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Master's Thesis
Academic Year 2021

V-concert: An Immersive Music Experience for
Virtual Live Concerts Using Vibro-Tactile
Feedback



Keio University
Graduate School of Media Design

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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

Jingjing Xu

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Abstract of Master's Thesis of Academic Year 2021

V-concert: An Immersive Music Experience for Virtual Live Concerts Using Vibro-Tactile Feedback

Category: Design

Summary

This research introduces the musical haptic wearables for audiences (V-concert), a set of wearable devices for the immersive music experience targeting audience of live music concerts.

V-concert system, a system to deliver haptic stimuli, contains VR-Oculus Quest, headphones, and Vibro-Transducers to output vibro-tactile feedback together with audio and video.

We validate our hypothesis with experiments under 2 conditions. The first condition involved the VR Oculus Quest and headphones. To make the comparison, the second condition, involved a prototype of the whole V-concert system which means with the 2 Vibro-Transducers which could output vibro-tactile sensations to the performed music.

Overall, according to the results of the questionnaires and interviews, V-concert can affect the participants' immersion in music concerts and have the potential to enrich the listening experience of live music concerts. The majority of participants expressed their appreciation for the promotion of vibration devices for musical expression. Based on the feedback of participants, at the iteration of this work, we redesigned the prototype and made it have another use as a bracelet.

As for the intensity adjustment of the wearable vibration device, due to the limitations of the amplifier equipment, we can not increase the intensity of vibration equipment to a higher level. However, from the results, we still need to further adjust the intensity so that the device can be adapted to more people.

Besides, we will further improve V-concert according to the comments given by the participants in the interview and add more functions that can interact with other audiences to make it more stimulating.

Keywords:

HMD, VR, live concerts, vibro-tactile, immersive music experience

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Contents

Acknowledgements	viii
1 Introduction	1
1.1. Motivation	1
1.2. Objectives	4
1.3. Contributions	4
1.4. Thesis Overview	5
1.5. Key Terms	5
2 Related Works	6
2.1. Augmented the live music performance	6
2.2. Haptics to enhance emotional responses	8
2.3. VR and vibro-tactile feedback	10
3 Design Approach for V-concert	13
3.1. Design Concept	13
3.1.1 On the Use of Virtual Reality	13
3.1.2 On the Use of Haptic	14
3.1.3 Target Audience	17
3.2. Designed Artifact Components	18
3.3. V-concert architecture	20
4 Evaluation	22
4.1. Experiments	22
4.2. Experimental Process	23
4.3. Questionnaire Results	25
4.4. Statistic Analysis	28
4.5. Interview Results	30

4.6. Discussion	32
4.7. Iteration	32
4.8. Evaluation Summary	34
4.9. Design limitations	34
5 Conclusion and Future Work	39
5.1. Conclusion	39
5.2. Future Works	39
References	40
Appendices	43
A. Demographic Information Form	43
B. Consent Form	44
C. Online Survey Full Result	44

List of Figures

2.1	Touching the audience:Performers and audience during the concert-experiment [1]	7
2.2	Smart Mandolin and Musical Haptic Gilet 1	7
2.3	Smart Mandolin and Musical Haptic Gilet 2	7
2.4	Mood Glove: A haptic wearable prototype system [2]	9
2.5	A body-conforming tactile jacket to enrich movie viewing	9
2.6	VIRTUAL CONCERT HALL 1	10
2.7	VIRTUAL CONCERT HALL 2	10
2.8	Surround Haptics:Tactile feedback for Immersive Gaming experience [3]	11
2.9	a Portable Hand Haptic System for Immersive Virtual Reality	12
3.1	Oculus Quest-A wireless VR	14
3.2	Henhaoro-A simple VR matched smartphones	15
3.3	Use the smartphone to watch with an adapter	15
3.4	the wearable vibration1	16
3.5	the wearable vibration2	16
3.6	The wearable vibrations-use as a neck collar	17
3.7	Age distribution chart	18
3.8	Prototype Components	19
3.9	Amplifier	19
3.10	Headphones and Oculus Quest	19
3.11	Sync between video, audio and vibrotactile	20
3.12	Schematic view of the architecture	21
4.1	Oculus Quest	23
4.2	360 degree Live concert used in the experiment	24

4.3	Likert Scale Questionnaire WITH vibration device	25
4.4	User Test: 1.upper left:with wearable vibration device;2.upper right:without wearable vibration device;3.bottom left:with wearable vibration device;4.bottom right:without wearable vibration device.	26
4.5	The result of Likert Scale WITH vibration device	27
4.6	The result of Likert Scale WITHOUT vibration device	27
4.7	Bar graph-Result of with vibration	28
4.8	Bar graph-Result of comparison	29
4.9	The normal distribution test	29
4.10	T-test	30
4.11	Use as a bracelet	33
4.12	Bottom decorations	33
A.1	Demographic Information Form	43
B.1	Consent Form page1	44
B.2	Consent Form page2	45
C.1	Question1 and the result	45
C.2	Question2 and the result	46
C.3	Question3 and the result	46
C.4	Question4 and the result	46
C.5	Question5 and the result	47
C.6	Question6 and the result	47
C.7	Question7 and the result	47
C.8	Question8 and the result	48
C.9	Question9 and the result	48
C.10	Question10 and the result	48
C.11	Question11 and the result	49
C.12	Question12 and the result	49
C.13	Question13(Your age) and the result	50

List of Tables

4.1	Comments of interview1	36
4.2	Comments of interview2	37
4.3	Comments of interview3	38

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Thanks to my family and friends for encouraging me, supporting me and understanding me.

Chapter 1

Introduction

1.1. Motivation

The need to attend concerts remotely

The Covid-19 pandemic has brought about unprecedented changes in today's world since 2020. Large-scale events are facing possible cancellations and delays to prevent the spread of the infection, and in Japanese entertainment industry, since the state of emergency was declared, people are taking measures to postpone or cancel many events, live performances, and concerts.

Moreover, from the news published by NEWS ONLINE, as the market for live entertainment grows each year, however, the entertainment market has been hit hard due to the Covid-19 pandemic. There is about 80% reduction in live music activities and the live entertainment market decreased by 470 billion in 2020 comparing with the previous year¹.

According to the online survey results published by the MMD Research Institute in Japan on 2020/11/24(Fact-finding Survey on Online Live Music Viewing)conducted 12577 people in Japan², reasons not attending offline concerts for public are: Do not like a crowded place(17.0%);High tickets(17.6%);Just listening to the music is enough(14.4%);Because of the Coronavirus(13.6%);Busy with work(11.8%). We can see from the data that a considerable number of people cannot choose offline concerts due to various objective and subjective factors.

1 NEWS ONLINE
https://mmdlabo.jp/column/detail_1921.html

2 the MMD Research Institute-Online Survey
<https://news.1242.com/article/270959>

As a consequence of changes in lifestyles and the spread of infectious diseases, the need for attending concerts remotely has increased.

The need for a high immersive music experience

With advances in visual and aural simulation technologies, People are trying to have a better immersive music experience by making them feel as if they have attended live concerts without physically leaving their homes.

To enhance the music experience and stimulate the live concerts, there is a work tried to build a live house environment in our own house with smart lighting devices synced to the music³. There is also a music streaming platform offering immersive experiences using 360 degrees 3d and 2d format⁴. There is also live social interactivity in Muxical. Users can define their own avatars and text or voice chat with other users.

To have a better music experience, Apple music also announced that spatial audio with support for Dolby Atmos. Spatial audio gives artists the opportunity to create immersive audio experiences with authentic multi-dimensional sound and clarity for the audiences⁵.

Also, Verizon adaptive sound produced a spatial surround experience that has universal support across hardware and streaming services. The spatial surround experience regardless of what devices you use or what application you're watching or listening to⁶. People can enjoy the music with high quality spatial surround experience brought by Verizon.

People pay more and more attention to the sense of immersion when watching

3 Immersive Music Experience Prototype for the Smart Home

<https://medium.com/swlh/immersive-music-prototype-for-the-smart-home-cdf2748e474c>

4 A music streaming platform-Muxical

<https://muxical.com/>

5 <https://www.apple.com/newsroom/2021/05/apple-music-announces-spatial-audio-and-lossless-audio/>

6 <https://www.theverge.com/2021/7/7/22567035/verizon-spatial-audio-adaptive-sound-motorola>

performances and listening to music. However, music is an auditory experience after all, and while many headphones and speakers provide a kind of sensory immersion, they're just discussing about hearing, not our sense of touch.

Nevertheless, what if the physical feelings of "sound waves" we felt in offline live concerts were available to us whenever we wanted? That's the aim of the wearable vibration that relates sound to touch, using vibro-tactile feedback to give us music that we can really feel.

A survey on the audience's evaluation of the factors that influence the music concert

To clarify the public's attitude towards online and offline concerts today and the factors that influence their attitude, we released an online survey and collected 104 survey results. The online survey is called "A survey on the audience's evaluation of the factors that influence the music concert" and according to the results of the online survey (full results in appendix), we can see that 89.4% of the people have been to offline concerts. However, more people (36.5%) reported that the percentage of offline concerts they have been to is less than 20% comparing with online concerts. And when we asked about the disadvantages of offline concerts, there are 88.5% reported that "The view and clarity depend on the seat position", 50% reported that "High price", and 46.2% reported that it is a waste of time and energy for them to watch an offline concert.

As for the altitude using VR headsets and stereo audio to simulate music concerts, 64.4% expressed that "Positive. The music experience can be enhanced." And 71.2% expressed that they would like to try the VR concert system to watch online concerts.

Based on the results of the online survey, we believe that in today's society where infectious diseases are prevalent, VR headsets and wearable vibrations can be used to simulate live concerts and provide them with an immersive experience closer to offline concerts, which can meet the spiritual needs of most people.

1.2. Objectives

This study aims to mainly explore a new way to enhance the immersive music experience with vibro-tactile feedback which refers to the vibration necklace in our design.

The objectives can be seen as:

(1)To explore a new way to enhance the music experience by using VR HMD and haptics.

(2)To explore a possible design of wearable vibration device both can realize the purpose of enhancing music experience and decorating as an accessory in our daily life.

(3)To identify the existing weakness and to explore the further improvement measure in vibro-tactile feedback in music expression and music experience.

1.3. Contributions

In this study, we convert the sound signals into vibrations on both sides of our neck(around collarbone), and at the same time experience the "sound wave sensation" similar to that of a live music concert. Also, the study has recorded data sets from a total of 12 people. The data sets include 3 types of questionnaire answers and interview recording data. The questionnaire answers show the participants' response toward wearable vibration devices and the interview recording data can be used for future studies in improving the wearable vibration to enhance musical expression and experience.

Overall, the contributions of this study are as follows:

- (1)V-concert Prototype (VR+Headphones+the wearable vibration)
- (2)Online survey (for 104 participants)
- (3)Experiments under 2 conditions(for 12 participants x2)
- (4)Interview recording data(for 12 participants)

1.4. Thesis Overview

This thesis consists of 5 chapters. Chapter 1 depicts the introduction of this thesis. The motivation, objectives, and contributions of the study are also expressed here. Chapter 2 is about the literature review including 4 parts of related works. Chapter 3 shows the design approach of the prototype. Chapter 4 express the experiments and the results. Chapter 5 expresses the study of the results, the conclusion, along with future works.

1.5. Key Terms

VR:Virtual Reality

HMD:Head Mounted Device

Chapter 2

Related Works

2.1. Augmented the live music performance

In recent years, a lot of research has been focused on how to enhance the audience experience in the context of live performance. Based on the human-computer interaction and signal processing technology to simulate human senses. For instance, by using the performer's gesture recognition and augmentation which used avatars [4] and techniques such as real-time audio analysis [5])or sound synthesis [6].

Additionally, in the experiment for the augmentation of live performance, the researchers compared four groups of participants, to complete the study of haptic wearables to enhance music experience which is called Touching the audience [1]. The wearable can be conceived to enhance communication between performers as well as between performers and audience members by delivering the tactile feedback [7]. The prototype aims to enrich musical experience by stimulating the sense of touch as well as providing new capabilities for creative participation.

Besides of the interaction between the audience to increase the musical experience, there are also studies to increase the interaction between the performer and the audience to improve the music performance. Smart Mandolin and Musical Haptic Gilet is research to figure out the effects of vibro-tactile stimuli during live music performance. The study designed a smart mandolin and haptic gilet(jacket) as the prototype, and the performer played live with smart mandolin for audience members wearing a gilet-based musical haptic wearable that provided vibro-tactile sensations in response to the performed music [8]. Figure 2.2 and Figure 2.3 show the prototype of this study.



Figure 2.1 Touching the audience: Performers and audience during the concert-experiment [1]

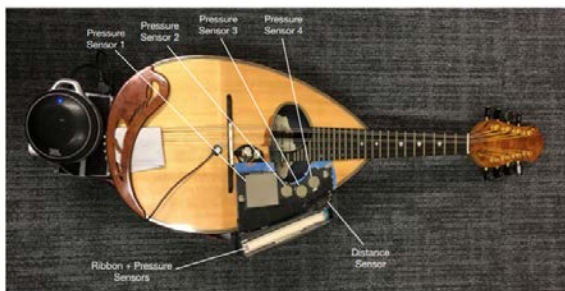


Figure 2.2 Smart Mandolin and Musical Haptic Gilet 1

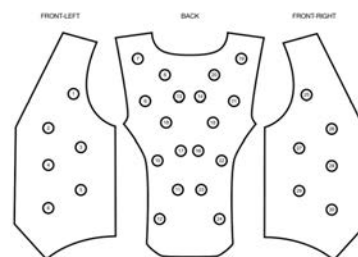


Figure 2.3 Smart Mandolin and Musical Haptic Gilet 2

2.2. Haptics to enhance emotional responses

In offline music concerts, we tend to sit and watch the performance, and for those who sit and listen, some researchers have explored embedding devices in chairs to provide vibrational stimuli at the same frequency as the sound. Merchel and Altinsoy designed a capable chair with whole-body vibrations, and analysed the effect of this stimulation on the perceived quality of audio replication. Their results reported that participants' perception of the reproduction quality of concert videotapes can be improved by haptic feedback [9]. Nanayakkara developed the tactile chair to enhance the hearing experience of the hearing-impaired [10]. This device, which consists of a chair with integrated speakers, recreates vibrations at the same frequency as the audio, and has been shown to be effective at enhancing the deaf's experience of music. Furthermore, similarly, Karam developed Emoti-Chair, which aims to improve the accessibility of music for deaf or hard-of-hearing people, by bringing a high-resolution audio-tactile version of music to the participant's body [11].

Offline concerts such as live house don't always provide seating, and in many live concerts(rock, heavy metal music, etc), the audience often sings, dances, and moves along with the performers. For this type of settings, haptic wearables may be better suited than seat-style solutions. Besides, researchers also designed Mood Glove, a prototype system consisting of an execution-enhanced Glove that envisions using vibration-tactile stimuli to amplify the Mood of music in movies [2]. In order to verify this system, the results show that vibrational tactile stimulation can enhance the audience's emotional response during the audiovisual experience of the film.

A wearable tactile jacket that is used to deliver movie-specific stimuli to the viewer's body. In terms of the result of the haptic jacket, the user test data shows that the tactile jacket has the intended effects on emotional immersion. Tactile patterns can help to become more immersed [12].



Figure 2.4 Mood Glove: A haptic wearable prototype system [2]



Figure 2.5 A body-conforming tactile jacket to enrich movie viewing

2.3. VR and vibro-tactile feedback

With advances in human senses simulation technologies, Virtual Reality (VR) continues to develop rapidly. It is becoming more and more important for us to understand the various aspects of VR [13]. By building completely virtual environments, VR plays an important role in long-distance communication between people through sensory-based virtual communication. [14].

In the present world, where almost all large-scale events are facing cancellation or delay due to the COVID-19 pandemic, the use of VR to simulate a live concert scene is very promising for researchers, and they has begun to focus on the application for the simulation, such as real time sports games and visual music live concerts [15]. Also, researchers argue that rendering pre-recorded live concerts through VR technologies may potentially give the opportunity of making them feel like they are attending live concerts even they have never physically leave their homes [16]. Moreover, the VR technologies can provide opportunity for users who are distant to attend a concert or for persons with special reasons who are not able to physically attend a concert.

In terms of 360-degree video and audio to enhance the music listening, Figure 2.7 and Figure 2.8 show the study produced a prototype for a classical music hall in Berlin with the Samsung GearVR [17]. It is also a virtual concert performance with a gesture recognition system.

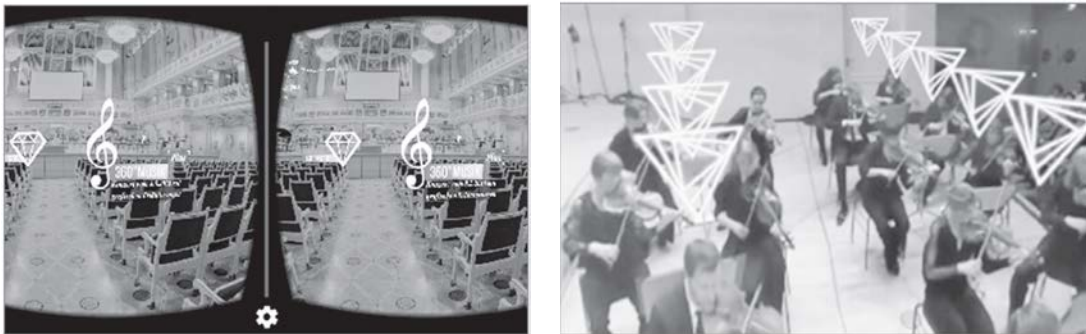


Figure 2.6 VIRTUAL CONCERT HALL 1 Figure 2.7 VIRTUAL CONCERT HALL 2

Out of the five senses, realizing two (sight and hearing) is very common and simple. Simulating these two feelings is not a complicated problem by using the current technologies. With the use of 360-degree audio, the study of wearable augmented reality audio was described by Aki Härmä which the result of the research suggested that the proposed transducer system may provide a foundation for the development of application of wearable augmented audio [18]. By contrast, achieving the other three (touch, etc) is relatively difficult and challenging. Therefore, providing vibro-tactile feedback on VR headsets can enhance the performance and human experience to a certain degree. The study which Figure 2.4 shows described the development of a vibro-tactile device called Mood Glove which can provide sensory feedback from a virtual environment and also along with sight and audio feedback systems. Instead of implementing the force feedback, they focus on tactile sensing to realize the same feedback [19].

Vibro-tactile feedback also can applied on the immersive games. Figure 2.6 shows the haptic architecture integrated the Surround Haptics system on the user's body with a driving simulation game to provide an enjoyable gaming experience [3]. The research transformed driving signals into vibration with vibratory transducers for the player to have a deeper understanding of driving and a more immersive gaming experience.



Figure 2.8 Surround Haptics:Tactile feedback for Immersive Gaming experience [3]

Adding haptic feedback to VR headsets can improve the game experience to a certain degree. Figure 2.9 is a study that built a hand haptics system along with the hand tracking system and VR headset. This study provided greater presence of vibro-tactile feedback and a more immersive environment in the virtual reality than only the hand tracking system.



Figure 2.9 a Portable Hand Haptic System for Immersive Virtual Reality

Chapter 3

Design Approach for V-concert

We defined the following design requirements:

1. Easy to use the wearable vibration
2. Able to enable tactile music expression
3. Easy to get the data of audience's response after the performance

3.1. Design Concept

3.1.1 On the Use of Virtual Reality

By building completely virtual environments, VR plays an important role in long-distance communication between people through sensory-based virtual communication. [14]. In the present world, where almost all large-scale events are facing cancellation or delay due to the COVID-19 pandemic, the use of VR to simulate a live concert scene is very promising for researchers, and they has begun to focus on the application for simulation of real-life events, such as music live concerts [15].

To increase the level of immersion in music concerts, we will use virtual reality. When we can't go to a concert offline, we often look for online sources like live streaming or Blu-ray DVD to experience the concert. However, none of these media can make us feel the change in our surroundings.

VR headsets can provide a 360-degree virtual environment and can make our vision change. In terms of the VR headset, there exists a lot of variations such as the HTC Vive, the Samsung Gear VR, the Google Daydream VR, etc. However,

we chose the Oculus Quest¹, a highly rated, high-definition, wireless device of late. It's also very easy to buy online, and besides of using it as a device to have an immersive music experience, we can also use it to play other VR games with the controllers.



Figure 3.1 Oculus Quest-A wireless VR

Also, for the simple use of VR, we can choose VR made by corrugated paper. Figure 3.2 shows the outer packing of this kind of VR headset. We can scan the QR code and put our smartphone into it and use our smartphone as a screen.

3.1.2 On the Use of Haptic

Considering the design of immersive music experience from the perspective of the use of haptic, we need to add vibro-tactile feedback and design a way to convert music to vibration at the same frequency.

In offline concerts, we can often feel the "vibration" of the audio equipment as a "sound wave" beats our chest due to the loud sound. In the previous studies, there was feedback that the haptic jacket was too heavy to move, so we need a light device that would allow us to move our arms around, or even jump around.

We also designed the device based on the use of haptic. Considering that we hear the sound with our ears, we need to place the device close to our ears. In

1 <https://assets.st-note.com/production/uploads/images/18482977/>



Figure 3.2 Henhaoro-A simple VR matched smartphones

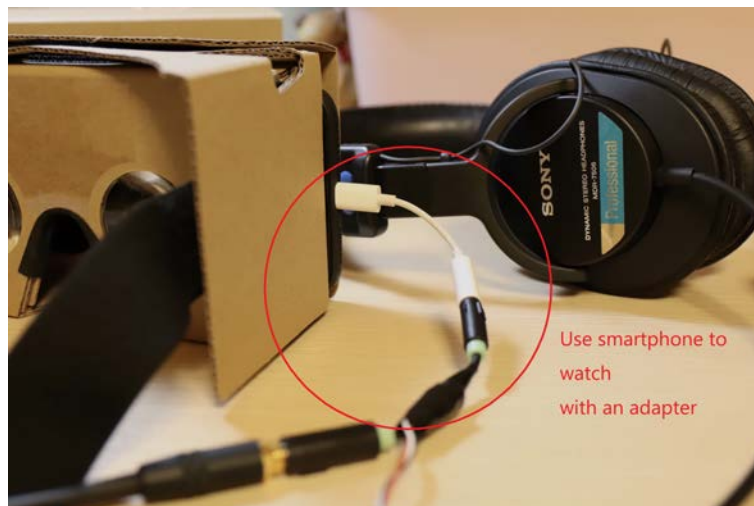


Figure 3.3 Use the smartphone to watch with an adapter

the previous studies, there was feedback that the haptic jacket was too heavy to move, so we need a light device that would allow us to move our arms around, or even jump around. Also, there will be headphones and VR around our heads, due to the weight of VR, we didn't place it around our heads.

In order to have a strong feeling of vibration so we place the wearable vibrations to both sides of the neck, which means around collarbones. It is close to our ears and chest, to make us have a feeling that music is beating our chest.

To sum up the above reasons, we can list them as:

1. Should close to auditory receptors(ears);
2. The wearable jacket is too heavy to move;
3. Around the head is too heavy to experience the music due to the weight of VR HMD.

According to the 3 reasons we summed, we decided to place the wearable vibration device around our neck near our collarbone just to look like a necklace. Figure 3.2 and Figure 3.3 show the prototype of the wearable vibrations.

we used four colors to make the strings of the wearable vibration. They are the most common colors we can see used for the lighting sticks.



Figure 3.4 the wearable vibration1



Figure 3.5 the wearable vibration2

Figure 3.6 shows what it looks like to actually wear the vibrator. Two vibration devices are connected by four cords of different colored wires, and we can put it

on our neck easily and also easy to remove it.



Figure 3.6 The wearable vibrations-use as a neck collar

3.1.3 Target Audience

From the results of the online survey we conducted in advance, which is called "A survey on the audience's evaluation of the factors that influence the music concert", we can extract age data and make them into a chart that can reflect the age distribution.

The chart we used is the Violin plot. It is useful to show the distribution of a numeric dimension. The shape width represents the number of items with the same value in the dataset².

From Figure 3.4 we can figure out that voters ranged in age from 18 to 38. And we can see clearly that people from 19 to 30 years old account for a large part of the total.

Therefore, from the survey results, we can conclude that the people who are interested in music and willing to attend online and offline concerts are mainly young people aged between 20 and 30 years old.

Consequently, target audience of V-Concert needs to be young people between 20 and 30 years old who can accept to attend the live concerts remotely.

2 RAWGraphs

<https://app.rawgraphs.io/>

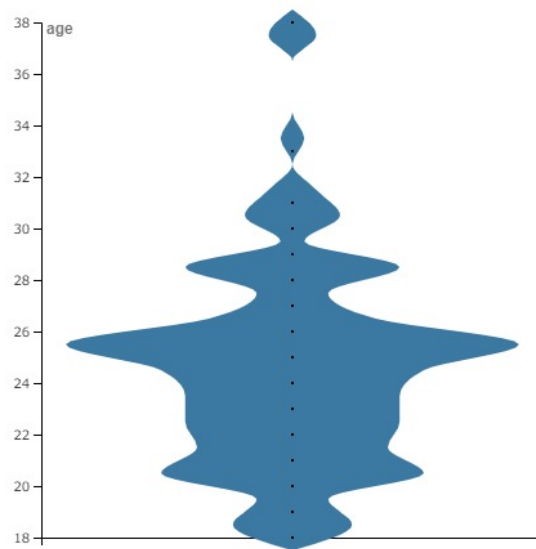


Figure 3.7 Age distribution chart

3.2. Designed Artifact Components

In a V-Concert environment, we need a VR device, a headphone, and a vibration device. For vibrating devices, we need to synchronize the sound in the VR device into a vibration of the same frequency. Amplifiers are also needed to amplify sound signals, and VP2 speaker impedance is used to make vibrotactile feedback. Considering that we use both ears to listen to music. We will also use impedance on both sides of our neck.

Figure 3.8 shows all of the designed artifact components. Therefore, the whole V-concert system contains VR(Oculus Quest), headphone(dynamic stereo headphone MDR-7506 Professional), 2Ch Output Power Amplifier, 2 Vibro-transducers (Speaker Impedance)for the both sides of neck, power input(battery), audio cables.

Figure 3.9 shows the amplifier we use. We can adjust the volume and vibration of the left and right sides in the front. Through the amplifier, we connected the cables that connect the headsets and Oculus quest at the same time. Figure 3

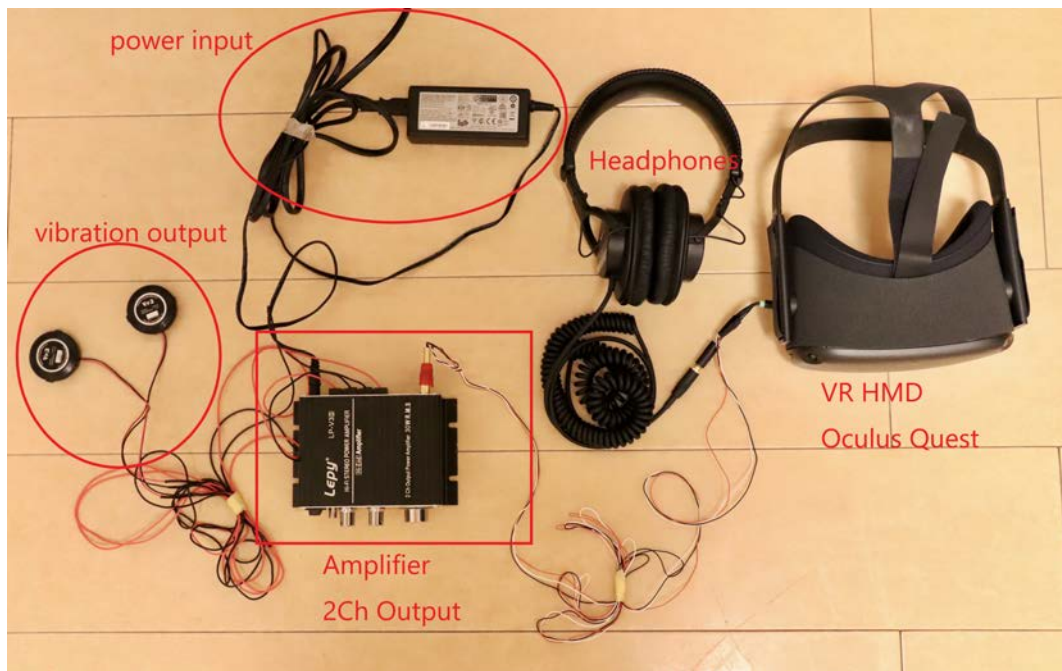


Figure 3.8 Prototype Components



Figure 3.9 Amplifier



Figure 3.10 Headphones and Oculus Quest

shows the headsets and Oculus Quest we used in the experiments.

3.3. V-concert architecture

V-concert System

To provide a highly immersive music experience, we need to synchronize the music, concert video, and vibration to enhance the performance of the music so that the listener can feel the vibration and sound at the same time.

Therefore, we input the sound signal to Oculus Quest through cables into an amplifier, which is connected to two Vibro-Transducers that generate the same frequency of vibration, and also connected to a headphone that allows the user to hear the sound at the same time. Figure 3.11 reflects the sync between a music concert videotape, audio, and vibro-tactile feedback.

Figure 3.11 shows the structure of the whole system. By using vibro-transducers, headphones, and Oculus Quest, we synced video and audio and the vibration.

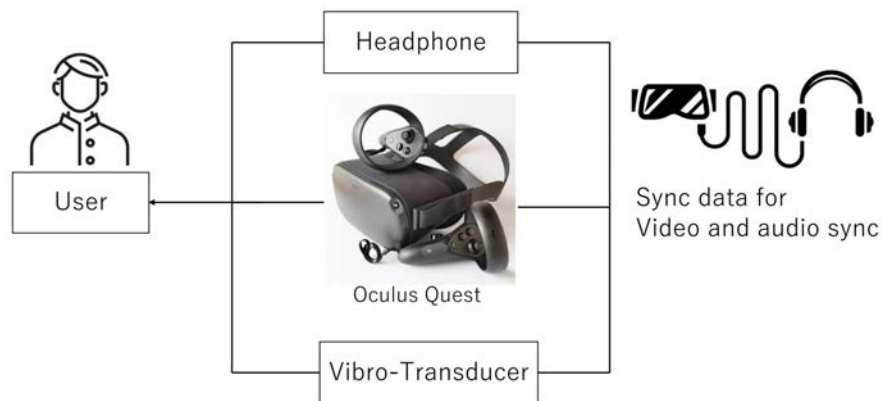


Figure 3.11 Sync between video, audio and vibrotactile

Figure 3.12 shows the schematic view of the architecture and data communication of a musical haptic wearable for audiences.

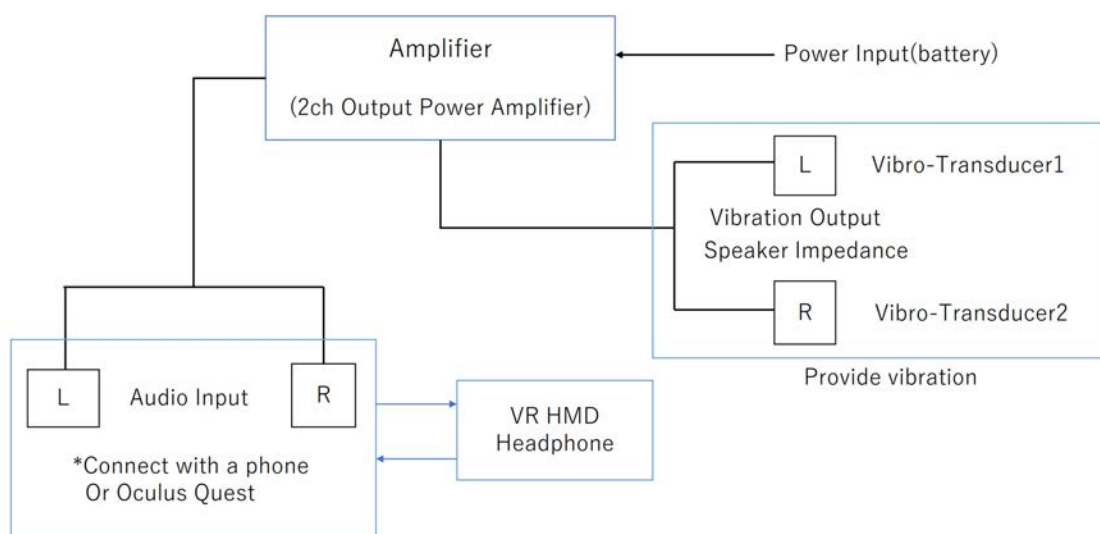


Figure 3.12 Schematic view of the architecture

Chapter 4

Evaluation

4.1. Experiments

In this study, we will conduct experiments under 2 conditions to verify the rationality of the design. To express the degree of stimulation and immersion of participants through wearable vibration devices, we will let participants wear VR headsets and vibration devices at the same time (V-concert environment). Under the other condition, we will set up another kind of experiment compared with the past research. In this case, we will only let the participants wear VR headsets to experience the live concert.

In choosing live music videos, we chose YouTube, a video platform that the general public can watch at any time. To make the participants immersive and feel the atmosphere of the music concert, we chose a VR video recorded in an outdoor live concert. For this video, we can choose from non-VR, VR 180 degree, VR 360 degree, and 2D or 3D. The video is also up to 4K in resolution.

In terms of the VR headset, there exists a lot of variations such as the HTC Vive, the Samsung Gear VR, the Google Daydream VR, etc. However, we chose the Oculus Quest, a highly rated, high-definition, wireless device of late. it's also very easy to buy online, and besides of using it as a device to have an immersive music experience, we can also use it to play other VR games with the controllers.

In terms of the evaluation of the experiments, we chose the Likert scale questionnaire. Widely used in psychological and other social science research today, Likert scales enable researchers to collect data that provides nuance and insight into participants' opinions. This data is quantitative and can easily be analyzed statistically.



Figure 4.1 Oculus Quest

4.2. Experimental Process

Live concert videotape

As for the selection of concert videos, we need to select the recorded videos online in advance. In order to achieve better experimental results, it is necessary to meet the following requirements:

1. High definition, you can choose to watch it in VR.
2. Music has a strong sense of rhythm.
3. There is no Mosaic of the audience's face (to prevent a loss of immersion)
4. the overall tone is bright and clear.

Therefore, the video tape we chose is shown below:

Experimental process

Condition 1: Watch a concert video tape with VR HMD & Stereo audio headphones.

Condition 2: Watch a concert video tape with V-concert (VR HMD & Stereo au-



Figure 4.2 360 degree Live concert used in the experiment

dio headphones &wearable vibration device)

As for the user test, we took place in Media studio for 12 participants. Considering the factors affected by the previous experiment, we will counterbalance the experiment for the participant group.

(For the same participant)

1. Take condition 1's experiment and fill in the Likert scale questionnaire (without vibration).
 2. Take condition 2's experiment and fill in the Likert scale questionnaire (with vibration).
 3. Interviewed by the researcher for about 5-10 minutes.
- Then we will change the order of conditions and let the next participant to take the experiment.

We did the experiments like, for the same participants, we will let him/her do condition1 first then condition2, and the next participant will do condition2 first then condition1. Then repeat this process. After each condition, they will fill in the questionnaire. At last, they will take a 5-10 minutes interview.

Likert Scale Questionnaire we used in the experiment (with vibration device) is shown as Figure 4.3.

Evaluation: Likert Scale

1 - strongly disagree, 2 - disagree, 3 - neutral, 4 - agree, 5 - strongly agree

Likert Item	1	2	3	4	5
I felt more connected to the performers when I had the wearable					
I felt more engaged with the music when I had the wearable					
I found the wearable vibrations irritating while listening to the music					
I enjoyed the wearable vibrations while listening to the music					
The wearable vibrations distracted me from the music					
The wearable enhanced my experience of the music					
I was able to relate the wearable vibrations to the music produced by the performers					
The wearable helped me to better understand the music					
The wearable helped me to better feel the music					
I found the wearable vibrations irritating while listening to the music					
I moved more when I had the wearable					
I was satisfied with the wearable vibrations during the performance					

Figure 4.3 Likert Scale Questionnaire WITH vibration device

4.3. Questionnaire Results

In the experiment, we tested 12 participants for 2 trials continuously. A likert scale questionnaire was conducted after each experiment. In the questionnaire, participants were asked to choose the one on a five-point scale that best matched their attitude.

In the first questionnaire(WITH vibration), we set up the evaluation questions about vibration equipment and the evaluation questions about the whole wearable device. And in the second questionnaire(WITHOUT vibration), we set the same questions however the questions related to vibration device are deleted because we did not use the wearable vibration in this condition.

Therefore, before we are going to evaluate and make comparison of the two questionnaires' result, we only need to compare the same questions about the whole device, which we called "the wearable" in our questionnaires. Also, we have told to participants this definition beforehand in the beginning of the experiment.

Figure 4.5 and Figure 4.6 show the results of Likert scale questionnaire. In



Figure 4.4 User Test:

1.upper left:with wearable vibration device;2.upper right:without wearable vibration device;3.bottom left:with wearable vibration device;4.bottom right:without wearable vibration device.

Figure 4.6, only the questions which marked red were be done, and we will only compare these questions' results in the evaluation part.

Likert scale-A Questionnaire WITH Vibration Device										
#	Likert Item	1-SD	2-D	3-N	4-A	5-SA	Total	Mean	SD	
1	I felt more connected to the performers when I had the wearable	0	1	4	4	3	12	3.75	0.8124	
2	I felt more engaged with the music when I had the wearable	1	1	1	7	2	12	3.66667	1.16619	
3	I found the wearable vibrations irritating while listening to the music	4	7	0	1	0	12	4.16667	1.36382	
4	I enjoyed the wearable vibrations while listening to the music	0	0	5	5	2	12	3.75	1.1225	
5	The wearable vibrations distracted me from the music	5	4	2	1	0	12	4.08333	0.92736	
6	The wearable enhanced my experience of the music	0	0	4	5	3	12	3.91667	1.02956	
7	I was able to relate the wearable vibrations to the music produced by the performers	0	2	3	5	2	12	3.58333	0.8124	
8	The wearable helped me to better understand the music	1	2	5	1	3	12	3.25	0.74833	
9	The wearable helped me to better feel the music	1	0	3	5	3	12	3.75	0.87178	
10	I moved more when I had the wearable	3	2	3	3	1	12	2.75	0.4	
11	I was satisfied with the wearable vibrations during the performance	1	1	5	2	3	12	3.41667	0.74833	
※:the wearable = VR HMD + Headphone + Vibration device										

Figure 4.5 The result of Likert Scale WITH vibration device

Likert scale-questionnaire WITHOUT vibration device										
#	Likert Item	1-SD	2-D	3-N	4-A	5-SA	Total	Mean	SD	
1	I felt more connected to the performers when I had the wearable	0	0	8	4	0	12	3.333333	1.6	
2	I felt more engaged with the music when I had the wearable	1	2	6	3	0	12	2.916667	1.029563	
3	I found the wearable vibrations irritating while listening to the music									
4	I enjoyed the wearable vibrations while listening to the music									
5	The wearable vibrations distracted me from the music									
6	The wearable enhanced my experience of the music	0	2	8	2	0	12	3	1.469694	
7	I was able to relate the wearable vibrations to the music produced by the performers									
8	The wearable helped me to better understand the music	0	6	5	1	0	12	2.583333	1.28841	
9	The wearable helped me to better feel the music	0	3	4	5	0	12	3.166667	1.029563	
10	I moved more when I had the wearable	3	3	4	2	0	12	2.416667	0.678233	
11	I was satisfied with the wearable vibrations during the performance									
※:the wearable=VR HMD+Headphone										

Figure 4.6 The result of Likert Scale WITHOUT vibration device

With the V-concert wearable device, audience members felt more connected to the performers ($M = 3.75$, $SD = 0.81$) and more engaged with the music ($M = 3.67$, $SD = 1.17$). And they felt the vibro-tactile feedback enhance their experience of the music ($M = 3.92$, $SD = 1.03$). They reported that the V-concert wearable device helped them to better feel the music ($M = 3.75$, $SD = 0.87$). Participants tended to enjoy the vibro-tactile feedback which was not found to be irritating ($M = 4.17$, $SD = 1.36$). They also expressed that they were not be distracted by the wearable vibrations ($M = 4.08$, $SD = 0.93$).

However, at the same time, the participants expressed that they did not move more with the vibrations ($M = 2.75$, $SD = 0.4$).

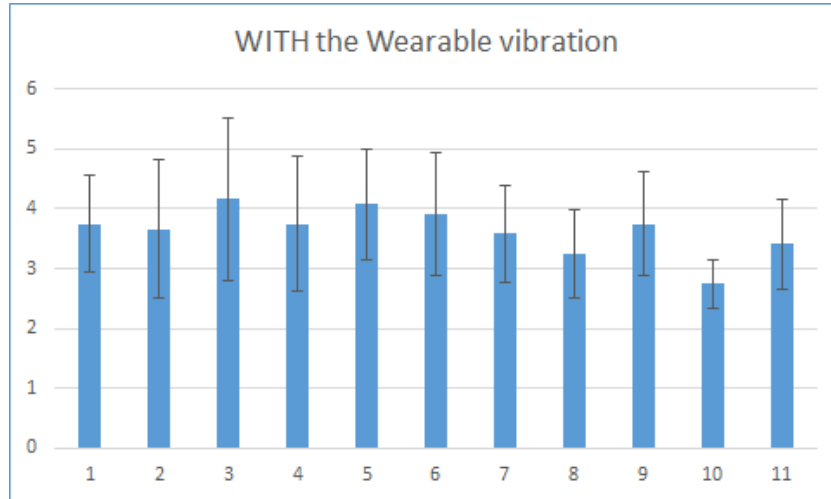


Figure 4.7 Bar graph-Result of with vibration

From the bar graph of the result with vibration, we can find that almost all scores are over 3 points. Also in the comparison of the two conditions, we can find that in most cases, wearing vibrators enhanced immersion and stimulates more than not wearing them.

4.4. Statistic Analysis

In order to verify the rationality of the experiment and compare whether there is a significant difference between the two experiments, we will do a T-test on the questionnaire results.

In terms of the application, we used for verifying, IBM SPSS Statistic is widely used and easy to operate. It can automatically output a series of results such as tables, histograms, etc.

When we enter the data in SPSS, we will change the number of the questions, make the question numbers into a series of consecutive numbers to observe the P-value, and to determine whether the data conform to the normal distribution,

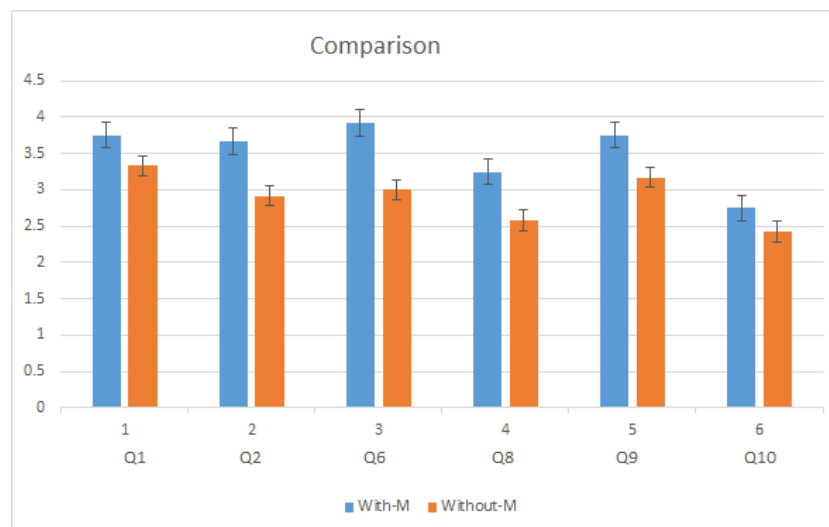


Figure 4.8 Bar graph-Result of comparison

and then carry out the next step of the parametric or non-parametric test.

The normal distribution test

Figure 4.7 shows the result of the normal distribution test.

The null hypothesis is that this data is "normally distributed", so if $P > 0.05$ it is nonparametric and not normally distributed. If $p > 0.05$, it is parametric that is normally distributed. In this case, the significance probability on the far right is "0.153" and "0.813", so the "Mean" is a "parametric test" because it is normally distributed.

正規性の検定							
		Kolmogorov-Smirnov の正規性の検定 (探索的) ^a			Shapiro-Wilk		
	with0without1	統計量	自由度	有意確率	統計量	自由度	有意確率
Mean	0	.303	6	.090	.849	6	.153
	1	.183	6	.200*	.959	6	.813

*. これが真の有意水準の下限です。

a. Lilliefors 有意確率の修正

Figure 4.9 The normal distribution test

T-test

Based on the above data, we conduct a t-test on the data to judge whether there is a significant difference between the two conditions.

Figure 4.8 reported the results of the t-test. We can find that Two-Sided $p=0.023$ ($0.023 > 0.05$), therefore there is a significant difference between the two conditions.

		等分散性のための Levene の検定		2つの母平均の差の検定							
		F 値	有意確率	t 値	自由度	有意確率		平均値の差	差の標準誤差	差の 95% 信頼区間	
						片側 p 値	両側 p 値			下限	上限
Mean	等分散を仮定する	.394	.544	2.686	10	.011	.023	.61102	.22752	.10408	1.11797
	等分散を仮定しない			2.686	9.524	.012	.024	.61102	.22752	.10063	1.12142

Figure 4.10 T-test

4.5. Interview Results

After 2 experiments, we did a short interview for each participant about 5-10 minutes to get the open comments. The additional questions related to the experience about music live experience and vibrotactile feedback will be asked in this part. Table 4.1, Table 4.2, and Table 4.3 report the results of the interview.

There are 5 additional questions in the interview part. The questions asked by us are:

1. Have you ever been to offline music concerts?
2. Can you relate the vibration to the performance? Or to the singer/musical instruments/other audiences?
3. How about the position and the vibration strength of the wearable vibrations?
4. Do you prefer to be an audience listening to music quietly or hope to have more interaction with the performance?
5. Do you have other suggestions or something about the disadvantages of the V-concert wearable device?

In the interview, we also expressed the concept of V-concert, included the reasons we set the wearable vibrations around the collarbones, and the method of evaluation for a deeper understanding for the participants.

Of the 12 participants in the experiment, three expressed they had never watched an offline concert, however had watched live or recorded concert clips online.

In terms of the positive comments, 11 participants said they could associate the vibration with the performance and could feel that the vibration enhanced the musical experience. 9 participants reported that vibration was more associated with an instrument (drum set, guitar, etc) and that they felt a greater sense of rhythm. In addition, some participants expressed that "Hearing the applause and cheers of the audience, I considered myself to be a member of the live audience and had a sense of atmosphere", "Recalled me of the sound waves I felt when I was close to the speakers in the offline concert". Even there is 1 participant who expressed that "The strong sense of rhythm brought by vibration can make people with a poor sense of music and rhythm better experience music".

Moreover, in terms of the negative comments, only 1 of 12 participants said that he/she could not relate the vibration to concert performance, and believing that there was no significant difference between the presence of vibration equipment and the absence of vibration equipment. The participant also reported that little interest in vibrations or music in his/her daily life.

Five participants reported that the current vibration intensity was appropriate for them, however could be louder. Four participants reported the volume could be louder because it was too loud to hear other sounds during an offline live concert. Six of the participants reported that the camera angle in the video was too low and that they need to look up at the performer after a while and caused fatigue.

As for the future improvements to the V-concert, participants suggested watching videos with their friends to increase interaction with them. Or you can randomly match other people who are watching the video at the same time and increase the interaction with them to add a social element.

There is also a suggestion which complains that we could add a gesture recognition system, which could make corresponding vibration feedback according to

their movements. For example, when participants and performers clapping their hands at the same time, the vibrations are enhanced.

Additionally, One participant reported the position of the vibrating device needed to be changed. The participant found the vibrating devices placed on both sides of the collarbones were uncomfortable for him/her. Admittedly, the vibrating device in this study was fixed and immutable, and it did produce negative feelings for a certain group of people. To improve this problem, we will redesign the prototype and increase the use of wearable vibrations.

4.6. Discussion

To summarize, the idea that Use VR, Stereo Headphones& wearable vibrations to provide an immersive music experience of Live Concerts was not disproven.

According to the results of the questionnaire and interview, V-Concert can affect the participants' immersion in the music concert and have a positive impact on their music experience. The majority of participants expressed their appreciation for the promotion of vibration devices for musical expression.

As for the intensity adjustment of the vibration device, due to the limitations of the amplifier equipment, we can not increase the intensity of vibration equipment to a higher level. However, from the results, we still need to further adjust the intensity so that the device can be adapted to more people.

4.7. Iteration

Through the interviews with the participants, we got some positive comments, however, there are still some problems that need to be improved. As for the existing problems, we redesigned the prototype to meet the needs of more people and make it more like an accessory.

Above all, as for the problems that need to be improved, we can list them as following:

- 1.The current vibration intensity could be higher(reported by 5 people).
- 2.The volume could be louder(reported by 4 people).

3. The viewing angle in the videotape needs to be higher (reported by 6 people).
4. The position of the vibration equipment needs to be changed (reported by 2 people).

To solve these problems, we will choose a new videotape with a better perspective, replace the amplifier, and redesign the position of the wearable vibration device.

For the iteration of the wearable device, we will lengthen the length of the rope in the middle part (connecting the two vibrating ropes) to make the vibration closer to neck collar and make the vibration feel stronger.



Figure 4.11 Use as a bracelet



Figure 4.12 Bottom decorations

Due to the lengthening of the middle part, we can also wrap it around the wrist and make it into a vibrating bracelet. When users feel uncomfortable, they can change the location of the vibration device and get a better user experience so that the wearable vibration can both use as a neck collar and as a bracelet. Also, we redesigned the bottom of the strings and decorated them with stars to present the light of light sticks audience used in the live concerts.

4.8. Evaluation Summary

Throughout the study, we carried out 2 conditions of the experiments and 1 interview to validate our hypothesis. This section explains the general evaluation and the results of the study.

The first condition of the experiments was carried out with the purpose of finding out the comparison with the previous research which means the VR Headset and stereo headphones. The experiment record participant's responses to immersive music concert experiences with VR headsets. The results showed that VR can slightly enhance the immersive music experience for participants.

The second condition of the experiments was carried out to validate the effectiveness of the V-concert prototype. In the experiment, we used the whole V-concert system which refers to VR headsets, stereo headphones, and wearable vibrations. We also asked the participants to fill in the Likert scale questionnaire to show their response and altitude about V-concert and the wearable vibrations.

The interview after the experiments was about the additional questions based on participants' life experiences. Each interview was about 5-10 minutes including 5 questions. Comparing the results of the 2 experiments, we found that participants were satisfied with V-concert System than the general VR headset.

Ultimately, based on the comments of interviews, we redesigned the prototype and made it into a multipurpose wearable vibration for different people to enjoy.

Overall, the V-concert system does provide a more immersive experience and engage the music expression during the streaming of music concert. The two experiments and the interview verifies the hypothesis that the wearable vibrations around collarbones(neck) can help people have a more immersive music experience in a virtual live concert environment.

4.9. Design limitations

As for the design of this study, we designed experiments under 2 conditions and an interview after the study. First of all, the limitation problem, the experiment could be more convincing if we could design a blank group and conduct participants to each of the three experiments and compare the results.

In addition, the limitation in the design of wearable vibration equipment, we placed the vibrator near the collarbone to give the participants a stronger vibration sensation and a position close to both the ear and the chest. However, the intensity of the vibration did not increase from the beginning to the end, and some participants said that they got used to the intensity and were less stimulated after a certain period of time. We should adjust the intensity of vibration according to the melody and rhythm of each song to make the vibration have variability.

There is a limitation on the amplifier so the intensity of wearable vibration couldn't be higher that may make the participants feel boring after a period of time. Also, there are limitations of the external environment, for instance, the temperature, the height of the chair, etc.

Table 4.1 Comments of interview1

Participant ID	Comments
1	<ol style="list-style-type: none"> 1. Have been to offline music concerts. 2. The device allows people to feel the sound waves which can be felt near the speakers offline. 3. Vibration highly matched the rhythm and can help people who have poor music sense to feel the rhythm. 4. Can easily experience offline music live when you are busy. 5. Add real-time interaction with friends. Vibration can have some variability.
2	<ol style="list-style-type: none"> 1. Never have been to an offline music concert. 2. Have a strong sense of rhythm and the drum set. 3. The atmosphere of a live concert is not enough. 4. Hope to listen to the music quietly as an audience and don't want to have too much interaction.
3	<ol style="list-style-type: none"> 1. Have been to offline music concerts. 2. Have the condition without vibration first. Just watching the concert video makes me more focused on the performance. 3. Could related the vibration with the musical instrument. Tried to distinguish and make connections between audio and vibration. 4. Hope for a stronger vibration. Guitar, drum set, singer, all kinds of music vibration can be separated and clearer. Hope for more interactions with the singer. 5. The camera's perspective makes me felt that I was sitting in a VIP seat. After getting used to it and feel like the perspective needs to be higher.
4	<ol style="list-style-type: none"> 1. Have been to offline music concerts. 2. Could combine the vibration with the performance. Could distinguish the rhythm of the guitar and the drum and feel the vibration accordingly. 3. The vibration can be stronger. 4. Hope to have more interaction with the audience and the singer. 5. The volume can be louder. Hope to feel the sound of other audiences. The position of the camera was too low in the current videotape.

Table 4.2 Comments of interview2

Participant ID	Comments
5	<ol style="list-style-type: none"> 1. Have been to offline music concerts. 2. Could relate the vibration with the performance. However, the video definition is not high enough and VR devices are too heavy. 3. The current vibration intensity is enough. 4. The position of vibration is expected to change with the rhythm. 5. The viewpoint is too low.
6	<ol style="list-style-type: none"> 1. Have been to offline music concerts. 2. Could connect the vibration with the performance. The poor network results in a pause in the middle playback, which reduces the experience. 3. The vibration intensity is enough but can be stronger. 4. Hope to have more interaction with friends rather than the artists.
7	<ol style="list-style-type: none"> 1. Have been to offline music concerts. 2. There is a sense of audience involvement. The audience applauded and cheered, which can make people have a sense of interaction with the audience. 3. Hope for a stronger vibration and audio volume. 4. Hope to have the percussion feeling of a drum set. And increase the interaction that can make me move and increase my sense of accomplishment. 5. Add a social component. Random match audience interaction or can interact with friends.
8	<ol style="list-style-type: none"> 1. Have been to offline music concerts. 2. Could connect the vibration with the musical instruments but not the singer. 3. The current vibration intensity is enough. Later adapt to the intensity of vibration, hope that the intensity can change with the rhythm. 4. Add some gesture recognition (e.g.clapping) to enhance the interaction with the singer.
9	<ol style="list-style-type: none"> 1. Have been to offline music concerts. 2. Could connect the vibration with the musical instruments. 3. The current vibration intensity is too strong. The vibrations are better to be around the ears or on the scalp. 4. When there is a fan service, the interaction with the singer could be more. 5. VR HMD is too heavy to wear. The viewpoint of the camera in this video is too close to the stage.

Table 4.3 Comments of interview3

10	<ol style="list-style-type: none"> 1. Have been to offline music lives. 2. Could connect the vibration with the musical instruments. 3. The current vibration intensity is enough. 4. Hope to have more interaction with friends or other audiences. 5. The viewpoint should be changed (looks like the audience is standing on the stage).
11	<ol style="list-style-type: none"> 1. Never have been to an offline music concert. 2. Could connect the vibration with the musical instruments. Hope to have more interaction with the singer. 3. The vibration intensity is enough but can be stronger and have more variability. 4. Hope to have more interaction both with the singer and the instruments. 5. The video is not clear enough.
12	<ol style="list-style-type: none"> 1. Never have been to an offline music concert. 2. Believe that it doesn't make much difference whether there's a vibration or not. 3. The vibration intensity can be much stronger. However, the position where around the neck(collarbone) was nice. 4. Hope to have more interaction with friends who can watch the concert at the same time.

Chapter 5

Conclusion and Future Work

5.1. Conclusion

This research introduces the musical haptic wearables for audiences (V-concert), a set of wearable devices for the immersive music experience targeting audiences of live concerts. Two conditions of experiments and an interview were carried out to verify the hypothesis. Based on the interview results, in the iteration part, we redesigned the prototype for a different use as a bracelet.

Overall, the V-concert system does provide a more immersive experience and engage the music expression during the streaming of music concert. The two experiments and the interview verifies the hypothesis that the wearable vibrations around collarbones(neck) can help people have a more immersive music experience in a virtual live concert environment.

5.2. Future Works

For future works, we will further improve V-Concert according to the opinions given by the participants in the interview and add more functions to make it more stimulating. We will conduct further research on enhancing the interaction between the audience. Participants report that attending offline music concerts was not only for enjoying a stronger musical atmosphere but also for experiencing some social interaction between other audience and their friends. To realize a better user experience, we will add random matching to other viewers or specify matching to friends in the system.

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Appendices

A. Demographic Information Form

Demographic Information Form

Geist Lab

Student Number:

Name:

1. What is your age?

- _____
- Prefer not to say

2. What is your sex?

- Male
- Female
- Other
- Prefer not to say

3. What is your nationality?

- _____
- Prefer not to say

Figure A.1 Demographic Information Form

B. Consent Form

Consent Form

To participate in the scientific study
“ V-concert: Designing a Virtual Environment of Live Concerts for the Immersive Music Experience with Vibro-tactile Feedback”

Information Sheet

This form called consent sheet will give you information about the study so you can make an informed decision about participation in this study. We would like to ask you to read the following explanations on the content of the study and to sign the consent form below if you agree.

During the study, the participants will be asked to wear a VR headset individually or with a vibrating device to watch 1-2 live concert video tapes. After the experiment the participants will also be asked to finish 2 questionnaires and interviewed by researcher. Participation in the study is expected to take 15 minutes. The data collected (questionnaire responses, interview recordings, etc) will be evaluated for scientific purposes.

The participants in this study are not exposed to any risk in everyday life. You may terminate your participation in the study at any time without giving any reason and without any disadvantages. In the event of termination, all data collected up to that point will be deleted.

Data Protection

The following data is collected within the scope of this study:
questionnaire responses, video and audiorecording during the interview part.

The following personal data is collected:
Age, gender, nationality.

Confidentiality

All data collected within the scope of this study are confidential and will only be used anonymously. Demographic data such as age or gender do not allow a clear conclusion to be drawn about your person.

We will never ask you to give your name or any other unambiguous information at any time during the respective study.

Data Storage

The data collected with this study will be stored at the GEIST research group at KMD and deleted after 1 year at the latest. The data is stored in a form that does not allow any conclusion to be drawn about your person. This consent form shall be kept separate from the other test materials and documents.

Figure B.1 Consent Form page1

C. Online Survey Full Result

Voluntariness & rights of the participants

Your participation in this investigation is voluntary. You are free to cancel your participation at any time during this study and thus withdraw your consent (revocation), without this resulting in any disadvantages for you. If you cancel your participation, no data from you will be stored and all existing personal data will be destroyed. You have the right to obtain information about the personal data concerning you and, if necessary, to demand its correction or deletion.

Consent

I have read the explanations of the study and agree to participate in the study. I agree that the data collected in the course of the study may be evaluated for scientific purposes and stored in pseudonymized form. I am aware that my participation is voluntary and that I can cancel the trial at any time without giving reasons. All questions regarding the study were answered by the present investigator.

Place, Date

Name

Signature

If you have any questions, suggestions or complaints, please do not hesitate to contact the test manager:
Prof. Kai Kunze
Keio Graduate School of Media Design
Email: kai@kmd.keio.ac.jp

Persons responsible for the data processing of this study:
Jingjing Xu
Email: izumixu@kmd.keio.ac.jp

Figure B.2 Consent Form page2

1. Have you ever been to concerts, music festival, live house or other music concerts ?

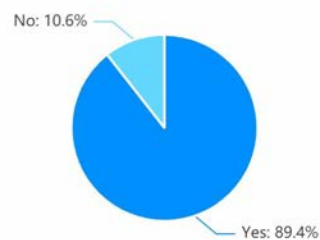


Figure C.1 Question1 and the result

2. What kind of music concerts have you ever been to?

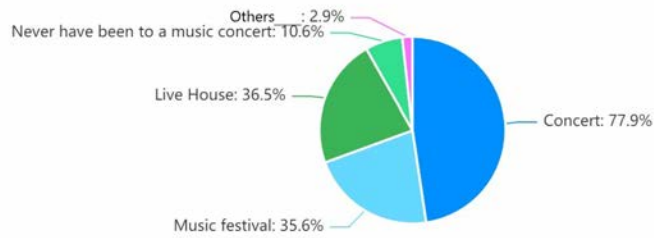


Figure C.2 Question2 and the result

3. What is the percentage of concerts you have seen online or offline?

(Offline: offline concerts, music festivals, live houses, etc

Online: Youtube, Bilibili Station, DVD, etc)

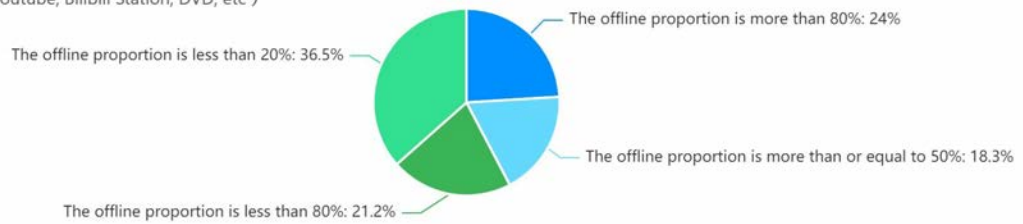


Figure C.3 Question3 and the result

4. What do you think are the advantages of offline music concerts?

(Offline: offline concerts, music festivals, live houses, etc)

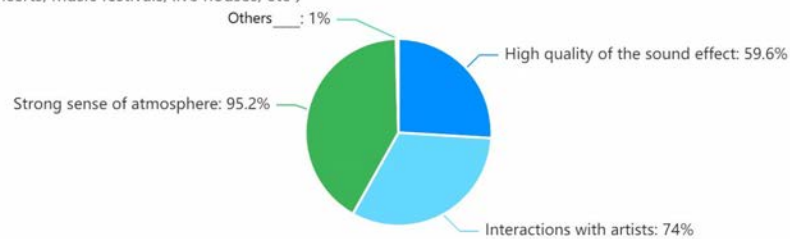


Figure C.4 Question4 and the result

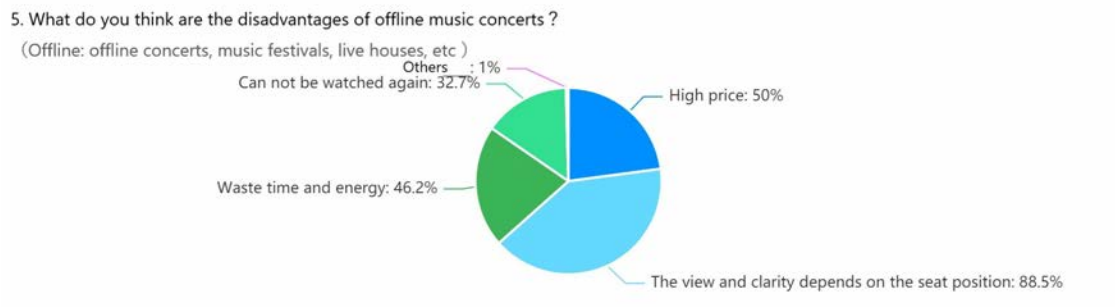


Figure C.5 Question5 and the result

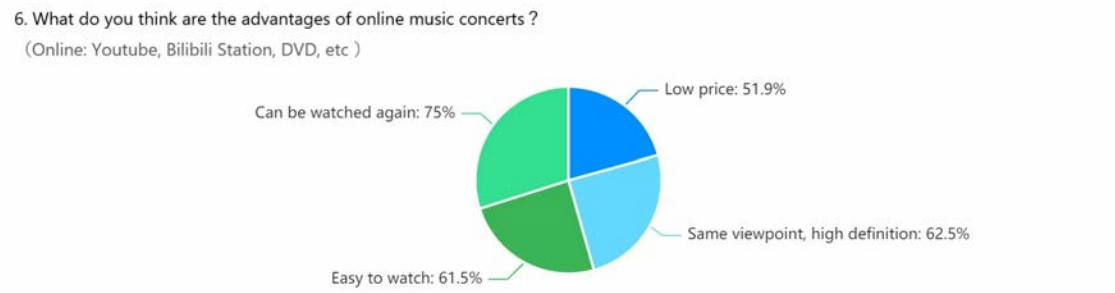


Figure C.6 Question6 and the result

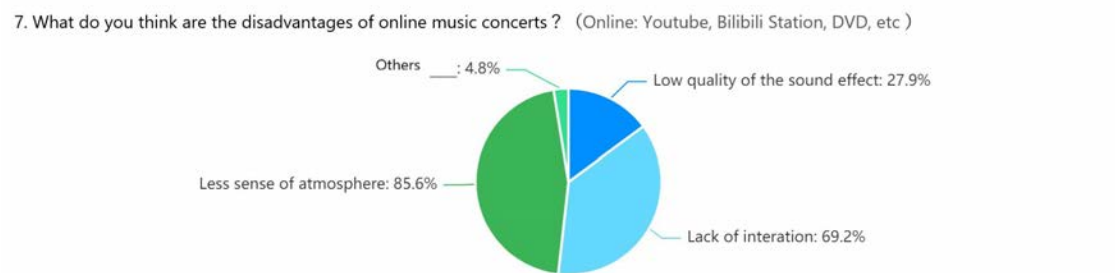


Figure C.7 Question7 and the result

8. Which concert format do you prefer?

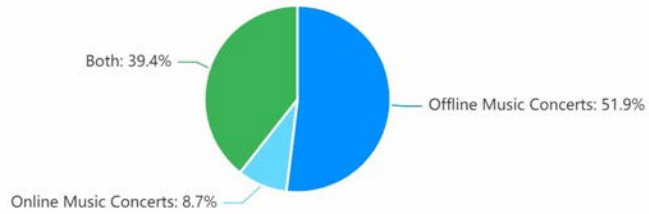


Figure C.8 Question8 and the result

9. What is your attitude towards using VR headsets and stereo audio to simulate music concerts?

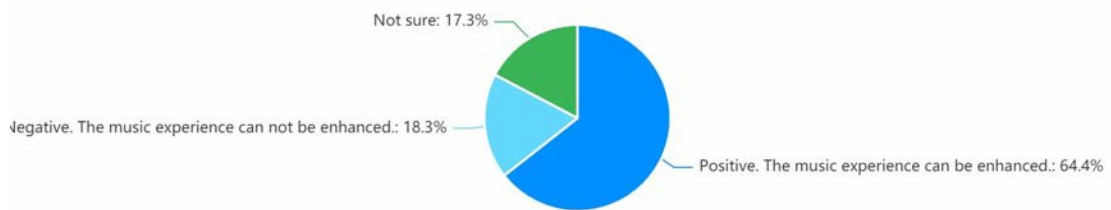


Figure C.9 Question9 and the result

10. Are you willing to use VR glasses and stereo equipment to watch the concert? (Online or offline is free to choose)

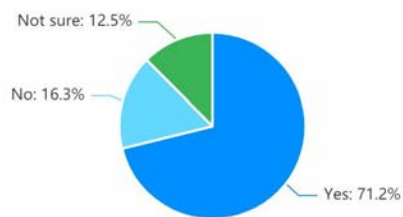


Figure C.10 Question10 and the result

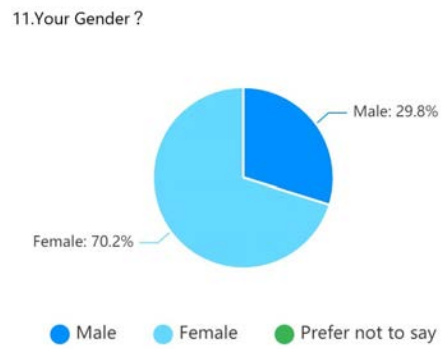


Figure C.11 Question11 and the result

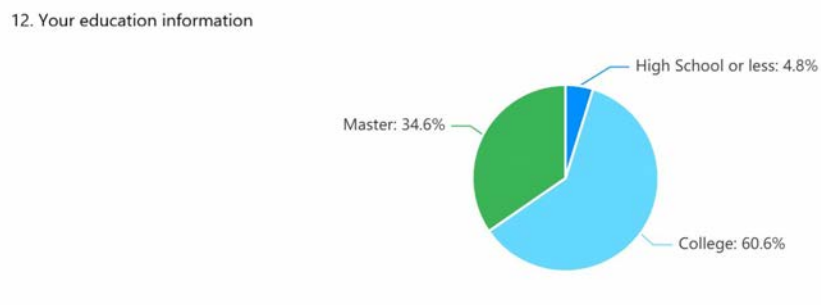


Figure C.12 Question12 and the result

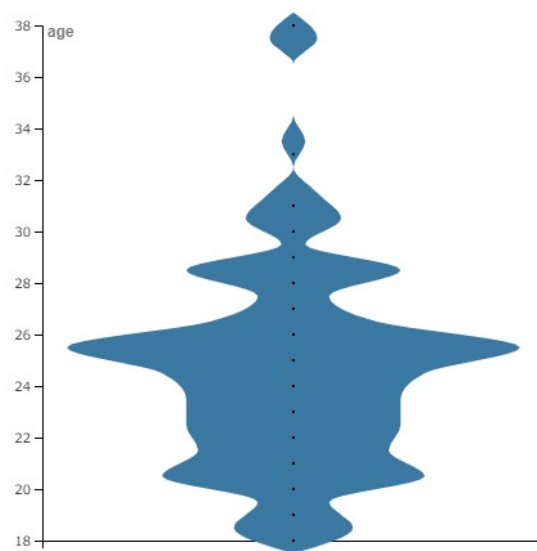


Figure C.13 Question13(Your age) and the result