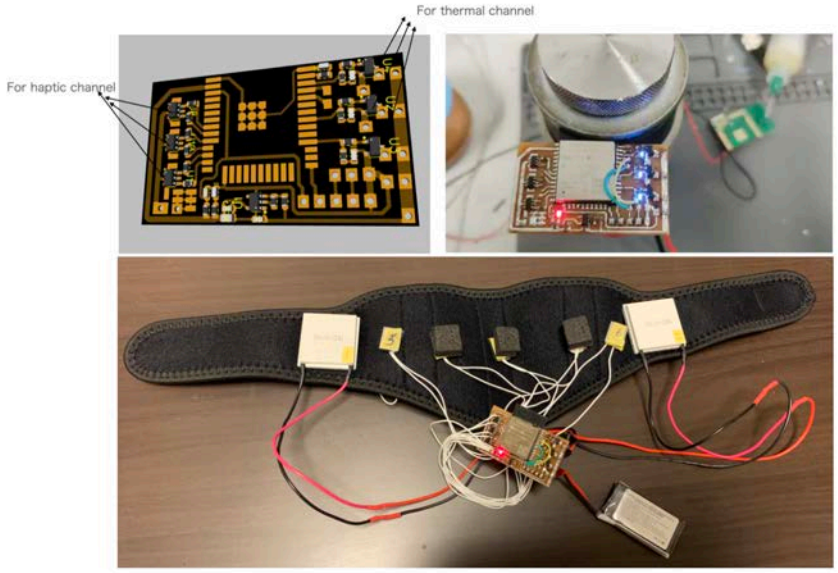


Figure 3.10 Control Board and Neckband One

of haptic feedback which is streaming from the wristband when another user is wearing the wristband. Two Peltier thermoelectric modules on the two sides of the neck are designed to generate cold sensation feedback like the iteration two set up.

This version of neckband is tested in two audiences in the context of a piano performance. One user is wearing the wristband which is streaming the real time heartbeat directly to the neckband to activate thermal modules to generate cold sensations and activate the vibration actuators in which four actuators are sequentially vibrating on the neck to provide direction information and two actuators are simulating the real time heart beats from the other user. Feedback from two pairs of users shows the heartbeat simulation is interesting and feels more connected with the other person who expresses their heart beat. Though to some extent, the two versions of neckband could trigger frisson feeling to people who wear it, the biggest problem of the iteration two and three is that the vibrotactile actuators are distracting users ' perception from both conscious and noise sides. The vibrotactile actuators are making quite noticeable sounds which are very disrup-

tive for music concerts. The direction sensation and heartbeat vibration feeling provided from vibrotactile actuators are actually conscious capacity costing and distracting in a context of music performances for both performer and audience. Therefore, this device is designed to minimize all the functions to only activate the two Peltier thermoelectric modules in the latest version prototype.

3.4.4 Iteration Four: Thermo-Haptic Neckband with Directional Cold Sensation

This version(see Figure.3.5) of neckband with two thermal modules that provide directional cold sensation aims to explore more with thermal perception of people. The two thermal modules will be activated in a sequence to, so the cold sensation will move from the same direction of the people who are feeling frisson. This version of prototype is implemented in the Frisson Waves Concert II.

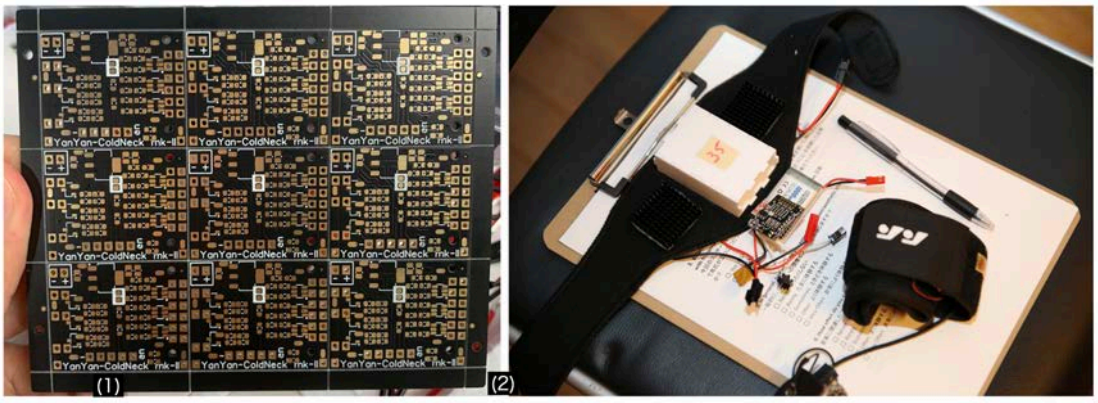


Figure 3.11 Control Board and Neckband Two

Frisson Waves Simulation

Frisson responses from the audience are simulated as waves in Touchdesigner. One version is abstract wave, another version is more impressionistic minimalist wave simulation. The location of the audience member who is detected to have frisson is mapped on the same coordinates of the wave simulation which could be more intuitive for spectators.

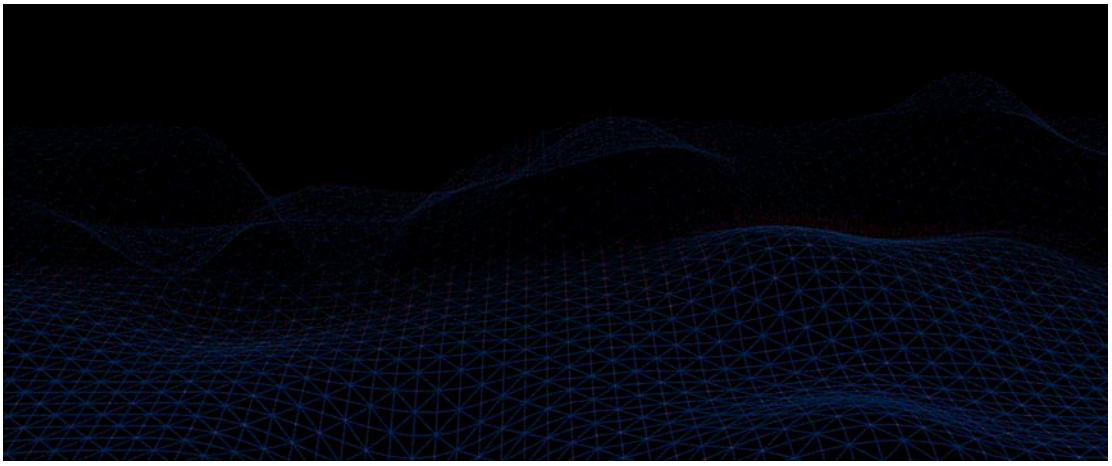


Figure 3.12 Frisson Waves Simulation in Touchdesigner

3.5. System Development Methodology

The system consists of three parts: triggering frisson, detecting frisson automatically, sharing frisson. Firstly, triggering frisson through cold sensations from a wearable neckband which is equipped with two Peltier thermal modules. Secondly, detecting frisson in real time based on physiological sensing and frisson machine learning model. Thirdly, sharing frisson to other audience members when frisson is detected on one of them based on the signals from wristbands and model classification score.

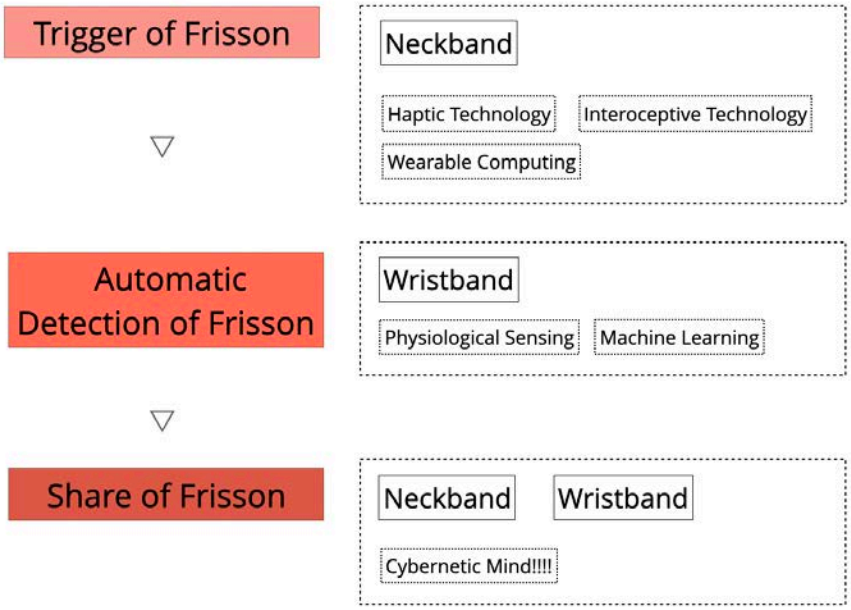


Figure 3.13 System Development Methodology

Chapter 4
Frisson Waves System Development

4.1. Overview

The Frisson Waves system conceptually can be divided into three parts as follows(see Figure.4.1).

- The first part is trigger of frisson through a thermo-haptic neckband with Peltier thermoelectric modules and a series of vibro-tactile actuators in a line.
- The second part is detection of frisson automatically in real time using data from a smart wristband that records and wirelessly streams physiological data to a machine learning frisson model that can detect the frisson signals approximately in real time.
- The third part is sharing the frisson between the audience members sitting next to each other by activating the thermo-haptic neck bands to induce frisson so to share frisson.

4.2. Inducing Frisson: Thermo-haptic Neckband

In order to trigger frisson, this research iterated multiple designs of frisson triggering ways including visual effects and tangible thorns which can be viewed in Chapter 3 Design Concept. The latest version, of the thermo-haptic neckband, includes two Peltier thermoelectric modules and up to six haptic vibrotactile actuators fixed on a neckband as shown in Fig.4.4. Each Peltier thermoelectric

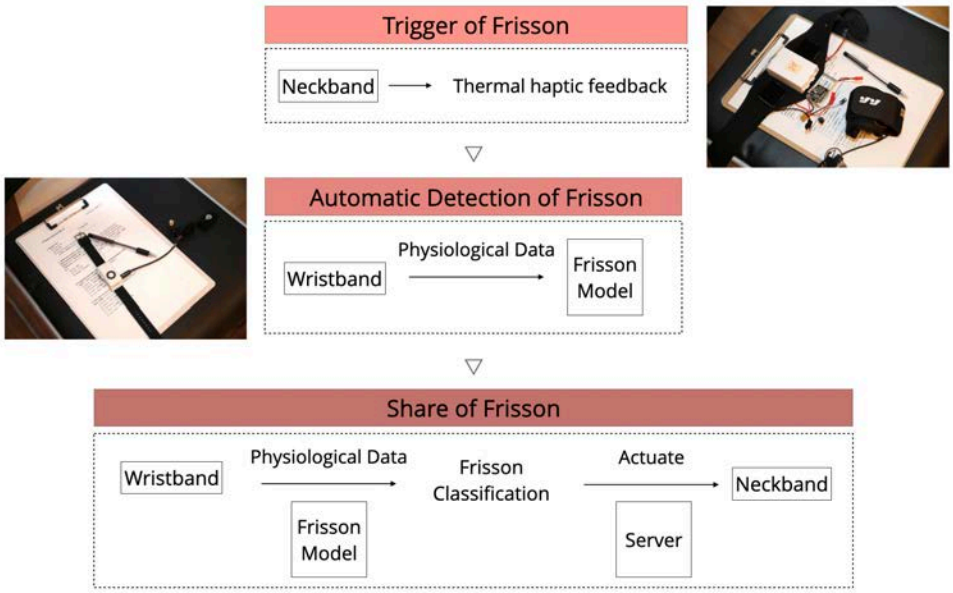


Figure 4.1 System Development Framework

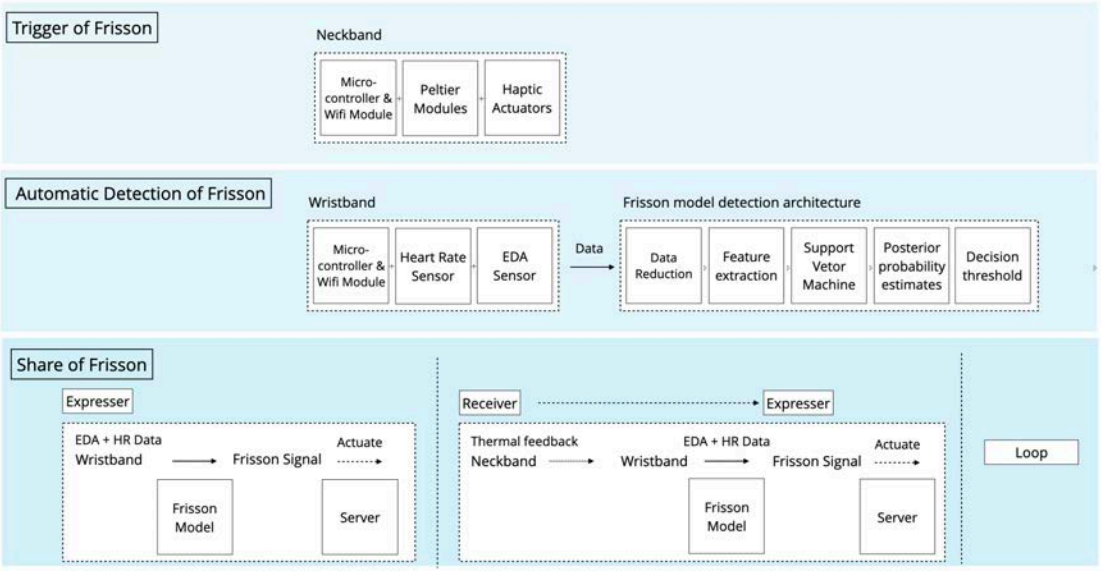


Figure 4.2 System Development Framework Details

module has an exposed heatsink attached to the side opposite to the user's skin. The device is controlled by an ESP32 module and communicates with the software using WiFi. In the event of an activation, each thermal module is turned on for 5 seconds with consecutive 5 seconds of cool-down time, allowing the heatsink to diffuse the accumulated heat, which ensures the constant performance of the thermal actuation. For safety reasons the battery is protected with a 2.5 A PPTC fuse and the board is covered by a small box.

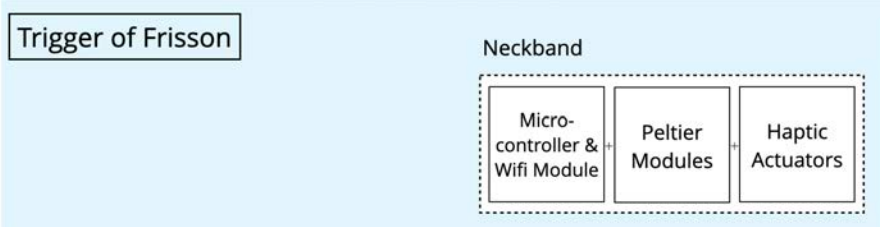


Figure 4.3 Frisson Trigger Thermo-Haptic Framework

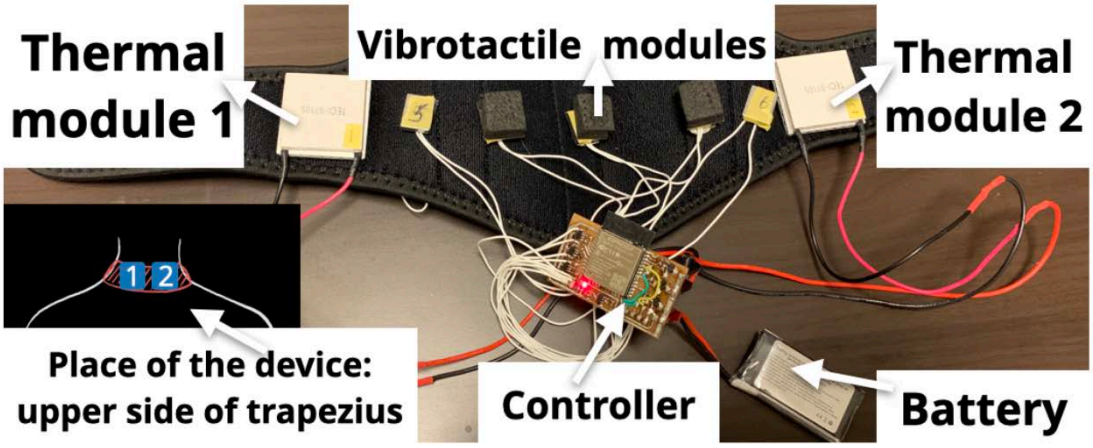


Figure 4.4 Neckband Development

4.3. Automatic Detecting Frisson

Automatic detection of frisson is performed using a smart physiological sensing wristband that measures blood volume pulse and electrodermal activity. Devices are also utilizing ESP32 modules and use WiFi to stream the recorded data. Heart activity is measured using a reflection-based optic plethysmograph. Electrodermal activity is referred to the change of skin conductance measured with a Wheatstone bridge and a differential ADC. Then heart rate variability and electrodermal activity-related features are extracted that are used to train the SVN frisson detection model. For the final design, the model is run every 10 seconds for each participant and operates with adjustable sliding window size which is usually within several minutes of data. From the literature reviews, physiological signals of electrodermal activity(EDA) and heart rate(HR) variability have the most obvious pattern changes and the measurements of these two properties are seemingly the most appropriate and suitable to conduct an in the wild experiment during a live music performance.

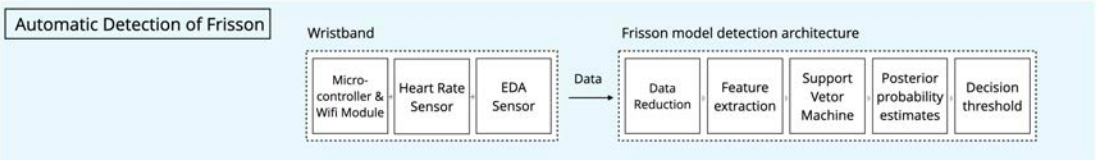


Figure 4.5 Automatic Detection Frisson Framework

4.4. Sharing Frisson

The flow of sharing frisson is as shown in the figure(see Figure.4.6. Firstly, detecting frisson signal through wristbands and frisson model calculation in real time. Secondly, server will activate neckbands of people sitting next to the person who's frisson was detected, so they will become the receivers of the frisson. If the neckband induced frisson successfully on the user, the wristband of the user will detect frisson signal and the server will activate the user's adjacent neckbands thus the

user becomes the frisson expresser. Thereby, the system technically enables to transmit frisson in a pattern like wave or a ripple.

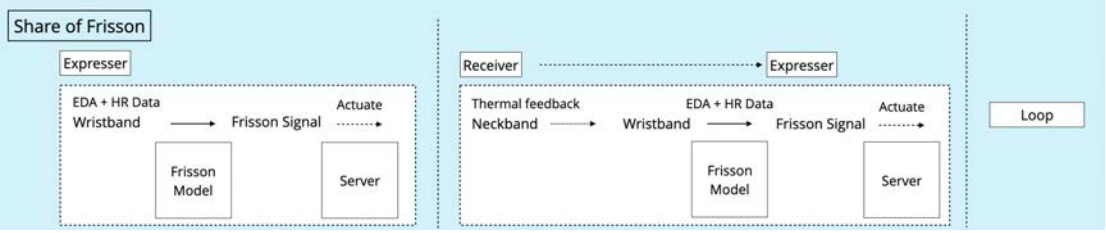


Figure 4.6 Frisson Sharing Framework

Chapter 5
Proof of Concept

5.1. Pilot Study: Recording Frisson in Liveness: Workshop Concert.I

In order to understand, record how people feel frisson in actual live music performance context, we scheduled the Frisson Waves Concert.I on April.9th, 2021. 20 audience members (female=13; male=7) from 4 countries between 20 and 60 years (average age=29.5) attended the first one-hour workshop in April which included a 40-minute classical piano recital.

Seven audience members wore our wristbands [51] with a frisson-report button attached because of physiological data to detect frisson accurately based on bio sensing. To achieve this, we integrated a self-report button into the wristband. Audience members were asked to press the button whenever they experienced frisson during the concert. We recorded self-report frisson experience together with their EDA and blood volume pulse (BVP) data. In order to get the pattern of frisson, the self-report button is integrated with the wristband [51] as 5.2

To understand the live audience's frisson experience, we asked them to fill out a questionnaire before and after the concert, as well as intermission. The questionnaire this study used is attached in the appendix.

5.1.1 Evaluation of Pilot Study

For our data collection of which we will report here. In accordance with previous works [52], 69.72% of them experienced frisson with various reactions such as crying, faster heart beating, and more sweating while the others did not. 83.33% reported that they would like to try out a device that can help them experi-

Figure 5.1 Scenes of Workshop Concert I.

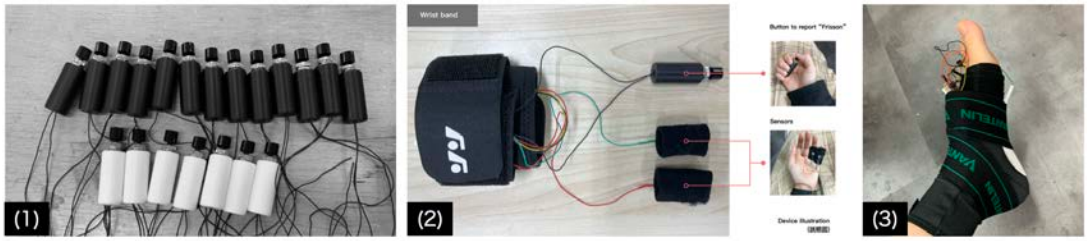


Figure 5.2 Button Integrated with Wristband and Sensing Device on Foot

ence frisson more frequently. This could suggest it is meaningful to share frisson between people with the help of external devices. Their subjective descriptions helped us to understand audiences' frisson experience in a live concert setting and supported our design concept.

The pianist was equipped with a physiological sensing device on her left foot (see Figure.5.2). **The pianist reported the device didn't disturb or affect her performance at all in the interview. The pianist reported it would be exciting to perform while the audience could feel her physiological state in real-time which is a novel way of performing and transforming classical music performance.** During this classical piano performance, the audience pressed the self-report button when they felt "Frissons" using the device (see Figure.5.2). Frisson are defined as "a sudden strong feeling of excitement or fear. which refer to a set of bodily sensations, such as shivers, or goosebumps." to audience People pressed the button whenever they felt strong emotions such as excitement and arousal. 66.67% audience reported in general they sometimes felt frisson daily, 27.78% audience reported they rarely felt frisson, 5.5% audience reported they never felt frisson.

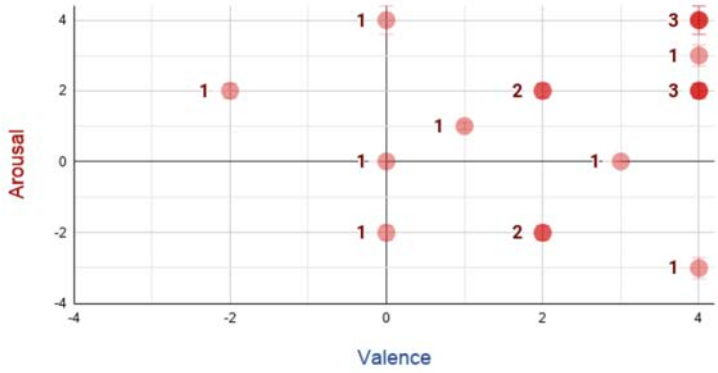


Figure 5.3 Self-Assessment Manikin of Audiences after Concert

The graph 5.3 shows that people's emotions are generally positive after the concert. SAM scores of Concert I after the performance. This dot graph of the audience's emotion analysis is based on a 1-9 alike scale of the Self-Assessment Manikin (SAM) Scales. The numbers next to the dots represent how many people

are on the same valence and arousal.

This pilot study helps this research to understand frisson in liveness and the relationship between performer and audience, audience and audience in music performance. Our current findings suggest that it is meaningful and feasible to trigger and share frisson among audience. The recording of the frisson data method also shows the possibility to detect frisson automatically. We will collect more empirical and physiological data to build algorithm for automatic frisson detection for conveying to performers in the following workshops to be held in June and October. We will also further evaluate the usability and the empathetic affordances of our frisson sharing system. The experience of holding and producing a concert is also important for the next concert workshops to combine promising music experience and experiment conduction. Questionnaires that were used in this concert could be referred in Appendix.

5.2. Study of Triggering Frisson

5.2.1 Thermo-Haptic Neckband Study One and Evaluation

15 participants (female=7; male=8) aged from 22 to 37 years (average age = 26.4) joined in a 3-5 minute user test. The participants were asked about their demographic information while the investigators helped them put on the wristband with a frisson-report button. The participants were asked to press the button whenever they experienced frisson. The two Peltier thermoelectric modules of the neckband were placed on the back of their neck (see Figure.4.4) for one minute and generated cold thermal feedback to trigger frisson. Later the participants were interviewed about whether they experienced frisson during the test and how intense it was with a 7-point Likert scale (1= not at all, 4= clear frisson feeling, 7= very intense frisson feeling). The two thermal modules of the neckband whose heat pumping wattage averaged 5-5.5W and generated 24 $^{\circ}$ C were placed on the back of the neck for one minute.

Evaluation

For the user study of the thermo-haptic neck device, we analyzed three sets self-report data: if the participants pressed the button during the test, if they reported had frisson and if they had intense than level 4 frisson according to the interview. If yes, we marked the feedback data as 1, otherwise 0. Three one-tailed T-tests were performed. A total of 52 button presses were recorded from 11 out of the 15 participants (M= 0.73; p= 0.034). 14 participants reported they experienced frisson-like feelings during the test (M= 0.93; p= 0.00001). 11 participants consciously experienced more intense level 4 frisson during the test (M= 0.73; p= 0.034).

5.2.2 Thermo-Haptic Neckband Study Two and Evaluation

There are 10 participants(female= 4; male = 6) from 6 countries aged from 24 to 31 years old (average age = 27) joined in a 30 minutes user test. The participants were asked to read through the consent form before the experiment starts. The experiment will start only if the participants agree with the experiment contents and requirements and sign their signature and print name. Once the experiment starts, participants will fill out the questionnaire about their demographic information while the investigators help them put on the neckband with two thermal modules placed on the back of their neck (see as 4.4). Then the participants are asked to fill out a pre-questionnaire with a general feeling of frisson. Then the investigators introduce the flow of the experiment as "there are three sessions you will experience in the experiment. Before every session there will be a notification from the audio to inform you. After all the sessions you will be asked to fill out a questionnaire about your experience." Later the participants were interviewed about whether they experienced frisson during the test and how intense it was with a 7-point Likert scale (1= not at all, 4= clear frisson feeling, 7= very intense frisson feeling). Frequency of feeling frisson is divided to 1-5times, 5-10times, 10-15times, others. The experiment is designed to play audio which include three frisson elicit session. Session A is a five minutes music the piece from "Gustav Holst - The Planets - Jupiter, the Bringer of Jollity". The 5 minutes music piece is cut out from 4:00-9:00 since the literature review [43] shows that part of this

piece is the chills elicitation part. Session B is a three minutes neckband cold thermal feedback stimulus session. Session C is a 5 minute piano recording from Frédéric Chopin ' s "Prelude, Op. 28, No.15". It was recorded from the first live concert we held and rated most likely to have frisson from the audience. The cold feedback frequency is three seconds. The two group are divided into two comparisons group in which has 6 persons. Experiment session order is the same as Session ABC. In comparison group A, the neckband is worn in session B and C, in comparison group B, the neckband is worn in session A and C to compare if the neckband could enhance feeling frisson in the lab controlling environment experiment.

Evaluation

There are five people in each comparison group. The three sessions in Group A is Session A with Neckband, Session B, Session C. The three sessions in Group A is Session A, Session B, Session C with Neckband. In the graph, blue color represents Group A, red color represents Group B thick lines represents the average value of the group. Participants from ID 1-5 in Group A has relatively higher frequency and intensity in session A with neckband than session B and session C. Participants from ID 6-10 in Group B has relatively higher frequency and intensity in session C with neckband than session A and session B. Participants from Group A has relatively higher frequency and intensity of frisson in Session A than participants from Group B, participants from Group B has relatively higher frequency and intensity of frisson in Session C than participants from Group A. Results from the double comparison suggests listening to music with thermal feedback provides relatively more frequent and intense feeling of frisson than only listening to music or only wearing neckband.

5.3. Study of Automatic Detecting Frisson

experiment design In order to train the model of the frisson responses through a machine learning algorithm from physiological data, this project conducted an experiment to collect EDA data and HR data through wristbands which are also embedded with a frisson self-reported button. The experiment is designed to play

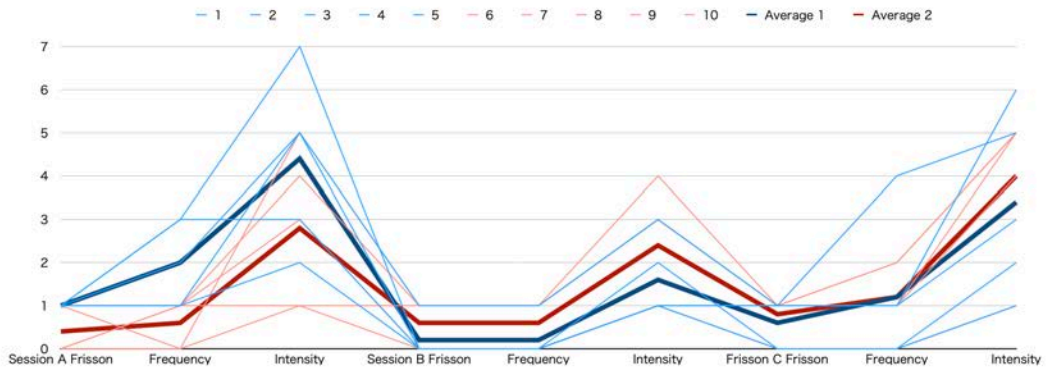


Figure 5.4 Frisson Frequency and Intensity in Session ABC

audio which include three frisson elicit session. Session A is a five minutes music the piece from "Gustav Holst - The Planets - Jupiter, the Bringer of Jollity". The 5 minutes music piece is cut out from 4:00-9:00 because of Bannister et al. [43] shows that part of this piece is the chills elicitation part. Session B is a three minutes neckband cold thermal feedback stimulus session. Session C is a 5 minute piano recording from Frédéric Chopin ' s "Prelude, Op. 28, No.15". It was recorded from the first live concert we held and rated most likely to have frisson from the audience. The cold feedback frequency is three seconds. The cold feedback frequency is three seconds In order to exclude ordering effects, Latin-Square Setup is used in the experiment order as the Latin Square Setup Table5.1.

Table 5.1 Latin-Square Setup of Experiment

1	a	b	c
2	b	c	a
3	c	a	b

Experiment Procedures There are 33 participants(female= 17; male = 16) from 7 countries aged from 22 to 37 years old (average age = 26.09) joined in a 30 minutes user test. The participants were asked to read through the consent form before the experiment starts. The experiment will start only if the participants agree with the experiment contents and requirements and sign their signature and print name. Once the experiment starts, participants will fill out the questionnaire

about their demographic information while the investigators help them put on the wristband with a frisson-report button and the neckband with two thermal modules placed on the back of their neck (see Figure.4.4). Then investigators explain the definition of frisson and the circumstances to press the frisson button. The definition of frisson is explained as "Frisson is a sudden strong feeling of excitement or fear. It's known as aesthetic chills or musical chills. Frisson refers to a set of bodily sensations, such as shivers, or goosebumps. Frisson could be caused by cold, fear or a strong emotional stimulus" with verbal words and corresponding moving pictures of chills, goosebumps, shivers on a screen to participants. The button pressing circumstances are explained as "Whenever you feel frisson, please press the button. If you feel frisson is a continuous feeling, please press it all the time or you can press the button multiple times based on how you feel from your intuition. The experiment is totally anonymous so please don ' t be shy to press it".

Then the participants are asked to fill out a pre-questionnaire with a general feeling of frisson. Questionnaires that are used in this experiment could be found in appendix. Then the investigators introduce the flow of the experiment as "there are three sessions you will experience in the experiment. Before every session there will be a notification from the audio to inform you. After all the sessions you will be asked to fill out a questionnaire about your experience." Later the participants were interviewed about whether they experienced frisson during the test and how intense it was with a 7-point Likert scale (1= not at all, 4= clear frisson feeling, 7= very intense frisson feeling).

5.3.1 Evaluation

Evaluation of collected physiological data and machine learning part is completed with Geist Real Project. The model of frisson which is trained with leave one subject out method through electrodermal activity and blood volume pulse of 32 people ralated physiological data has 85% accuracy of detecting frisson. Features of the data that are used are normalized-EDA-Tonic, normalized-Tonic-diff 60, normalized-Tonic-diff-30, normalized-HRV-MeanNN, normalized-HRV-pNN50, normalized-HRV-pNN20, normalized-EDA-Phasic (selected by random forests feature importance). Since physiological data has huge individual

Figure 5.5 Detection of Frisson Study Setup

difference, normaliaztion of data for each person is neccessary. EDA's normalization for each person was by MinMax Scalar[1]. Pnn20 and pnn50 features of heart rate variability are normalized for each person by Individual's Average HR [53] from Sacha et al. Support Vector Machine(SVC) is ultilized as Classifier. Leave-one-subject-out is the method used for cross validation method. Cross validation score report mean value and standard deviation value. The confusion matrix5.7 is used to reflect the classification results of a certain classification model. The rows represent the true classes and the columns represent the predicted label.

5.4. Sharing Frisson in Liveness: Workshop Concert II.

We conducted the experimental Frisson Waves Concert II. at June 25th, 2021 at Kawasaki Symphony Hall Assembly Room to share frisson through the system we described above where frisson sensation was detected and shared with others. Collective physiological data of the Participants will be interpreted into different

1 MinMax urlhttps://scikit-learn.org/stable/modules/generated/sklearn.preprocessing.MinMaxScaler.html

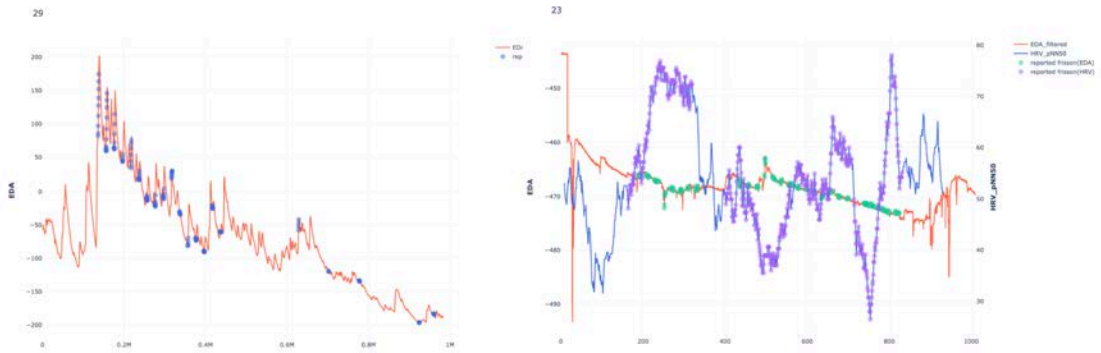


Figure 5.6 Example of EDA and HRV Pnn50 Plot with Self-Report Button

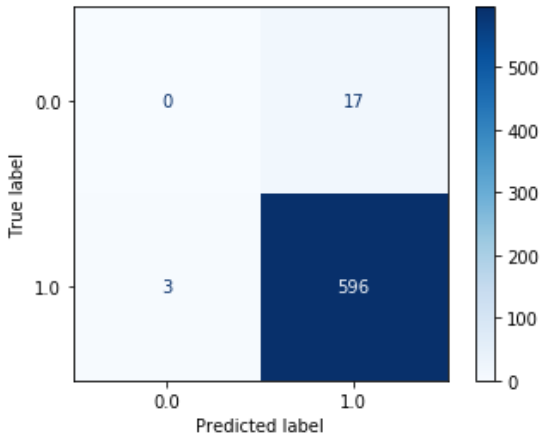


Figure 5.7 Example of Confusion Matrix

haptic feedback representations such as thermal feedback or vibration. where wearable devices are used to share the participants ' frisson and augment the performance.

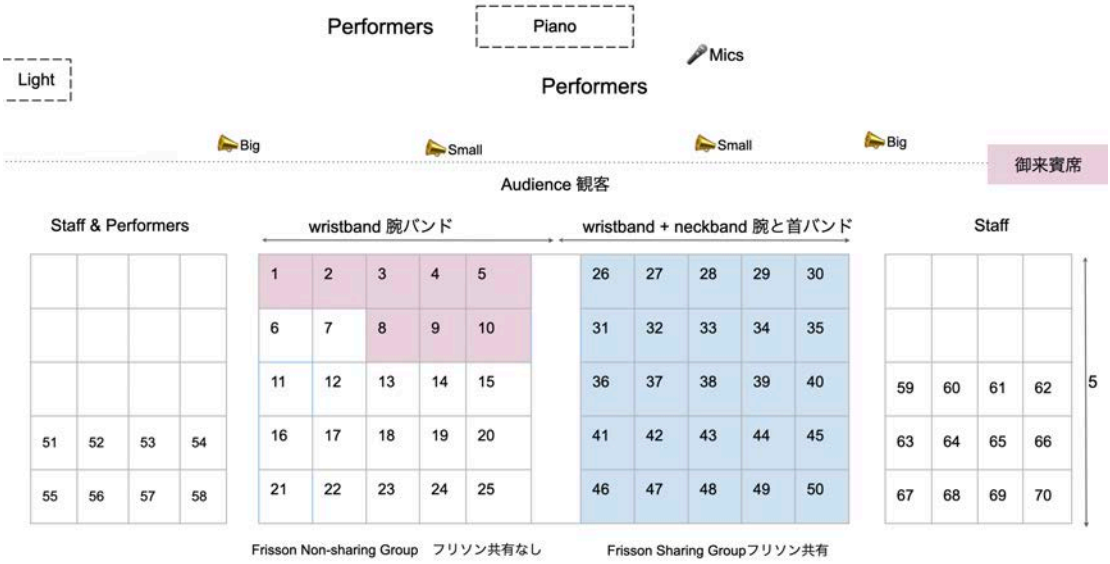


Figure 5.8 Experimental Frisson Waves Concert II. Design

The participants were asked to read through the consent form of explanation and photography before the experiment starts. The experiment will start only if the participants agree with the experiment contents and requirements and sign their signature and print name. This concert included a 20 minutes ensemble interactive performance and a 50-minute classical piano performance(see Figure5.11). The ensemble performances brings audience real-time physiological signals such as heart beats and frisson signals into the performance pieces. The classical performances performed by the pianist Muyu Liu. **In order to focus more on audience experience this time, performers didn't wear any external devices and their physiological data is not planned to be interpreted in this current experimental concert.**

48 audiences are divided in to two comparison group of sharing-frisson and non-sharing frisson group. The sharing frisson group feathered 24 audience members

Figure 5.9 Preparation of Concert II.

worn our neckbands and wristbands. The non-sharing frisson group feathered 24 audience members worn our wirstbands.

To understand live audience's frisson experience and find out: 1)how frisson feeling is enhanced during live concert context. 2)how frisson feeling is different during the two comparison groups. 3)how frisson is induced by neckbands during live concert context. 4)how sharing frisson enhanced connectedness in the two comparison groups.

5.4.1 Evaluation

The questionnaires that audience members were asked to fill in after the concert onsite, there were 48 responses were recorded. According to the survey answers, 48 audiences attended (female=28; male=19, 1 as other or preferred not to say) between 19 and 83 years (average age=38.53) attended this concert workshop and their the overall enjoyment of the concert was rated at 6.2 out of 7. 60% of the audience was familiar with the concept of frisson, 20%were familiar in certain extent, and the remaining 20% audience members were not familiar with it. About

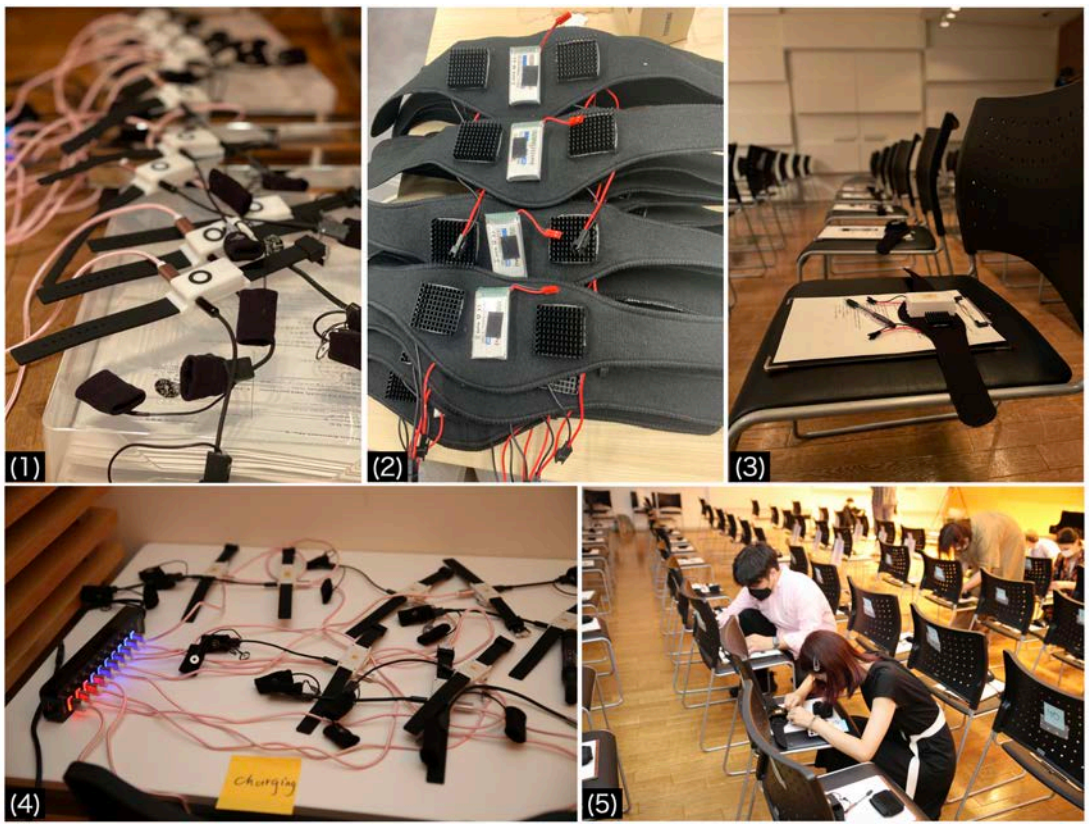


Figure 5.10 Preparation of Concert II.

Figure 5.11 Ensemble and Classical Performances of Concert II.

Figure 5.12 Audiences

half of the audience reported feeling frisson sometimes to often, the other half reported feeling frisson rarely to never. However, the numbers of feeling frisson in relation to music are slightly different. 60% of the audience reported to feel frisson in relation to music, and only 40% felt in relation to music rarely to never in relation to music.

40% audience members reported that they have felt more frisson during this concert than usually during a concert, only 8.3% had less frisson. 3 people reported to feel no frisson at all, the rest of the audience found it hard to compare. 62.5% audience members reported that they enjoyed their experience more than other similar events and only 14% answered that they had better experiences at other such concerts, the majority (6 out of 7 people) of them were in the frisson sharing group who were wearing the neckbands. This also almost matches the number of participants who found the neckband to be uncomfortable and have a reduced overall enjoyment of the performance (7 people). This suggests that re-design of the neckband may be necessary in order to make it less obtrusive and have a better user experience.

Out of 24 people in the frisson sharing group, 54% of the audience members reported that they had more frisson than usually, 25% of them felt less, and the rest found no difference. **In order to evaluate the frisson contagion situation, we evaluate the connectedness of the audience between the frisson-sharing group and the non-frisson-sharing group. Self frisson situation and the contagion frisson situation are obvious for the audience themselves to differentiate in the live concert since they could feel frisson is self-generated or triggered through the cold thermal feedback on the neck. However, audiences don't need to report how they differentiate between the two frisson feelings situation as long as the audiences subjectively report how they feel frisson and feel connected with other audiences sit around them in the questionnaires would be enough for evaluation. To differentiate between self frisson situation and the contagion frisson situation of the audience, we add aspects about how the audience usually experiences frisson in suck similar events in the questionnaire, so we could normalize their frisson experience and connectedness score against their personal subjective reports. Actually, there**

are three kinds of frisson happening in the experience which include aesthetic self-generated frisson, the thermal cold feedback triggered frisson, and interpersonal shared with thermal cold feedback triggered frisson, since the current goal of this research is not to look into the neuroscientific difference between self-generated frisson or contagious frissons, we focused more on the goal of sharing frisson and enhancing frisson and connectedness. Also since the goal of the frisson sharing was not only to improve the overall frisson experience and enjoyment, which was proved based on the survey data but also to improve the sense of connectedness and togetherness of the audience, so these these aspects questions were also included in the questionnaire.

The hypothesis is that the sense of connectedness in the non-sharing control group would be higher than in the sharing group. The result is against the expectation that the connectedness score is 4.17 out of 7 in the non-frisson-sharing group, the scoare is 3.54 out of 7 in the frisson-sharing group. However, it can be explained by the number of friends sitting around each spectator. According to the answers that the non-frisson-sharing group knew each other much better than the frisson-sharing group, in the no-sharing group, the average number of friends sitting in adjacent seats was averaging 1.8. In the frisson sharing group, it was only 1.08 which is 40% significantly less($p=0.017$) than the no-sharing group. This highlights the importance of controlling personal relationships between people in such experiments as one of the important variables. Although the groups were not balanced by the personal relationships, we cannot show the significance between the reported sense of connectedness. Despite the sharing group having 40% fewer friends than the non-frisson-sharing group, the sharing group only felt 16% less connected, and we cannot state the significance of this difference($p=0.11$), it can be assumed that there should be a much stronger decrease in the connectedness in the sharing group, as the two variables of number of friend and connectedness are correlated ($R=0.31$, $p=0.03$). There was a significant difference in the number of friends between the groups and an insignificant difference in sense of connectedness, plus 7 participants in the sharding group reported uncomfortable with the neckbands, this result could lead to believe that the performance of the system was adequate.

Another noticeable difference between the groups is the reported number of frisson occurrences during the concert. Although the no-sharing group has reported feeling frisson in relation to music, in general, more often than the frisson sharing group, the no-sharing group did not experience more frisson during the concert than usual. However, the frisson-sharing group had 8.8% more frisson than usual, which suggests that the frisson-sharing mechanism does increase the number of frisson occurrences. Also, it is important to note strong relation between the reported frequency of experiencing frisson usually and during this concert (R=0.62, p¡0.0000). This would lead to think that achieving such an increase in a group less familiar with frisson is a success.

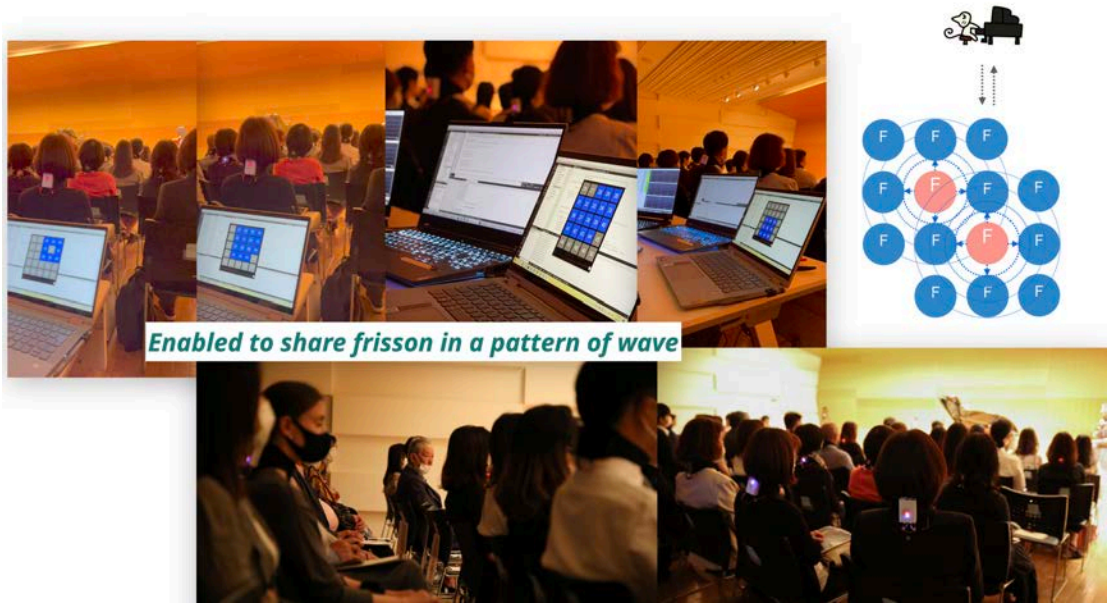


Figure 5.13 Visualized Spatial Share Frisson in a Pattern of Wave

As for the analytical approach of evaluation, this frisson sharing experience creates higher enjoyment of live music experience and transforming classical music concert and experimental music concert into enhanced enjoyable, empathetic and intimate communication event for multi-generational and multi-cultural background audience.

Since the result of enhancing connectedness and frisson sharing experience is

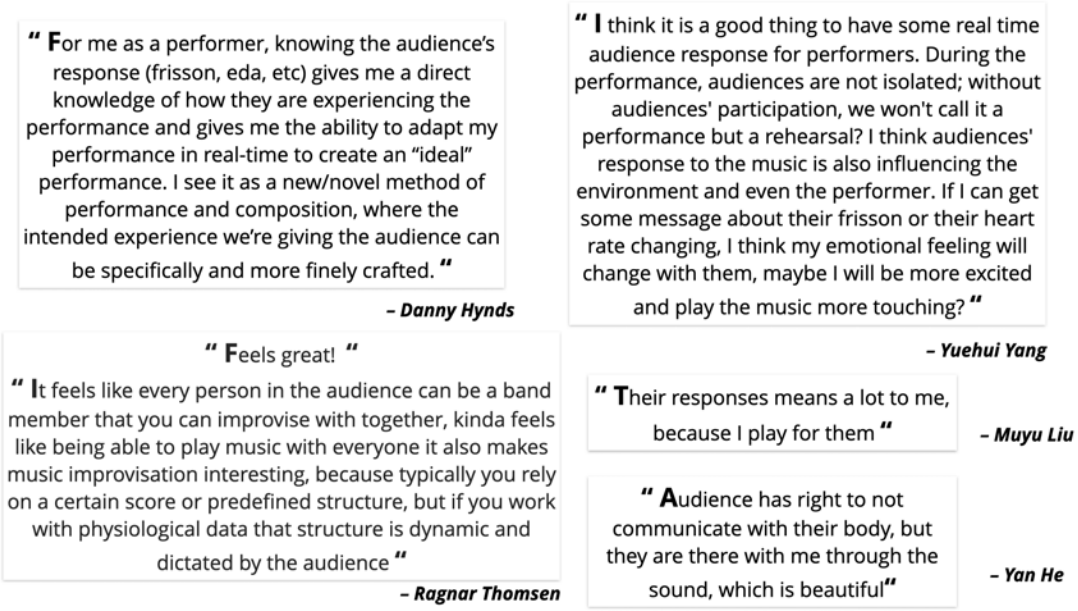


Figure 5.14 Feedback from Performers

not significant enough, we will conduct another concert to prove the concept at the Karuizawa International Youth Concert at Oct, 3rd,2021.

5.5. Designing of Karuizawa International Youth Concert

Karuizawa International Youth Concert aims to create a chance for people from all over the world to communicate with each other through music to remedy the loss of social connection in the pandemic time and also motivates people to innovate in this concert. Frisson Waves project will mainly collaborate with Karuizawa International Youth Concert in interaction technical support and interactive ensemble music playing.

In the Karuizawa International Youth Concert, we will enhance the accuracy of detecting frisson and the efficiency of triggering frisson through the neckband. In the seating chart(see Figure.5.15), this time we designed the seating chart with devices set up as chess box pattern, the blue dots in the seating charts are the

audience seats with wristbands and neckbands, other seats people will only wear wristbands. In order to decrease the negative influence of neckbands in live music performances, we will improve the design of the neckband as well. Karuizawa Ohga Hall is a spatial music hall that has a more intimate atmosphere and seat design which could be interesting to trying to share frisson with people who are indifferent floor or angles or even exploring more novel ways of interaction and communication. We are also looking forward to looking into more possibilities we could try out and experiment with this scheduled concert workshop on Oct.3rd, 2021.

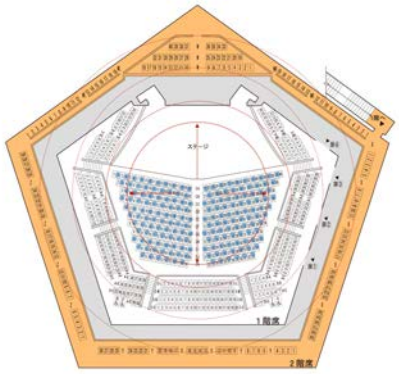


Figure 5.15 Karuizawa International Youth Concert Design

Chapter 6
Conclusion

This chapter will summarize the motivation and goal, then findings from the literature review and related works. The concept design process and iterations of prototypes, system development will be summarized too. After that, studies implementation results for proving the concept will be concluded. Limiation and future works will be discussed in the end.

From the motivation of understanding frisson, sharing frisson, and create communication chances, this research looked into psycho-physiological responses frisson and live music performances, the goal was set to trigger, detect and share the personal feeling of frisson to enhance the connectedness of people and create collective experiences. Mind to body model, body to mind model, and individual to individual contagion model are structured out through literature review and related works.

- Mind to body model is combined with an aesthetic stimulus which explained the mechanism of receiving external aesthetic stimulus through exteroception system such as vision, hearing, etc to the mind which generated drives, emotions, or feelings and then drive the body to occur various reactions. Mind to body model also provided solid literature results of embodied aesthetic emotions occurring context which is a footstone of triggering frisson for this thesis.

- Body to mind model is combined with an external thermal stimulus which explained the mechanism of receiving external thermal stimulus through interoception system such as skin, organs, etc to the body which generated body responses and then drives minds to feel various drives, feelings, emotions. The body to mind model also provided a solid basis of interoceptive

interaction technology and the utilization possibility for this thesis to trigger frisson.

- Individual to individual contagion model combined mind to body model and body to mind model and emotion contagion process to explain the mechanism of sharing body responses or emotions to create a contagion emotion of body reactions effect between individuals. The individual to individual contagion model also provided a solid basis for sharing frisson to create collective experiences and share personal psychological or physiological to have an effect on social significance.

This thesis proposed Frisson Waves, a system that enables to trigger frisson, detect frisson automatically so as to share frisson. The system consists of a smart neckband with two Peltier thermal modules and six linear vibrotactile modules to trigger frisson, a smart wristband to detect frisson automatically with the trained frisson model calculating in real-time. Sharing frisson conceptually could be realized by the Frisson Waves system with the two devices.

In order to prove the concept, five studies including two experimental concerts in total are conducted.

- Pilot Study Frisson Concert I.: Recording frisson in liveness: this pilot workshop aims to understand, record frisson in a live music context. From subjective responses from 20 audience members that 69.72% of audiences experienced frisson and frisson feeling is regarded as a good maker of live music performances. Experiencing frisson more is also expected to by 83.33% audience members. This pilot study not only helps this research project understand more about frisson feeling and other aesthetic emotions responses but also helps to learn the experience of producing concerts and experiment together.

- Triggering of Frisson through Neckband Study One: this study tested the best location to put Peltier thermal modules on the neck and tested the neckband frisson triggering effect. 93% of 15 participants reported feeling clear frisson experiences which suggested the wristband could trigger frisson.

- Triggering of Frisson through Neckband Study Two: this study tested neckband with wireless controlling frisson triggering effect in the controlled context of music listening environment. The frisson frequency and intensity of 90% of 10 participants reported being enhanced compared to listen to music without listening to music which suggested the wristband could trigger frisson in the context of listening to music.

- Automatical Detecting of Frisson through Wristband Study: this study recorded physiological data of blood volume pulse and electrodermal activity of 32 participants with a self-frisson-report button. The frisson model has averaged 85% accuracy detecting frisson is able to work in real-time with wristband data collecting which suggests the possibility to detect responses that have significant individual difference through the smart wristband and be utilized in wild context since there is no similar finding of frisson detection so far.

- Frisson Waves Concert II. Sharing frisson in Liveness: this concert utilized the system setup described in the concept design that triggering frisson through the neckbands and detecting frisson automatically through the wristbands so as to share frisson. 48 audience members are divided into two comparison groups that one group wears both neckbands and wristbands as the frisson-sharing group, one group only wears wristbands as the non-frisson-sharing group as the comparison group. The result which suggested frisson is sharable through our system, and the performance of system to enhance the frisson feeling for people are not familiar with frisson is contributing, the performance of the system to enhance connectedness is adequate.

Overall, These studies proved a significant effect of triggering frisson, detecting frisson automatically, and sharing frisson to enhance frisson and connectedness and resonance between people. This thesis focused on the concept design and the framework and workflow part, system development part, and interactive performances mainly collaborate with Geist Real project and members from Embodied Media. However, there are still limitations of our research such as better performance of frisson model and better design of neckbands for better user experience.

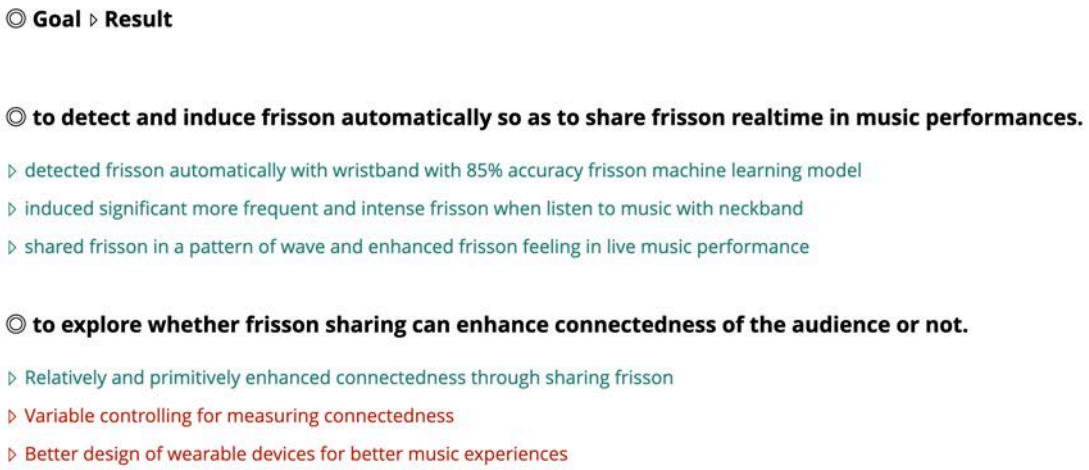


Figure 6.1 Summary of Goal and Result

Connectedness and togetherness evaluation of our system also need more variables controlling method. We will schedule another experiment concert which is collaborated with Karuizawa International Youth Concert on Oct,3rd,2021. In the future, we also want to look into more possibilities to provide abundant experiences to people and free people's minds and bodies through technology and art.

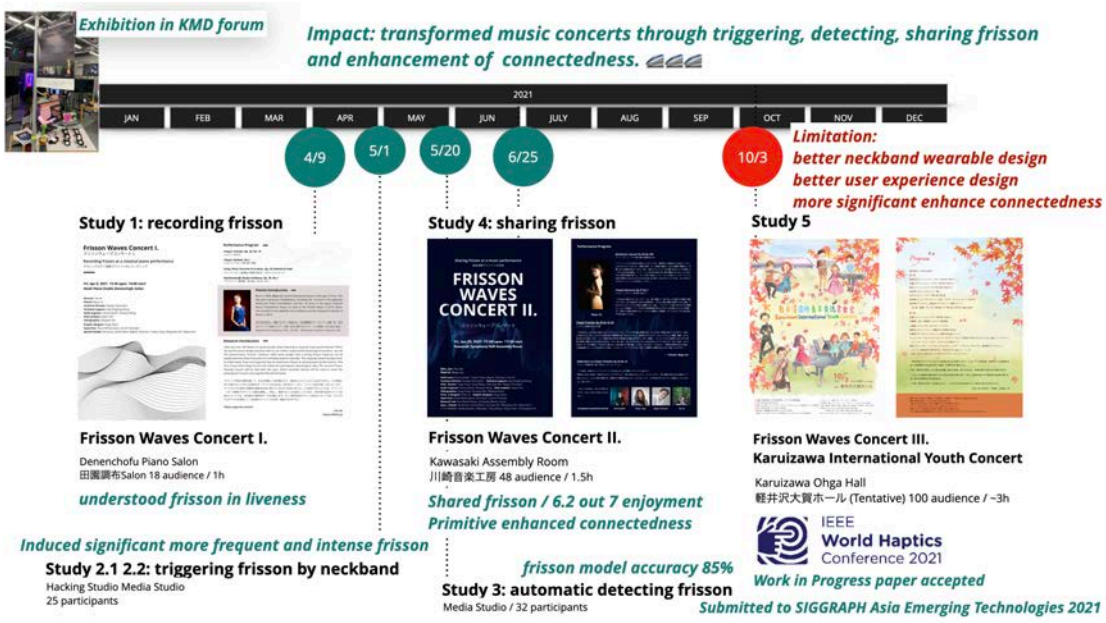


Figure 6.2 Summary of Contribution

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Appendices

A. Study of Detection of Frisson Study

A.1 Questionnaires of Detection of Frisson Study

A.2 EDA Plot of Frisson Model Traning

A.3 EDA and HRV pnn50 Plot of Frisson Model Traning

A.4 Confusion Matrix of Frisson Model Traning

B. Workshop Frisson Waves Concert I.

B.1 Questionnaires of Frisson Waves Concert I.

B.2 Flyer of Frisson Waves Concert I.

C. Workshop Frisson Waves Concert II.

C.1 Questionnaires of Frisson Waves Concert II.

C.2 Flyer of Frisson Waves Concert II.

D. Poster of Frisson Waves Concert III. x Karuizawa Youth Concert

Frisson Recording and Detecting Study

Please help us to know you better with following questions:
今後の研究の参考にさせていただきたく、よろしければ下記のアンケートにご協力をお願いできますと幸いです。

1. Subjective Number

Frisson is a sudden strong feeling of excitement or fear. It's known as aesthetic chills or musical chill

Frisson refers to a set of bodily sensations, such as shivers, or goosebumps.

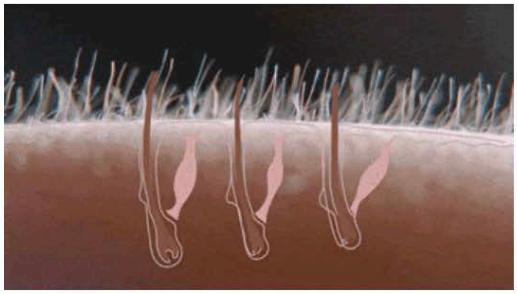


Figure A.1 Detection Frisson Study Questionnaire Page 1

Frisson could be caused by cold, fear or a strong emotional stimulus.

2. Age / 年齢:

3. Gender / 性別:

- ◯ Female / 女性
- ◯ Male / 男性
- ◯ Other / その他: _____
- ◯ Prefer not to say / 答えたくない

4. Native Language / 母国語:

Figure A.2 Detection Frisson Study Questionnaire Page 2

5. Please leave your email address if you wish to get invitations for 6/25 frisson wave concert. 6/2
のフリッソンウェーブの演奏会への招待状を受け取りたい場合は、メールアドレスを記入してく
ださい。

6. In general, how often do you experience frisson? 一般的に、どのくらいの頻度でフリソンを経験
しますか？

	1	2	3	4	5	
Never	◯	◯	◯	◯	◯	Always

7. If you felt frisson before, could you briefly describe what situation you experienced frisson?

a_Music Stimulus

Session

8. Did you feel frisson in this session? このセッションでフリソンを感じましたか？

◯ Yes はい
◯ No いいえ
◯ Other:

Figure A.3 Detection Frisson Study Questionnaire Page 3

9. If yes, how many times you felt frisson? はいの場合、何回フリソンを感じましたか？

- ◯ 1-5 times
- ◯ 5-10 times
- ◯ 10-15 times
- ◯ 15-20 times
- ◯ Other: _____

10. If yes, when did you felt frisson? はいの場合、いつフリソンを感じましたか？

_____

11. From a scale of 1 to 7, please describe how strong you felt frisson? 1から7のスケールで、フリソンをどのくらい強く感じたかを説明してください。

	1	2	3	4	5	6	7	
I didn't feel frisson at all	◯	◯	◯	◯	◯	◯	◯	I felt very intense frisson

b_Haptic Stimulus

Session

12. Did you feel frisson in this session?

- ◯ Yes
- ◯ No
- ◯ Other: _____

Figure A.4 Detection Frisson Study Questionnaire Page 4

13. If yes, how many times you felt frisson?

- 1-5 times
- 5-10 times
- 10-15 times
- 15-20 times
- Other: _____

14. If yes, when did you felt frisson?

_____

15. From a scale of 1 to 7, please describe how strong you felt frisson?

	1	2	3	4	5	6	7	
I didn't feel frisson at all								I felt very intense frisson

c_Music+Haptic Stimulus

Session

16. Did you feel frisson in this session?

- Yes
- No
- Other

Figure A.5 Detection Frisson Study Questionnaire Page 5

17. If yes, how many times you felt frisson?

- 1-5 times
- 5-10 times
- 10-15 times
- 15-20 times
- Other: _____

18. If yes, when did you felt frisson?

_____

19. From a scale of 1 to 7, please describe how strong you felt frisson?

	1	2	3	4	5	6	7	
I didn't feel frisson at all								I felt very intense frisson

Figure A.6 Detection Frisson Study Questionnaire Page 6

Figure A.7 EDA Plot with Self-report Button

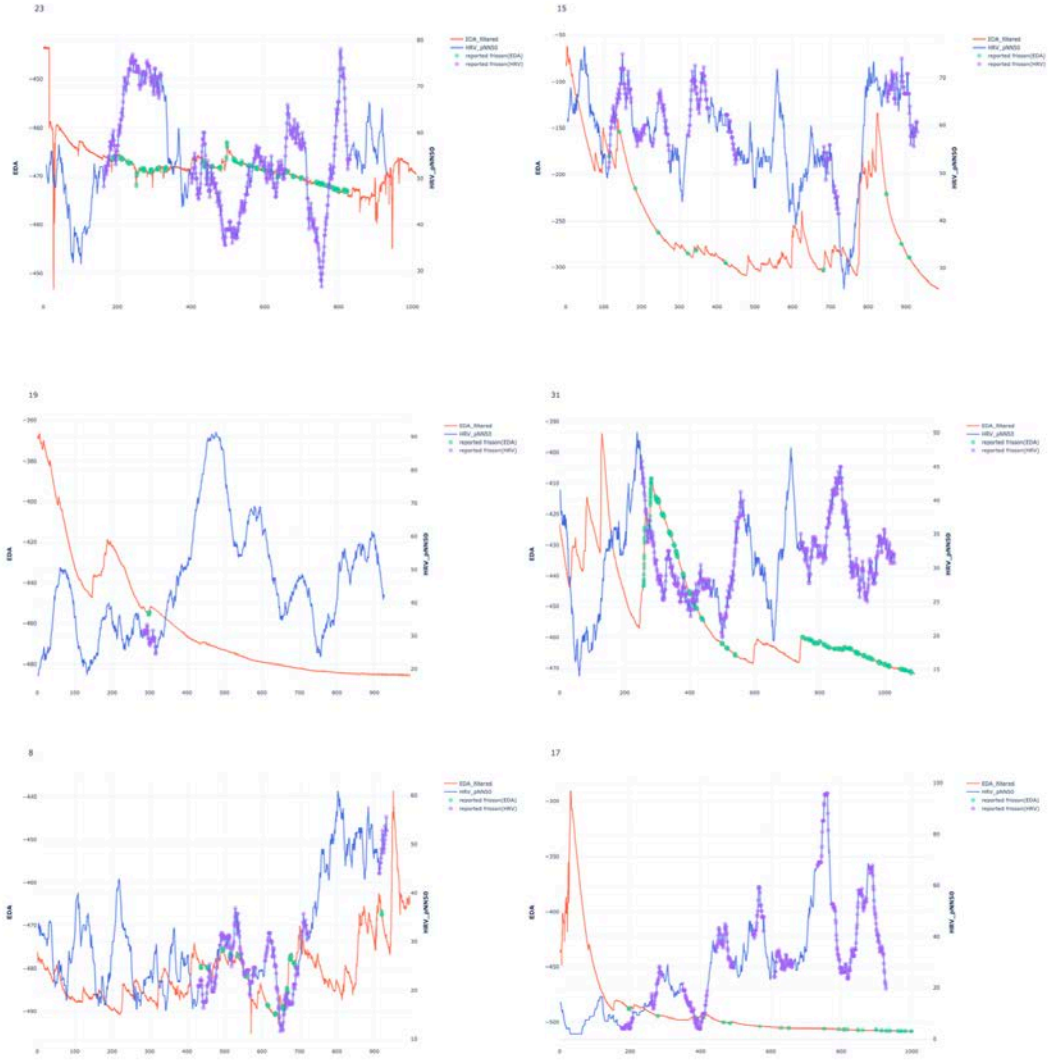


Figure A.8 EDA and HRV pnn50 Plot with Self-report Button

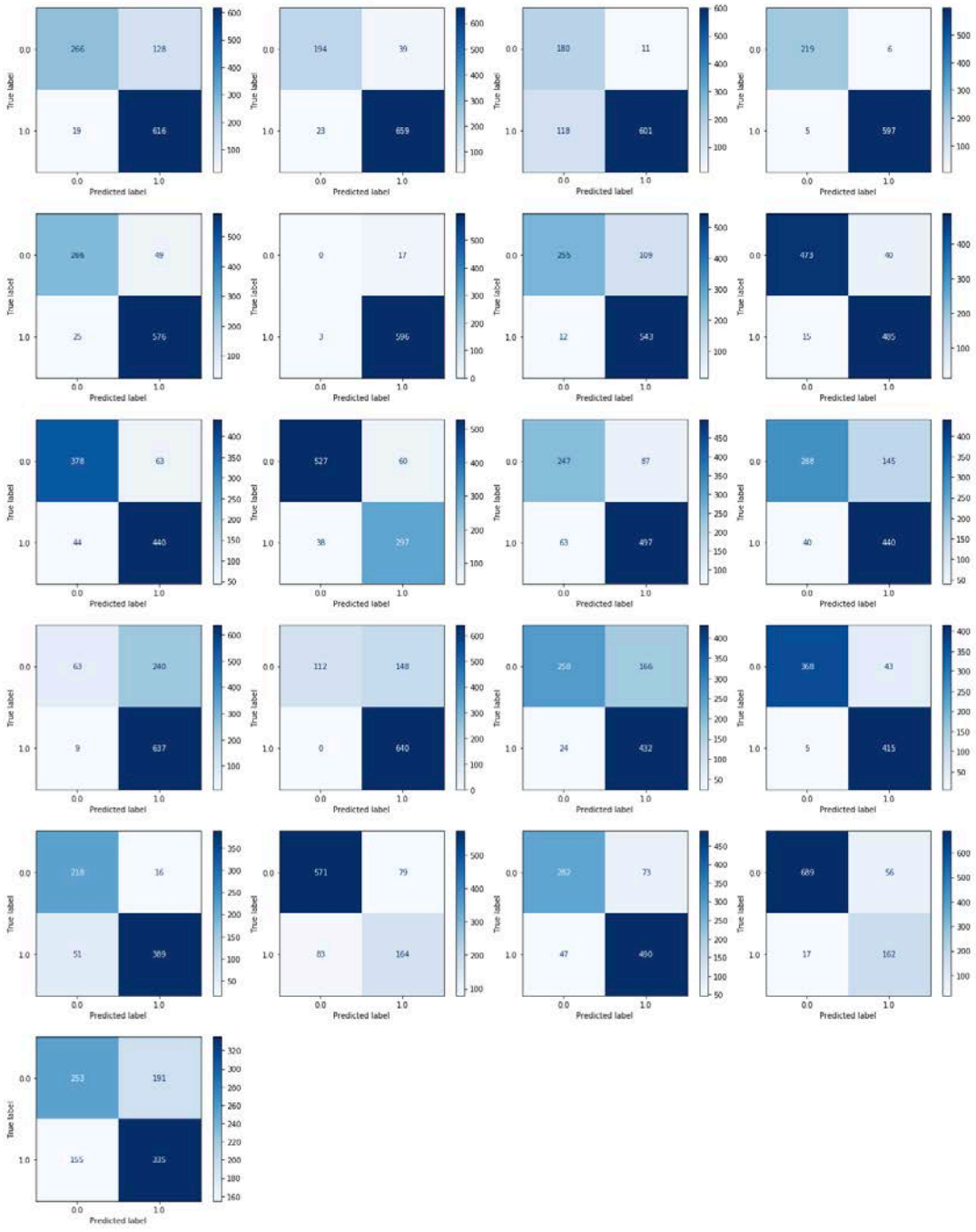


Figure A.9 Confusion Matrix of Frisson Model Classification

Please help us to know you better with following questions:
今後の研究の参考にさせていただきたく、よろしければ下記のアンケートにご協力をお願いできますと幸いです。

1. Age / 年齢:

2. Gender / 性別:

- ❑ Female / 女性
- ❑ Male / 男性
- ❑ Other / その他: _____
- ❑ Prefer not to say / 答えたくない

3. Highest education level / 最終学歴:

- ❑ High school / 高校
- ❑ Bachelor's / 学士
- ❑ Master's / 修士
- ❑ PhD / 博士
- ❑ Other / その他: _____

4. Native Language / 母国語:

- ❑ Japanese / 日本語
- ❑ Chinese / 中国語
- ❑ English / 英語
- ❑ Other / その他: _____

5. Would you be interested to try out a device that lets you experience frisson more? /フリソンをより頻繁に体験できるデバイスを試してみたいと思いますか？

- ❑ No / いいえ
- ❑ Yes / はい
- ❑ Other / その他
  :_____

6. Please leave your email address if you wish to get invitations for our future frisson wave concerts.
/ 今後のフリッソンウェーブの演奏会への招待状を受け取りたい場合は、メールアドレスを記入してください。

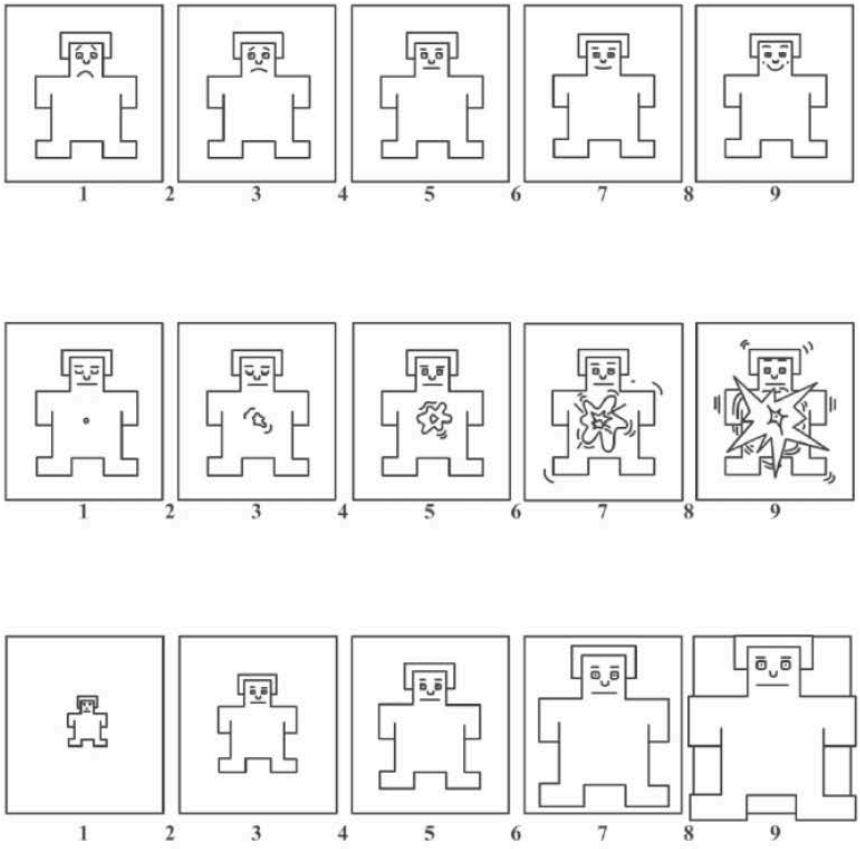
Email /メールアドレス: _____

Figure B.1 Frisson Concert I. Questionnaire Page 1

Subject #:
Seat number:

Questionnaire 1

1. Below, you will be presented with three rows of images. For each row of images, please circle the number from 1 to 9 that best corresponds to your current feelings.



2-1 In general, how often do you experience frisson?

- ❑ Never
- ❑ Rarely
- ❑ Sometimes
- ❑ Often

2-2 If you have experienced frisson before, please select in which situations. (Select all that apply) If never, please read the next question.

Figure B.2 Frisson Concert I. Questionnaire Page 2

Subject #:
Seat number:

a. In everyday situations
b. While listening to classical music
c. While listening to other music
d. Other:_____

3. How often do you listen to classical music?

a. Never
b. Less than once a year
c. Several times a year
d. Several times a month
e. Several times a week
f. Several times a day

4-1 How often do you go to classical concerts?

a. Never
b. Less than once in past 5 years
c. several times in past 5 years
d. Several times a year
e. Once a month
f. Server times a month

4-2 If you have been to classical concerts before, how do you usually communicate with other people during concerts? (Select all that apply) If never, please read the next question.

a. Eye contact
b. Holding hands
c. Talking, whispering
d. Other: ___

5. Do you have a background in music? If yes, please describe your background. (E.g., you play or have played an instrument, you received formal training in music etc.)

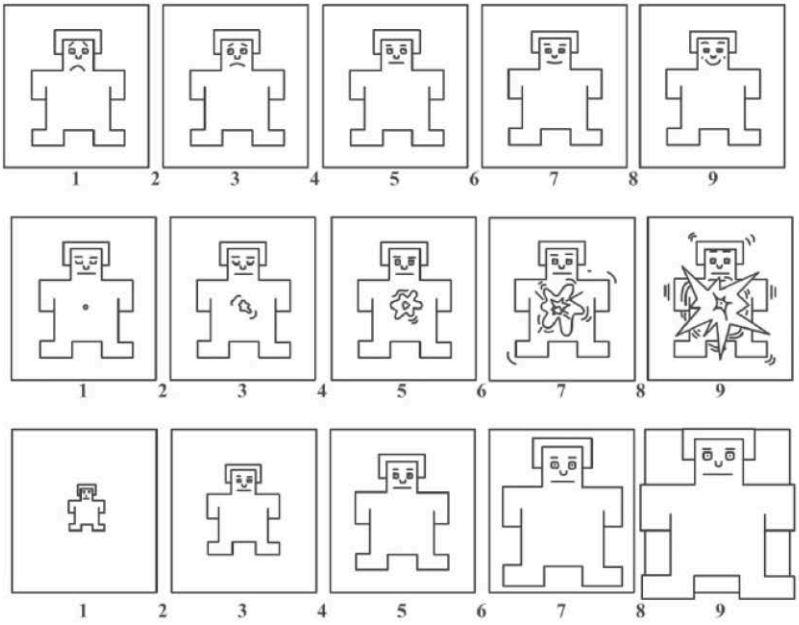
❑ No
❑ Yes. I play _____

Figure B.3 Frisson Concert I. Questionnaire Page 3

Questionnaire 2

アンケート2

1. Below, you will be presented with three rows of images. For each row of images, please circle the number from 1 to 9 that best corresponds to your current feelings. 以下に、5つの画像が3列に並んでいます。各列の画像について、今のあなたの気持ちを最もよく表している画像に1- 9 から選んで、円を描いてください。



Please use the scale below by circling a number between 1 and 7 to indicate how well or poorly each statement corresponds to you. 以下の記述について、1-7 当てはまるものを選択してください。

1. "Overall, I have found the concert to be engaging."
   全体的に見て、魅力的なコンサートだと感じました。

1	2	3	4	5	6	7
Disagree Strongly			Neutral/ Mixed			Agree Strongly
全く思わない			どっちとも言えない			とても思う

Figure B.4 Frisson Concert I. Questionnaire Page 4

Questionnaire 3

1. Below, you will be presented with three rows of images. For each row of images, please circle the number from 1 to 9 that best corresponds to your current feelings.
(以下に、5つの画像が3列に並んでいます。各列の画像について、今のあなたの気持ちを最もよく表している画像に1- 9 から選んで、円を描いてください。)

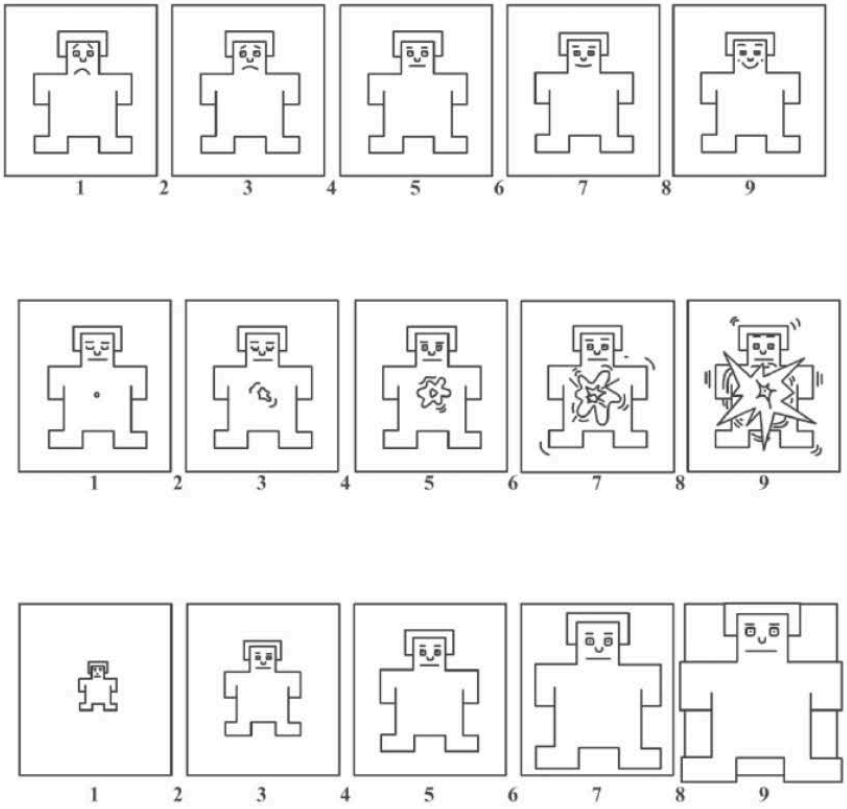


Figure B.5 Frisson Concert I. Questionnaire Page 5

2. Please use the scale below by circling a number between 1 and 7 to indicate how well or poorly each statement corresponds to you.
(以下の記述について、1-7 当てはまるものを選択してください。)

1----------2----------3----------4----------5----------6----------7
Disagree Strongly Neutral/ Mixed Agree Strongly

a. "Overall, I have found the concert to be engaging."
(全体的に見て、魅力的なコンサートだと感じました。)

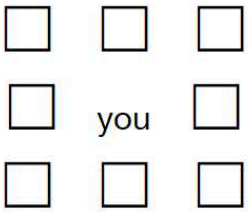
1	2	3	4	5	6	7
Disagree Strongly			Neutral/ Mixed			Agree Strongly

b. "During the concert, I felt physically comfortable." (e.g. the temperature, air quality, seating etc. were comfortable)

(コンサート中、身体的な快適さを感じた". 例:温度、空気感、座席などが快適だった)

1	2	3	4	5	6	7
Disagree Strongly			Neutral/ Mixed			Agree Strongly

3. In the image below represents your seating position. The empty squares represent the people sitting around you. Please check the empty square if you know the person who is sitting in this position.
(あなたの周りに座っている人のうち、コンサート前から知っている人は何人いますか？下の図で、Youはあなたの座席位置を表しています。空いている四角は、あなたの周りに座っている人を表しています。この中で知っている人がいた位置の四角に〇をつけてください。)



2

Figure B.6 Frisson Concert I. Questionnaire Page 6

Piece No. 1 “Chopin: Prelude Op. 28, No. 15”

1. From a scale of 1 to 5 please describe how familiar are you with this piece? 1 as Not familiar at all and 5 as Very familiar. (この作品をどのくらい知っていますか？)

1	2	3	4	5
Not Familiar at all (全く知らない)		Neither (どちらでも ない)		Very Familiar (よく知っている)

2. Did you experience frisson while listening to this piece? If yes, please try to describe the feelings you had in the moment of frisson.
(この作品を聴いていて、フリソンを感じましたか？「はい」と答えた方は、フリソンの瞬間に感じた感情を表現してみてください。)

❑ No (いいえ)
❑ Yes（はい）. _____

3. Did you have any other emotional reactions or feelings when listening to this piece?If yes, please describe your reactions.
(この作品を聴いて、他に何か感情的な反応や感じ方をしましたか？「はい」の場合、あなたの反応を詳しく教えてください。)

❑ No（いいえ）

❑ Yes（はい）. _____

4. Did you experience any other bodily reactions (E.g. tears, sweating etc.)? If yes, please describe your reactions.
(その他の身体的な反応はありましたか (例: 涙が出る、汗をかくなど)？「はい」の場合、あなたの反応を詳しく教えてください。)

❑ No（いいえ）

❑ Yes（はい）. _____

Figure B.7 Frisson Concert I. Questionnaire Page 7

Piece No. 2 “Chopin: Ballade, No. 1”

5. From a scale of 1 to 5 please describe how familiar are you with this piece? 1 as Not familiar at all and 5 as Very familiar. (この作品をどのくらい知っていますか？)

1	2	3	4	5
Not Familiar at all (全く知らない)		Neither (どちらでもない)		Very Familiar (よく知っている)

6. Did you experience frisson while listening to this piece? If yes, please try to describe the feelings you had in the moment of frisson.
(この作品を聴いていて、フリソンを感じましたか？「はい」と答えた方は、フリソンの瞬間に感じた感情を表現してみてください。)

   ❑ No(いいえ)

   ❑ Yes(はい). _____

7. Did you have any other emotional reactions or feelings when listening to this piece?If yes, please describe your reactions.
(この作品を聴いて、他に何か感情的な反応や感じ方をしましたか？「はい」の場合、あなたの反応を詳しく教えてください。)

   ❑ No(いいえ)

   ❑ Yes(はい). _____

8. Did you experience any other bodily reactions (E.g. tears, sweating etc.)? If yes, please describe your reactions.
(その他の身体的な反応はありましたか (例: 涙が出る、汗をかくなど)？「はい」の場合、あなたの反応を詳しく教えてください。)

   ❑ No(いいえ)

   ❑ Yes(はい). _____

Figure B.8 Frisson Concept I. Questionnaire Page 8

Piece No.3 “Grieg: Concerto in A minor, Op. 16 Cadena & Coda”

9. From a scale of 1 to 5 please describe how familiar are you with this piece? 1 as Not familiar at all and 5 as Very familiar. (この作品をどのくらい知っていますか？)

1	2	3	4	5
Not Familiar at all (全く知らない)		Neither (どちらでもない)		Very Familiar (よく知っている)

10. Did you experience frisson while listening to this piece? If yes, please try to describe the feelings you had in the moment of frisson.
(この作品を聴いていて、フリソンを感じましたか？「はい」と答えた方は、フリソンの瞬間に感じた感情を表現してみてください。)

- ❑ No(いいえ)
- ❑ Yes(はい). _____

11. Did you have any other emotional reactions or feelings when listening to this piece?If yes, please describe your reactions.
(この作品を聴いて、他に何か感情的な反応や感じ方をしましたか？「はい」の場合、あなたの反応を詳しく教えてください。)

- ❑ No(いいえ)
- ❑ Yes(はい). _____

12. Did you experience any other bodily reactions? (E.g. tears, sweating etc.) If yes, please describe your reactions.
(その他の身体的な反応はありましたか (例: 涙が出る、汗をかくなど)？「はい」の場合、あなたの反応を詳しく教えてください。)

- ❑ No(いいえ)
- ❑ Yes(はい). _____

Figure B.9 Frisson Concert I. Questionnaire Page 9

Pièce No. 4 :“Rachmaninoff: Etudes-Tableaux, Op. 39”

13. From a scale of 1 to 5 please describe how familiar are you with this piece? 1 as Not familiar at all and 5 as Very familiar. (この作品をどのくらい知っていますか？)

1	2	3	4	5
Not Familiar at all (全く知らない)		Neither (どちらでもない)		Very Familiar (よく知っている)

14. Did you experience frisson while listening to this piece? If yes, please try to describe the feelings you had in the moment of frisson.
(この作品を聴いていて、フリソンを感じましたか？「はい」と答えた方は、フリソンの瞬間に感じた感情を表現してみてください。)

- ❑ No(いいえ)
- ❑ Yes(はい). _____

15. Did you have any other emotional reactions or feelings when listening to this piece?If yes, please describe your reactions.
(この作品を聴いて、他に何か感情的な反応や感じ方をしましたか？「はい」の場合、あなたの反応を詳しく教えてください。)

- ❑ No(いいえ)
- ❑ Yes(はい). _____

16. Did you experience any other bodily reactions? (E.g. tears, sweating etc.) If yes, please describe your reactions.
(その他の身体的な反応はありましたか (例: 涙が出る、汗をかくなど)？「はい」の場合、あなたの反応を詳しく教えてください。)

- ❑ No(いいえ)
- ❑ Yes(はい). _____

Figure B.10 Frisson Concert I. Questionnaire Page 10

Frisson Waves Concert I.

フリソンウェーブコンサート I.

Recording frisson at a classical piano performance

クラシックピアノ演奏でフリソンのレコーディング

Fri, Apr.9, 2021 13:30 open 14:00 start
Noah Piano Studio Denenchofu Salon

Director: *Yan He*
Pianist: *Muyu Liu*
Technical director: *George Chernyshov*
Technical support: *Lady DingDing Zheng*
Audio engineer: *Danny Hynds / Zhaoyue Wang*
Data analysis: *Jiawen Han*
Videographer: *Qianqian Mu*
Graphic designer: *Kinga Skierś*
Supervisor: *Kouta Minamizawa / Junichi Yamaoka*
Special thanks: *Kai Kunze / Jamie Ward / Ragnar Thomsen / Yuehui Yang / Mengchen Shi / Reiya Horii*

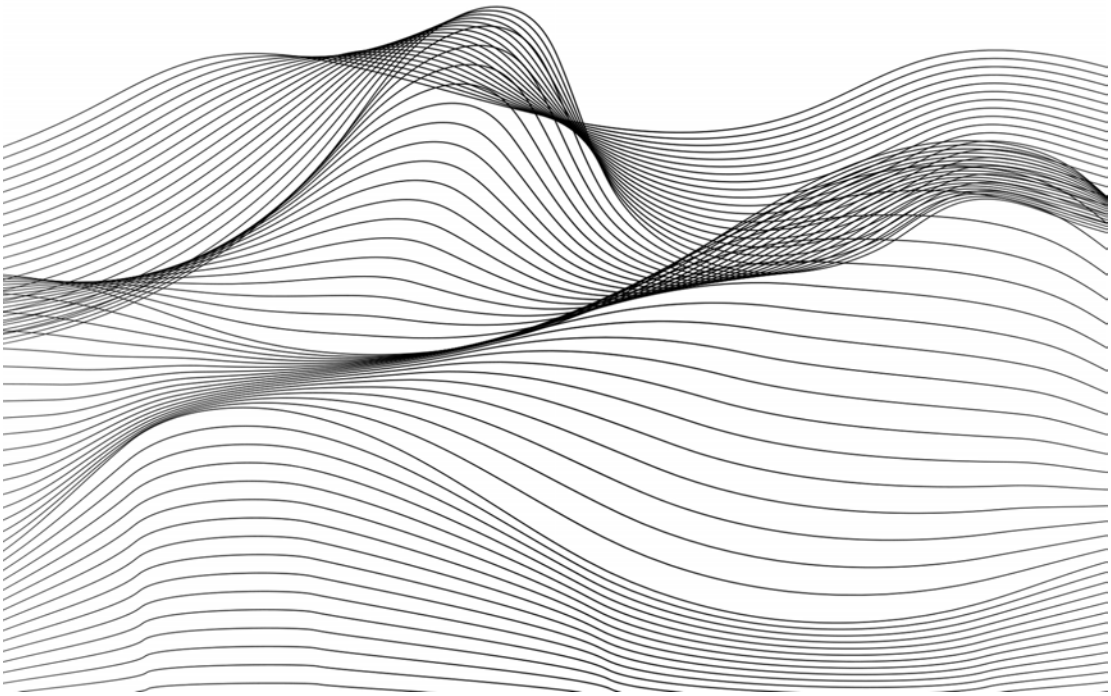


Figure B.11 Frisson Waves Concert I. Flyer

Performance Program

Chopin: Prelude, Op. 28, No. 15
ショパン: 雨だれ

Chopin: Ballade, No.1
ショパン: バラード第1番ト短調

Grieg: Piano Concerto in A minor, Op. 16 Cadenza & Coda
グリーグ: ピアノ協奏曲イ短調 作品16　カデンツァとコーダ

Rachmaninoff: Études-Tableaux, Op. 39, No.1
ラフマニノフ: 練習曲「音の絵」Op.39, No.1

Pianist Introduction

Born in 2000, **Muyu Liu** started playing the piano at the age of three. She has won numerous competitions, including the 1st prize in the Japanese Performer Piano Competition and the 1st prize in the Japan Classical Music Competition. Muyu Liu went to the United States in 2016, where she enrolled in the Idyllwild Arts Academy and the Cleveland Institute of Music in 2019.

2000年生まれ。3歳からピアノを始める。日本演奏家ピアノコンクール第一位、全日本クラシック音楽コンクール第一位など数々のコンクールで受賞。2016年に渡米。Idyllwild Arts Academyに入学。2019年、米Cleveland Institute of Musicに入学。

Research Introduction

Have you ever felt shivers or goose bumps when listening to classical music performances? When live performances deeply resonate with us, our bodies respond with physiological reactions - we call this phenomenon “frisson”. However, while some people have a strong frisson response, not all people perceive these moments of mind-body dualism naturally. This ongoing research project aims to understand, share and augment how we experience frisson at classical piano performances. This first Frisson Recording Concert will collect the participants’ physiological data. The second Frisson Sharing Concert will be held later this year, where wearable devices will be used to share the participants’ frissons and augment the performance.

クラシック音楽の演奏を聴いて、気分が高揚して体が震えたり、鳥肌が立ったりしたことはありますか。この演奏に深く共感することで伴う生体反応を『フリソン(Frisson)』と呼びます。しかし、フリソン反応が強い人がいる一方で、すべての人が心身共に感動的な瞬間を自然に感じているわけではありません。この研究プロジェクトは、クラシック・ピアノ演奏時でのフリソン体験を理解し、共有し、増強することを目的としています。今回の第1回目のフリソン記録コンサートでは、参加者の生理学的データを収集します。そして第2回目のフリソン共有コンサートでは、ウェアラブルデバイスを使用して、参加者のフリッソンを共有・増強する予定です。

Please enjoy the concert!

- Yan He
heyann@keio.jp

Figure B.12 Frisson Waves Concert I. Flyer

Frisson Concert No. 2

Seat Number 席番号 ____

1. Gender 性別

- ☐ Female 女
- ☐ Male 男
- ☐ Other or Prefer not to say
  その他／回答したくない

2. Age 年齢

_____

3. Before the concert, were you familiar with frisson/aesthetic chills.
今回のコンサート参加以前にフリソン（感動で鳥肌が立つこと）について知っていましたか？

- ☐ Yes はい
- ☐ No いいえ
- ☐ Maybe なんとなく

4. Estimate, how often did you feel musical frisson/aesthetic chills while listening to music in the last 6 months:
最近6ヶ月の間に、音楽を聴いた時にフリソン（感動で鳥肌が立つこと）を体験した回数を推定でよいので教えてください。

_____ **times 回数**

5. In general, how often do you experience frisson/aesthetic chills?
一般的に、どのくらいの頻度でフリソンを体験しますか？

- ☐ Never まったくしない
- ☐ Rarely たまに体験する
- ☐ Sometimes ときどき体験する
- ☐ Often よく体験する
- ☐ Very Often 非常によく体験する

6. How often do you experience frisson in relation to music?
音楽に関連したフリソンを体験する頻度はどのくらいですか？

- ☐ Never まったくしない
- ☐ Rarely たまに体験する
- ☐ Sometimes ときどき体験する
- ☐ Often よく体験する
- ☐ Very Often 非常によく体験する

1

Figure C.1 Frisson Concert II. Questionnaire Page 1

Frisson Concert No. 2

Seat Number 席番号 ____

7. How often did you feel frisson during the concert?
今回のコンサート中どのくらいの頻度でフリソンを体験しましたか？

- ☐ Never まったくしなかった
- ☐ Rarely たまに体験した
- ☐ Sometimes ときどき体験した
- ☐ Often よく体験した
- ☐ Very Often 非常によく体験した

8. Did you feel more or less frisson during the concert compared to other similar performances?
他の類似のコンサートに比べて、今回のコンサート中のフリソン体験は多かったでしょうか、または少なかったでしょうか？

- ☐ More 多かった
- ☐ Less 少なかった
- ☐ Don't know 分からない
- ☐ Didn't feel frisson フリソンを体験しなかった

Please use the scale below by circling a number between 1 and 7 to indicate how well or poorly each statement corresponds to you.
以下の記述について、1（全く思わない）～7（非常にそう思う）のスケールのうち、自分にあてはまる数字に○をつけてください。

1----------2----------3----------4----------5----------6----------7

Disagree Strongly 全く思わない — Neutral/ Mixed どちらともいえない — Agree Strongly 非常にそう思う

9. I feel frisson (aesthetic chills) often when listening to music.
音楽を聴いている時、フリソン（感動による鳥肌）をよく体験する。

1	2	3	4	5	6	7
Disagree Strongly			Neutral/ Mixed			Agree Strongly

10. I have felt very intense frissons during this concert.
今回のコンサート中に非常に強いフリソンを体験した。

1	2	3	4	5	6	7
Disagree Strongly			Neutral/ Mixed			Agree Strongly

2

Figure C.2 Frisson Concert II. Questionnaire Page 2

Frisson Concert No. 2 **Seat Number 席番号 ____**

11. I enjoyed the music performances. 今回の演奏を楽しんだ。

1	2	3	4	5	6	7
Disagree Strongly			Neutral/ Mixed			Agree Strongly

12. I found the concert more engaging than other similar performances I attended.
過去に行った他の類似のコンサートに比べて、今回のコンサートでは、より気持ちを引き付けられる感じがした。

1	2	3	4	5	6	7
Disagree Strongly			Neutral/ Mixed			Agree Strongly

13. In which of the performances did you feel most connected to the performers?
演奏者とのつながりを最も感じたのは、どの演目でしたか？

- ☐ Ensemble アンサンブル
- ☐ Classical Music Performances クラシック音楽演奏
- ☐ Both 両方
- ☐ Neither どちらでもない

14. The right image represents your seating position. The empty squares represent the people sitting around you. **Please check the empty square if you know the person who is sitting in this position.**
(あなたの周りに座っている人のうち、コンサート前から知っている人は何人いましたか？右の図で、Youはあなたの座席位置を表しています。空いている四角は、あなたの周りに座っている人を表しています。この中で知っている人がいた位置の四角に○をつけてください。)

☐ ☐ ☐
☐ you ☐
☐ ☐ ☐

15. I felt connected with people sitting around me. 周りに座っている人とのつながりを感じた。

1	2	3	4	5	6	7
Disagree Strongly			Neutral/ Mixed			Agree Strongly

Figure C.3 Frisson Concert II. Questionnaire Page 3

Frisson Concert No. 2 **Seat Number 席番号 ____**

[Section only if you were wearing a neckband
以下のセクションはネックバンドを着用した方のみお答えくださいde]
---

16. I experienced more frisson than in a normal concert performance.
通常のコンサートでの演奏よりも、フリソンを多く体験した。

1	2	3	4	5	6	7
Disagree Strongly			Neutral/ Mixed			Agree Strongly

16. I found the neckband decreased my enjoyment of the performance.
ネックバンドが気になって演奏を楽しむことが通常より難しかった。

1	2	3	4	5	6	7
Disagree Strongly			Neutral/ Mixed			Agree Strongly

Figure C.4 Frisson Concert II. Questionnaire Page 4

Figure C.5 Frisson Waves Concert II. Flyer

Performance Program

Muyu Liu

Beethoven: Sonata No.30 Op.109
ベートーヴェン：ソナタ第30番ホ長調作品109

"This sonata, composed by Beethoven in 1820, is very compact both spiritually and technically. It has a wide variety of emotions, including melancholy, joy, and feeling of grace, and sometimes resentment and conflict. In particular, the third movement, which begins with a naive and romantic theme and consists of six variations and coder, expresses various human emotions skillfully such as deep love and conflict hidden in Beethoven's innermost. It is one of Beethoven's works that I really like and can attach with my own feelings and various memories in my life. "

Chopin Nocturne Op.27 No.1
ショパン: ノクターン 第7番 作品27-1

"This nocturne, composed in 1835, is written in a deeply sorrowful tonality in C sharp minor. A theme consisting of a wide-range left-handed distributed chord and a simple melody that echoes above it. Chopin's delicacy has changed from the mysterious grace to the dramatic appearance of Mazurka in the middle part and the sudden appearance of Mazurka as if to express the national feelings towards Chopin's home country Poland, and the quiet return of the theme. It makes me feel his love of homeland, and the resentment and anxiety that dwells somewhere in his heart. "

Chopin Preludes Op.28 No.18~24
ショパン: 前奏曲 第18-24番

" This prelude which was completed on Mallorca in 1838 was influenced by Bach's equal temperament and was composed one piece each using all 24 tonalities. The length and difficulty of each piece. Although there is no unity in the songs, the characters of each tonality are expressed in a delicate, graceful, and bold way of thinking that is typical of Chopin, and the harmony of the songs before and after is well maintained. And each piece, which is a straightforward projection of Chopin's music and feels for life, seems to appeal to our hearts straight from each note, and myself, my daily life. The song that best suits every situation in my life often reverberates in my head. It is a collection of preludes that skillfully expresses human emotions. Chopin composed this pieces to cover the travel expenses for his escape to Mallorca with George Sand. "

---- Pianist: Muyu Liu

Reflections on Chopin Preludes Op.28 No.15
ショパン: 前奏曲 第15番「雨だれ」のリフレクション

"This original piece is also performed by Muyu ちゃん in the previous frisson concert.
Our reflection on this piece changes all the time just like this piece, going up and down, feeling gloomy and relieved. This time we would like to bring the audience implicitly together with us to complete this piece. "

"This piece is also for our dear honored, Tintin, Kiku."




Composed and performed by ***Danny Hydns*** ***Yuehui Yang*** ***Ragnar Thomsen*** ***Yan He***

Figure C.6 Frisson Waves Concert II. Flyer

Figure D.1 Karuizawa International Youth Concert Flyer