MUSIC TACTILIZATION

A Thesis

Presented to

The Academic Faculty

by

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In Partial Fulfillment

of the Requirements for the Degree

Master of Science in the

Digital Media Program

Georgia Institute of Technology

May 2017

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Date Approved: April 26, 2017

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1. INTRODUCTION

Emotion can be solely communicated through sensory modes among humans. Emotion can also be coordinated/integrated with other sensory displays in a multimedia system. [1] From an empirical perspective, music listening experience always involves listener's affective dynamics. Previous studies in the field of Music Emotion Variation Detection (MEVD) have shown some quantifiable relations between music features (tempo, pitch, timbre, etc) and variables of emotion quantification (arousal and valence). [2] Meanwhile, many existing projects and works in the field of affective haptics have demonstrated and utilized the relationship between tactile experience and emotion. The innate experience known as synesthesia [3] even shows the neurological evidence of the relationship. Therefore, the affective factor embedded in musicology and affective haptics establishes the basis of our thinking that music can be a reflective source for tactile experience.

In order to illuminate some of the basic principles and dimensions behind affective haptics as much as possible and facilitate future tactile design process, I attempt to look at emotional mapping from musicology to tangible media design. I hope what comes out of our music-affect-tactilization mapping process can be constructive to guide tactile design implemented in scenarios where affect is involved. One of those possible applications could be an interface for augment of media consumption or perception. For example, SUBPAC's product is a wearable with tactile stimuli that can express auditory information through high-fidelity vibration.

Figure 1. SUBPAC's S2

Another potential application could be an interface for users to program with. Empowered by the interaction with vibration stimuli, users are free to design, craft and interpret their own information and become a community under the sharing goal of construction of tactile language. In one of my previous prototypes, (figure 4) I applied vibration motors to enhancing choreography experience. Users can program the vibration motors based on a choreography video and use the vibration sequence/patterns to help them memorize and practice dance movements.

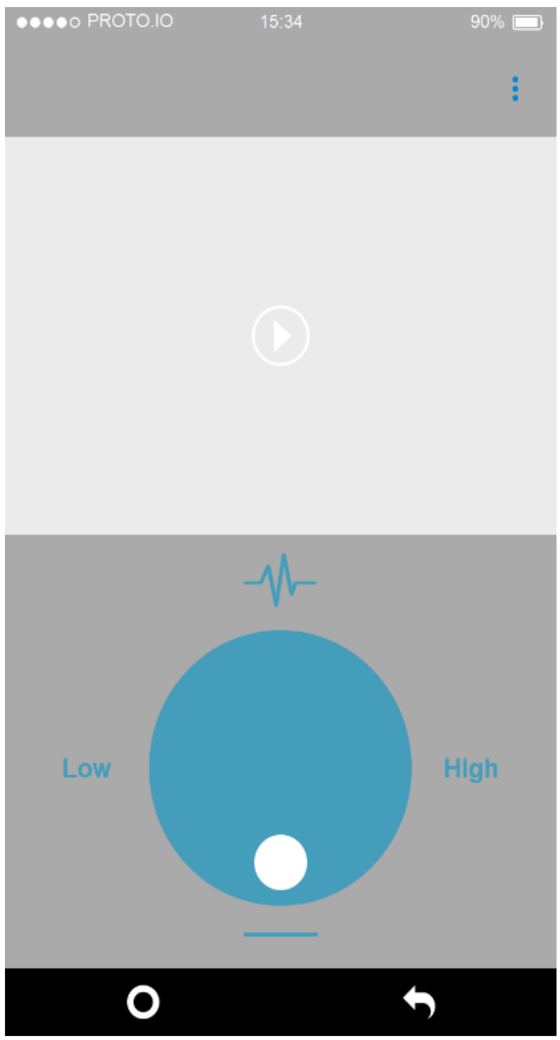


Figure 2. My previous prototype for users to program the vibration sequence based on choreography video

The following part of my documentation is going to be structured as follows. First, the background of this project is going to be illustrated through problem definition, my proposed solution (framework) and review of related works that may motivate or contribute to this project. Then, the rationales of the design of this project, technical components used and data analysis methods will be discussed in Design the Project session, followed by my actual implementation process. Findings from data analysis and related discussions will be presented in Conclusions session later on. According to the discussions and reflections of the design of this project, Future Work session will list several potential directions that this project might iterate to. This documentation will end with listing the reference sources used in Reference session.

2. BACKGROUND

Tactile interfaces are not simply an expansion of visual and auditory media design, more importantly, they can also be developed to an independent library, comprising its own principles, conventions and disciplines, by many artists, scientists, developers and hobbyists. I propose that, based on previous projects, these patterns inside the tactile library are capable of forming more intuitive, universal languages for interpretation of human emotions, literature plots, logics and for communication. For instance, researchers at the Institute of Human and Machine Cognition have developed a tactile pilot-to-aircraft interface, known as the Tactile Situation Awareness System (TSAS) [26]. TSAS can provide information on aircraft orientation, spatial location, velocity, and/or acceleration of objects, change in flight management system configurations and so on. The objective is to provide an extremely intuitive information under stressful, high-performance scenario. Signals were formatted into tactile patterns, sent to the torso, the forearm, and the legs. This project largely demonstrates the idea that tactile language is an intuitive language for information communication, especially when visual and audio perception channels are under overload condition.

There are also some artistic projects that use tactile channel as a medium to convey certain information. Emma Frid at Royal Institute of Technology presents a tactile display system for live-electronics performance. [27] In the project, she uses two rotating eccentric mass actuators driven by PWM signal generated by an Arduino microcontroller as tactile display to convey some music information. This project is quite a relevant project to mine when considering the tactile display as a medium to convey some music information. Another artistic project could be MatchAtria e x t e n d e d. MatchAtria e x t e n d e d is a multimedia dance installation, which invites the audience to contact with a fabricated heart. [28] A pulsating feeling is conveyed through the fabricated heart, the LED lights inside the heart get bright and faint, resonating with the dancer’s heartbeat. To experience seeing, hearing and with haptic perception during the dance by simply holding the heart in the palm of audiences’ hands. This is a project pioneering how the tactile display is implemented in the communication between performer and audiences.

2.1 Problem and solution

Utilizing visual perception is the major research realm and methodology in AR (Augment Reality). Most products in the market nowadays interact with users also through visual and auditory channel. However, with the predicable future development of real-time rendering algorithm and platform embedding, visually augmenting reality is approaching to the point when other physiological perception methods can be systematically added into the media family. Tactile perception is one among those that can be fully researched and developed and that offers opportunities for interaction designers, as the combination of tactile feedback with VR or AR visualizations remains a challenge for technology as well as design.

Technologies have allowed us to expand from visual and audio performative means to tactile ones and, with the development of VR (Virtual Reality)/AR/MR (Mixed Reality), tactile platforms are next in line to offer a huge potential but there is little systematic and consistent work scholarly and industrially on that for us to refer to.

Therefore, in this project, I plan to investigate the problem from the perspective of design. I reflect on the field of MEVD (Music Emotion Variation Detection) and affective haptics. I use some quantitative methods to bridge music with emotion and emotion with tactile display for the purpose of proposing a potential guideline for tactile design. I use vibration for tactile display and try to map 3 tactile variables (amplitude, frequency and location) to 2 emotion variables (arousal and valence) obtained from a MEVD analysis. I hope what comes out of our music-affect-tactilization mapping process can be constructive to the community of tactile design in terms of guiding tactile design implementation process.

2.2 Music Emotion Variation Detection and Affective haptics

With the rapid development of digital technologies, a lot of insightful work has been done in the field of MEVD in the past decades. This project builds particularly on the existing findings from a systematic, rigorous study conducted by Emery Schubert [2] on musicology end. For the affective haptics end, however, the long list of existing academic work and industrial applications

[15][17][18][19][20] reveal that those prototypes are both exploratory and discontinuous. [1] More rigorous and systematic research efforts should be made to construct consistent understandings of affective haptics. Despite the effort made in MEVD and affective haptics, little attention has been paid to seeing emotion as a bridge between these two fields. Our work proposes one of the first attempts pioneering this novel perspective. Following, we give an overview of Schubert's research and affective haptics and clarify the rationales of adopting both Schubert's findings and our mapping methods.

Measurement and Time Series Analysis of Emotion in Music

Back in 1999, Emery Schubert tried to build dynamic connections between music features and emotional responses. After collecting serial responses (valence and arousal) to music from 67 subjects and selecting five music features (frequency spectrum centroid, loudness, melodic pitch, tempo and number of instruments playing) for data analysis, he built OLS regression models that tell the serial correlations between music features and emotional responses. Two main components constituting Schubert's methodology and inspiring my project are listed below.

a. 2DES (Two-Dimensional Emotion Space)

The representation of emotion by Russell (1979) consists of a square with two bipolar dimensions: valence and arousal. Valence refers to whether a certain emotion is positive or negative. Arousal refers to the activeness or passiveness of the emotion. In contrast with categorical methods of grouping emotions in a discrete way, these dimensions not only capture all emotions as dynamically related within a semantic space, but also make it possible to quantify emotions in a continuous way. Moreover, the dimensions were determined by analyzing empirical data and explain the greatest amount of variation in psychological investigations in Russell's work. [4] [5]

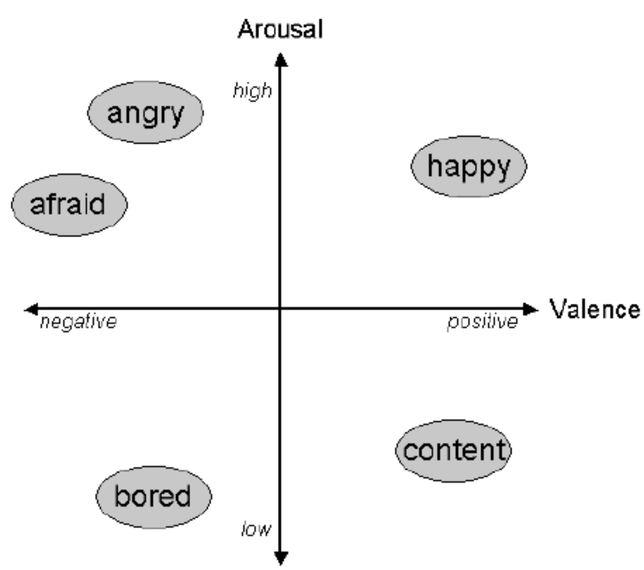


Figure 3. A two-dimensional emotion space with a valence and an arousal axis [24]

Inspired by Russell and many other empirical findings of dimensional operationalization of emotion by Asmus [6], Collins [7], Thayer [8] and Wedin [9], Schubert built his own computer program, controlling 2DES, to continuously measure participants' valence and arousal values in his experiment. In order to demonstrate the reliability and validity of adopting 2DES as a research instrument, Schubert conducted an experiment in his work in 1999. The instrument was found to be reliable (test-retest $r > 0.83$, $p = 0.01$) and valid (external data set $r > 0.84$, $p = 0.01$) (Schubert, 1999, p. 383). Nevertheless, in my project, I do not use 2DES as an experiment instrument directly. Instead, I use Schubert's final data of his participants' emotional responses to the music pieces (four pieces hypothetically express emotions in four quadrants of 2DES, see figure 17) as the emotional responses for my participants who listen to the same music pieces. The reason behind doing this is to reduce my participants' workload since being asked to provide tactile interpretation of the music pieces throughout is already a challenging task for them. In addition to that, Schubert showed the validity of generalizing his data of emotional responses in his work. (Schubert, 1999. p. 294) *b. Time series analysis*

Music is a time dependent phenomenon. Using inferential statistical methods to construct a Music Features – Emotional Responses (MF-ER) system helps us to approximate potential relationships between music features and emotional responses and maximize the generalizability of the relationships. Likewise, if my project aims to build the connection from emotional responses to tactile feedback, I have to adopt the strategy of Time Series Analysis as well. By using time series models, it is possible for me to measure and analyze tactile responses through another time-serial and emotional stimulus, music. After certain explorations of analytic methods (Schubert, 1999, chapter. 6), Schubert documented the analytic

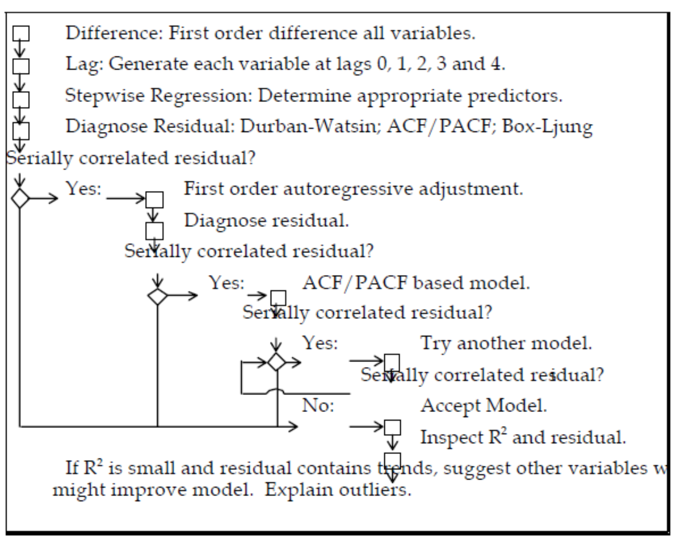


Figure 4. Sequence of Steps Used in Time Series Data Analysis in Schubert's work, 1999, p. 338.

sequences (see figure 4) for his MF-ER system (Schubert, 1999, chapter. 7).

Through four music pieces that Schubert meticulously selected, the model yielded eight equations (equation of arousal and valence for each music piece), illuminating the dynamic relationships between music features and emotional responses.

Therefore, based on the emotional responses Schubert collected and rigorously checked, my project is one step further to investigate potential dimensions or principles behind tactile feedback aroused by the 4 music pieces.

Affective haptics

Some music practitioners have also explored to map sonic experience to its tactility based on the theoretical overlap between emotion, perception and touch. Garcia believes that tactile, auditory and visual experience are intersecting and interconnected by qualitatively identifying their shared nature. [10]

Besides directly mapping other media to tactile through qualitative methods, more and more research and projects are investigating the capability of communication between touch and emotions. [12][13][14][15][16][17]

In general, great efforts have been made to explore the design, effect and implementation of tactile experience in related fields. But dependencies between haptics connected to emotions have never been accurately modeled, let alone more dimensions that might affect the accuracy of the affective haptics model such as gender, age, culture. Therefore, we schedule to conduct our own experiment which tries to explore a novel mapping of emotions on tactile interface with the help of musicology through Schubert's model.

Ultimately, Schubert provides a time-based analysis of emotional arousal and valence for selected music pieces. This shows varying emotional activities. I am going to use his findings to guide my own mapping that tracks Schubert's variables of valence and arousal over the experience of selected musical pieces.

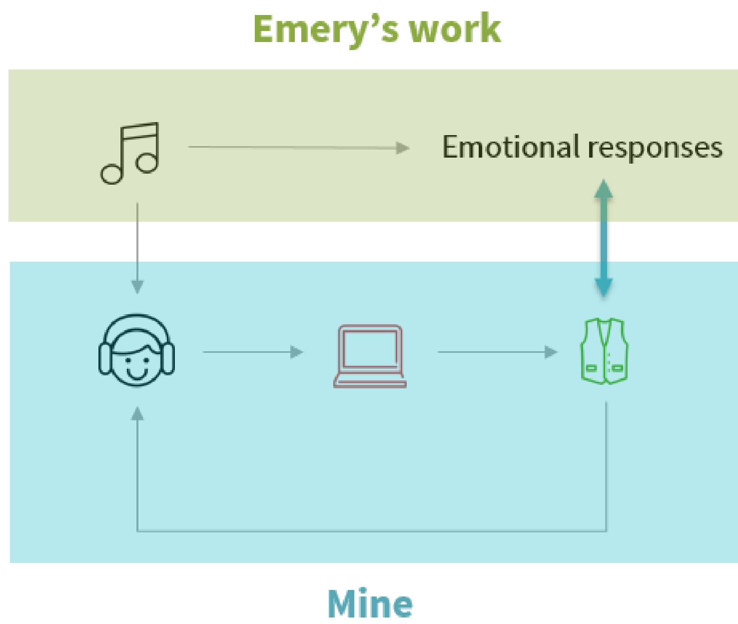


Figure 5. Overview of project architecture

3. FROM DESIGN TO IMPLEMENTATION

3.1 The digital interface

How to create a tactile interface that can, first, produce tactile effects by participants' interaction with it, and, second, make participants feel the effects is the first concern when I started the design of this project. To address the former part of the concern, I decided to design and build a pc-based interface for participants to manipulate vibration motors with. A digital interface not only makes it possible for participants to give their tactile feedback in respond to music, but also facilitates the experiment process regarding experiment instruction and participants' workflow.

Since giving tactile feedback during the playback of the 4 music pieces is already a demanding task, I try to design a clean, easy-to-follow program. The design follows the strategy of One Page One Task in User Experience Design, which helps to reduce user's mental workload and makes the experience more visually recognizable and clear. In my case, instruction breaks down into separate pages based on the interaction components in the interface (Play button, Next button, Music progress bar, Intensity

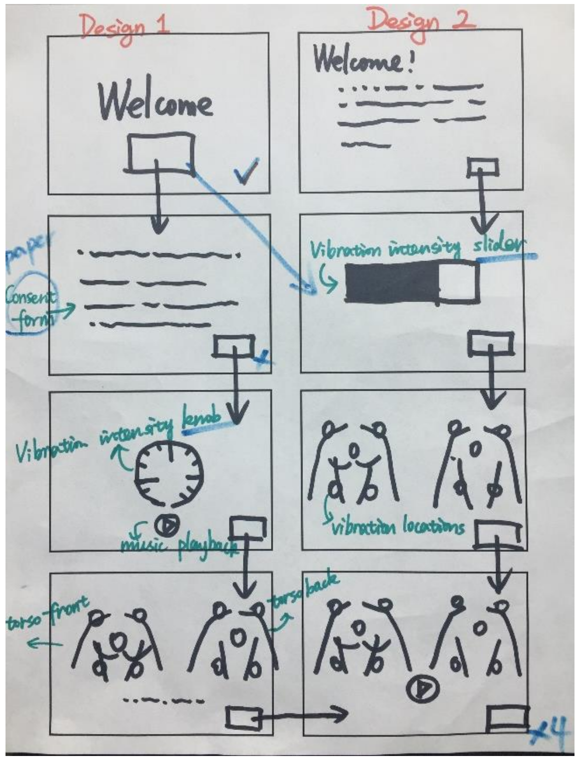


Figure 6. The initial sketch of the interface

slider, Vibration Location toggles). Initially, I sketched the low-fidelity screens of the taskflow (figure 6). UI components were discussed and iterated at this stage. For example, consent form was initially to be shown on the screen. But for the ease of reference for participants, I chose to print it out and put it beside participants. Also, I replaced knob with slider on the interface because slider is more “visually intuitive” regarding the task of changing vibration value between “high” and “low”, according to one of my participants. What’s more, the shape of slider also visually contrasts with another circular UI component, the Playback button on the interface. The taskflow was determined by the design of experiment process, which will be discussed in later chapter.

The program is built in an open source programming IDE, processing. More detail and rationales behind the design choices of the program are discussed below.

The welcome page is the start page of this program. This page is initially a visual cue to notice participants that the experiment is about to begin.

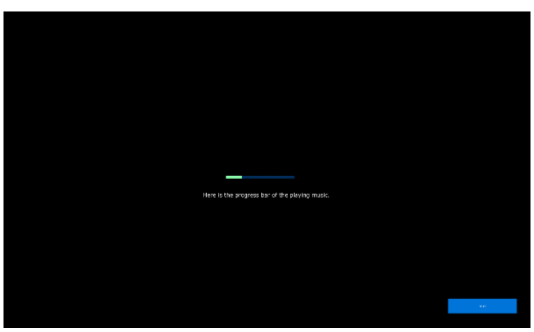


Figure 7. Learn the progress bar in the program

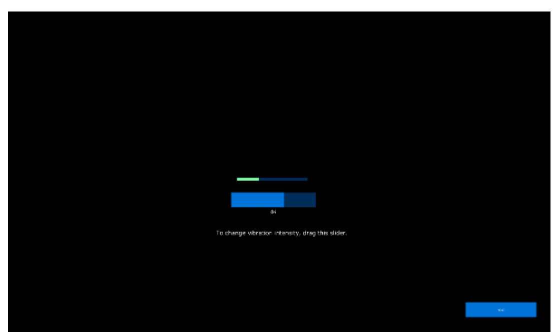


Figure 8. Learn the Intensity slider in the program

The following 3 pages (figure 7, 8, 9) are set up for instruction purpose. By going through these pages, participants are able to learn the UI components of the program (how they can trigger certain tactile effects) and get familiar with the experiment setting.

Figure 9. Learn how to turn on/off vibration at 10 different spots on a torso

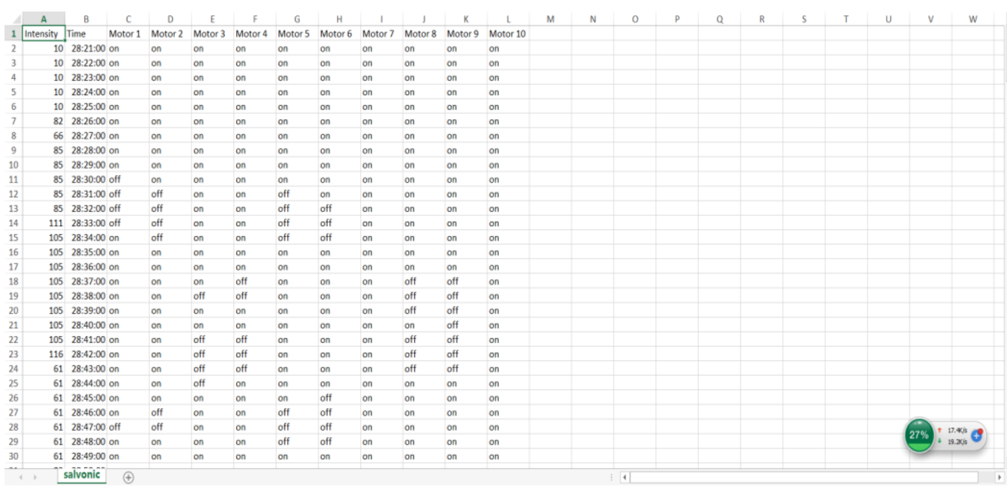
The design of instruction follows the strategy of One Page One Task in User Experience Design, which helps to reduce user's mental workload and makes the experience more recognizable and clear. In my case, instruction breaks down into separate pages based on the interaction components in the interface (Play button, Next button, Music progress bar, Intensity slider, Vibration Location toggles). In the first step, participants play music by clicking on the Play button. When the music is playing, the Next button will pop up at the down right corner. This design choice is made out of guiding participant to the right process, diminishing the confusion that might come from other components in the interface. In the second step (figure 7), the progress bar of the playing music is displayed. Since the progress bar gives participant a sense of a) What tasks user has completed, preferably with a visual results, b) Current section he/she is on, c) Which and how many steps still remain also preferably with clear designation, it will be displayed throughout the 4 selected music pieces in experiment session later on. The third step (figure 8) is set up for participants to get to know how to change vibration intensity using the slider. The fourth step (figure 9) is for participants to learn how to turn on/off the vibration at 10 different spots on his/her torso by manipulating the toggles. Given participant’s right hand is already occupied with the interaction with the slider, the toggles thus will be triggered through the interaction of key mapping on participant’s left hand. Another design regarding the interaction with the toggles were considered, which is to click the “on/off” icons to turn on/off the vibration. However, in my pilot experiment, many participants and I found out such interaction would only lead to serious lag between the tactile effect participants want and the one they can. Hence 10 keys on the keyboard are used to switch on/off the vibration at the

10 spots. In order to smooth the learning process, I chose the keys that are both reachable within one palm and relatively easy to remember. Q, W, E, R, T are respectively for upper left, upper right, down left, down right and center vibrations at the front of a torso, while A, S, D, F, G are for upper left, upper right, down left, down right and center vibrations at the back.

When participants report that they are ready to start the experiment, they click the Next button to process to the experiment session. This session consists of 4 pages. Participants are asked to give response to respective music piece at each page, using the interaction components they learned from instruction session.

Figure 10. The first music piece in experiment session

After completing each music piece, the program will export an excel data sheet containing the data of intensity and on/off along the playing period. In order to be consistent with Schubert's experiment, my program records those data every second. I need data to be formatted in this way because my data should be consistent in format with Schubert's data of emotional responses which were recorded per second. Also, for intensity, I need over-time data to see whether there is a correlation between intensity and arousal/valence in my later data analysis. For vibration location, it is also time-squenced so that I can use t-test to tell whether the vibration at a specific location, from participants' point of view, is impactful in terms of influencing participants' emotional arousal/valence. The sample data sheet are shown below.



Intensity	Time	Motor 1	Motor 2	Motor 3	Motor 4	Motor 5	Motor 6	Motor 7	Motor 8	Motor 9	Motor 10
10	28:21:00	on	on	on	on	on	on	on	on	on	on
10	28:22:00	on	on	on	on	on	on	on	on	on	on
10	28:23:00	on	on	on	on	on	on	on	on	on	on
10	28:24:00	on	on	on	on	on	on	on	on	on	on
10	28:25:00	on	on	on	on	on	on	on	on	on	on
82	28:26:00	on	on	on	on	on	on	on	on	on	on
66	28:27:00	on	on	on	on	on	on	on	on	on	on
85	28:28:00	on	on	on	on	on	on	on	on	on	on
85	28:29:00	on	on	on	on	on	on	on	on	on	on
85	28:30:00	off	on	on	on	on	on	on	on	on	on
85	28:31:00	off	off	on	on	off	on	on	on	on	on
85	28:32:00	off	off	on	on	off	off	on	on	on	on
111	28:33:00	off	off	on	on	off	off	on	on	on	on
105	28:34:00	on	off	on	on	off	off	on	on	on	on
105	28:35:00	on	on	on	on	on	on	on	on	on	on
105	28:36:00	on	on	on	on	on	on	on	on	on	on
105	28:37:00	on	on	on	off	on	on	on	off	off	on
105	28:38:00	on	on	off	off	on	on	on	off	off	on
105	28:39:00	on	on	on	on	on	on	on	off	off	on
105	28:40:00	on	on	on	on	on	on	on	on	off	on
105	28:41:00	on	on	off	off	on	on	on	off	off	on
116	28:42:00	on	on	off	off	on	on	on	off	off	on
61	28:43:00	on	on	off	off	on	on	on	off	off	on
61	28:44:00	on	on	off	on	on	on	on	on	on	on
61	28:45:00	on	on	on	on	on	off	on	on	on	on
61	28:46:00	on	off	on	on	off	off	on	on	on	on
61	28:47:00	off	off	on	on	off	off	on	on	on	on
61	28:48:00	on	on	on	on	off	off	on	on	on	on
61	28:49:00	on	on	on	on	on	on	on	on	on	on

Figure 11. A sample data sheet used in this experiment

To sum up, in order to address the problem of how to create a tactile interface that can produce tactile effects by participants' interaction with it, I decided to develop a digital interface. Its design tried to be visually clean and clear in terms of reducing participants' mental workload and facilitating their workflow. The design and implementation choices were iterated and determined based on respective rationales mentioned above and experiment process that will be discussed in later chapter.

3.2 The physical prototype

How to make participants feel the tactile effects rendered by the digital interface? What parts of a body should the tactile effects be mounted on?

A previous prototype I created for one of my master's courses answered the first question above. Actually, it is the prototype, the music jacket that motivates this project. In the project of music jacket, I used Matlab to recognize certain frequency patterns in a song so that the 10 vibration motors inside the jacket can render random but “interesting” tactile effects to users[1]. The music jacket inspired me from 2 perspectives. One is that the form of wearable should also be considered in this project to convey tactile effects through digital interface. The other one is that, according to the feedback from the users of the music jacket, 10 vibration motors are “sufficient” to render “satisfying” tactile effects. Too many motors might not only lead to “overwhelming” experience, but also be a heavy budget burden for me. Given the common flat-shape, coin-size vibration motor in the market has fragile wires, I have to buy more than 15 vibration motors (figure 13) in case some of them might get disconnected unexpectedly.

But, again, what parts of a body should the tactile effects be mounted on? Mealani in his An Actuator for the Tactile Vest mentioned that not only does torso has a long history of being used as sensory substitution, but also is able to accommodate more information than other areas of skin available [25]. His and many other tactile-vest-based projects answered the second question listed at the first paragraph of this chapter.

[1] Note that users here are people who wear the jacket while listening to the song being analyzed at the same time.

In the project of music jacket, I used a down jacket and hooked up all the wires in its interlayer (figure 14). However, I found out not

Figure 12. The previous "music jacket"

all users' body shape can fit in the jacket. If the jacket is too loose for a thin girl, then she might not be able to sense the vibration since the motors are not attached to her body. Thus in this project, I decided to buy a flexible garment like a high visibility vest (figure 15). In terms of the choice of vibration motor, I chose the coin-size, flat-shape motors. The vibration motors are relatively cheap, accessible for me and are able to fit in the dynamic workspace of a wearable.

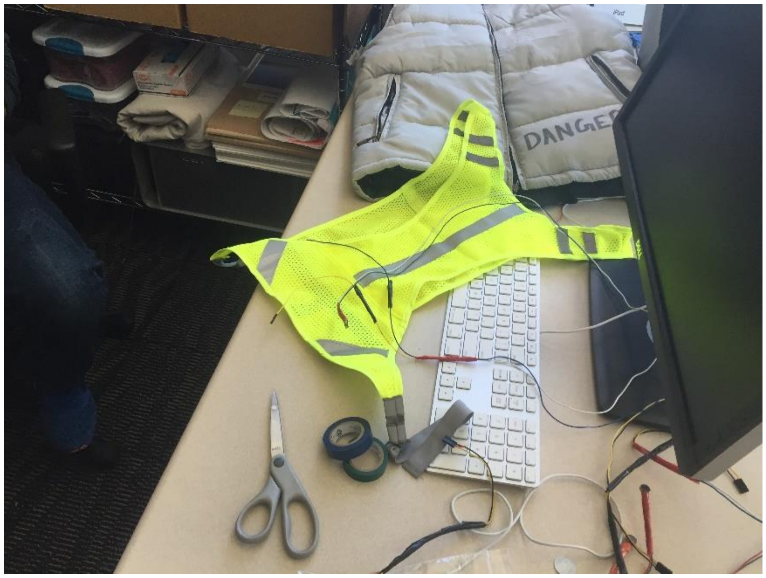


Figure 13. The flexible high visibility vest

Finally, the design outcome is a high visibility vest, containing 10 vibration motors covering the front and back of a torso. The modified hardware design allowed me to convey the tactile effects from the digital interface to participants. It also fits the required

Figure 14. The final physical prototype, vibration vest

need of flexibility for different body shapes of participants to fit in.

3.3 The tactilization mapping experiment

I came up with 2 research questions that want to tell the relationship between tactile and emotional variables from two perspectives. One is what is the correlation, if any, between vibration intensity and emotional responses? Another one is what is the significance, if any, of relationship between vibration locations and emotional responses?

In order to achieve the goal stated in Chapter 1 and 2 while bearing the inspiring parts of Schubert's work in mind, I drafted my experiment based on the research questions, tactile variables needed and steps required. The rationales of determining the tactile variables and experiment process are discussed below.

3.3.1 Determine the tactile variables

Determining what tactile variables I was going to work on was the very first step of my design. After reading some of the existing works in the field of affective haptics, I found out that, when it comes to affective display through tactile haptic devices, the amplitude of vibration, inter-burst duration, and inter-actuators distance are crucial parameters to stimulate emotions [15][18][19][20][21]. Hence I chose 3 basic and common variables in affective haptics as our tactile variables to keep consistent with other relevant studies as much as possible. However, due to some constraints that mentioned in [29], amplitude and frequency are linked and cannot be controlled independently by the voltage. They are considered as one variable, intensity, in this project. Thus the two tactile variables are:

Intensity

Combination of amplitude and frequency of a vibration motor. This variable stands for the general strength of the vibration stimulus.

Location

The location of the stimuli plays a crucial role in tactile experience. Since researching specific psychohaptics principles of placing vibro-tactile stimuli around torso is beyond the scope of our project, we will put it in our future work and simplify our experiment by covering subject's torso using 10 vibration stimuli (half at front and half at back).

3.3.2 Design the experiment process

Pre-session

Subjects are recruited through resources available, consisting of half male and half female. My experiment starts with a pre-session, where subjects are asked to go through three steps. The first step is to listen to music pieces from Schubert's study. (figure 5) After subjects report that they are familiar with the music pieces, they are directed to play with the vibro-tactile stimuli. The final step of the pre-session is to manipulate the vibro-tactile stimuli with the digital interface while the music piece is playing. The pre-session is set up to get subjects prepared for the experiment setting and diminish the novelty effect. Figure 5, 6, 7, 8, 9, 10 show the actual design of this session.

Controlled-session

Subjects are then asked to provide the intensity value with which all the vibro-tactile stimuli make them feel "relaxed" in the controlled session. The values are considered as the baselines. By figuring out the baselines, the individual differences of tactile perception are diminished as well. Figure 8 is the actual design of this session.

The experiment session

In the actual experimental session, subjects listen to 4 selected music pieces and are asked to match tactile effects, vibration intensity and location, to the emotional state they are in through manipulating slider of intensity and toggles of locations of vibro-tactile stimuli. The 4 music pieces, which hypothetically express the typical emotions in the four quadrants of 2DES according Schubert (Schubert, 1999, p. 253-256), are selected. They are ”Slavonic

Title	Composer	Performers	Length[80]	Abbreviation	Quad
"Slavonic Dance", Op. 46 No. 1	Antonin Dvorak	Slovak Philharmonic Orchestra, Zdenek Kosler (conductor)	3:45	Slavonic Dance	1
"Pizzicato Polka"	Johann (Jr.) and Joseph Strauss	[not mentioned]	2:30	Pizzicato	1
"Morning" from the incidental music to Peer Gynt	Edvard Grieg	CSSR State Philharmonic Orchestra, Stephen Gunzenhauser (conductor)	3:38	Morning	4
"Adagio" from Concierto de Aranjuez for guitar and orchestra	Joaquin Rodrigo	Gerald Garcia (guitar), CSSR State Philharmonic Orchestra, Peter Breiner (conductor)	10:52	Aranjuez	2 & 3

Figure 15. Music pieces selected in Emery Schubert's and my experiment.

Dance” No. 1 Op. 42 by Dvorak (Slavonic Dance), “Morning” from Peer Gynt by Grieg (Morning) and the Adagio movement from Rodrigo’s Concierto de Aranjuez (Aranjuez). A short Polka by Johan Strauss Jr. and Josef Strauss (Pizzicato) was also chosen. Although the piece duplicated Quadrant 1, it was an appealing selection because it was considerably contrasting in character to the other pieces, being performed with pizzicato articulation throughout (Schubert, 1999, p. 256). Note that the experiment is IRB approved.

3.4 Data analysis

3.4.1 Relationship between vibration intensity and emotion variables

In order to build a potential connection between vibration intensity and emotion variables as what I proposed in previous chapters, I use Pearson Correlation here as one of my methods for data analysis. Details are illustrated below.

The raw data of our experiment is the tactile variables changing with time t:

$$I_n(t) = I_m(t) - I_b$$

I represents vibration intensity, n = 1,2,3,4 is the index of the 4 music pieces, m represents a subject's response of intensity and b represents the baseline of intensity for each subject. The emotion variables (arousal and valence) in respond to the 4 music pieces changing with time are recorded by Schubert, (Schubert, 1999) which are written as $a_n(t)$ and $v_n(t)$ here. By putting together all the subjects' responses of vibration intensity to the music pieces, we have variable arrays: I(k), a(k) and v(k), in which k is the index of every single measurement.

$$\mathrm{k} = 1,2,\ldots,\mathrm{K}, \mathrm{K} = \mathrm{j}\sum_{n=1}^{4} T_n$$

K is the total number of measurements and T_n is the number of seconds in music piece n. j is the number of subjects.

Then, Pearson correlation is employed to build the relationship between emotional responses and vibration intensity. We establish a(k) or v(k) as X axis. I(k) and their lagging variables, I1(k), I2(k), I3(k), I4(k), are structured as Y axis in the correlation. (I1 to I4 represents I(k) lagged by 1 to 4 time index). Note that the rationales behind selecting 0-4s as lags are mentioned in Schubert's work (Schubert, 1999, p. 308-310). For the last measurements in each music piece, the lagged variables are set to the final measurement of the piece.

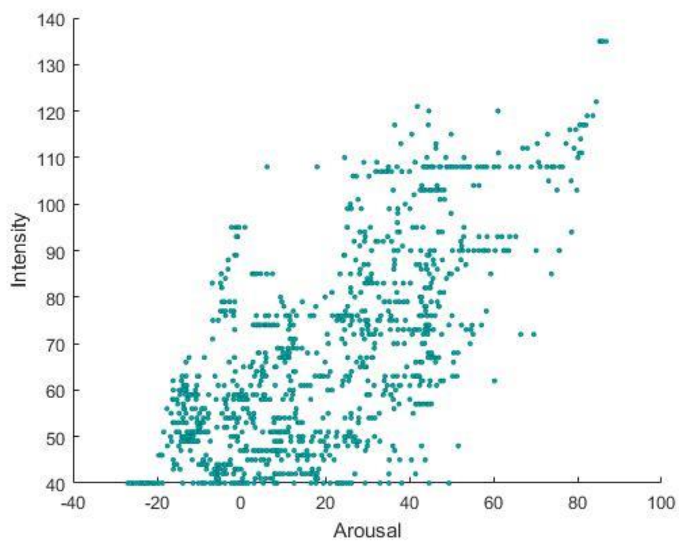


Figure 16. A relatively clear positive correlation relationship in one subject's data

3.4.2 Relationship between vibration locations and emotion variables

In order to tell, during the swing of emotional states, whether participants think vibration at a specific location is significantly important to express music, I use t-test as another method of my data analysis. Details are illustrated below.

In my experiment, we record the location of the vibration controlled by subjects for each music piece: $P_i(k)$, in which i = 1,2,…,10 represents location index. $P_i(k)$, which represents subjects' choices of a vibration location in respond to the music pieces, are used, as well as their lagged variables: $P1_i(k)$ to $P4_i(k)$. Hence $P_i(k)$ should be either on or off. For instance, $P_2(28)$ = off stands for at the 28th second of a certain music piece, vibration of motor 2 is switched off. Note that if the vibration is on/off for more than 90% of the length of a music piece, its data will be removed and not be included into $P_i(k)$. Then, for each vibration location and each music piece, Schubert's respective data of emotion variables, a(k) and v(k), are separated based on two vibration conditions, which are when $P_i(k)$ = off or $P_i(k)$ = on. Following t-tests are employed, for each vibration location and each music piece, to compare the emotion variables under the two vibration conditions. For example, if k_1 refers to the seconds in a music piece when motor 2 is on while k_2 refers to off, a t-test between $a_2(k_1)$ and $a_2(k_2)$ is to compare all the arousal values when motor 2 is on with all arousal values when motor 2 is off.

Valence arrays are analyzed in the same way.

3.5 Process review

After gathering all the hardware components, I started to assemble the vest. Due to limit of budget, I used 2 Arduino UNO boards that I already have instead of buying smaller Arduino boards. The Arduino UNO boards communicate with the interface through the code uploaded to the boards. The code is comprised of two parts. One part is for determining either to turn on/off the vibration of a specific motor, the other is for, when the vibration of a motor is on, determining how much the intensity of a specific motor should be.

Then I hooked up the 10 vibration motors to Arduino boards through socketing and soldering. Each vibration motor was wired to a PWM pin on Arduino UNO board. However, during the experiment, 4 vibration motors got disconnected due to participants and my improper actions. To be more specific, the soldering point of each motor was pretty fragile. Hence the problem reminded me that strengthening the wire connection on the vest is a must. Later on, I used insulating tape to fix the relative position of the 10 motors and wires on the vest.

Meanwhile, I had been programming the digital interface based on my design of the physical prototype and experiment process.

Regarding the experiment I was about to conduct, IRB (Institutional Review Board) approval is another component needed for me to accomplish the project. I had to submit and revise IRB proposal of the experiment in order to get it approved. By doing so, I can be eligible to recruit human subjects for the experiment. Participant recruit launched after IRB approval. My participants were recruited from resources available in Georgia Tech community. 5 female and 5 male students agreed to take part in my experiment. All of them signed on the consent form before the experiment started.

After every component needed in this experiment was set, I conducted the experiment as designed for 4 days. Quantitative data were collected by the processing-based program, qualitative data were also collected through participants' feedback after each experiment was done. The data collected were analyzed in MATLAB by my teammate, Aoxing Zhang. Results and discussions will be presented in Conclusion section.

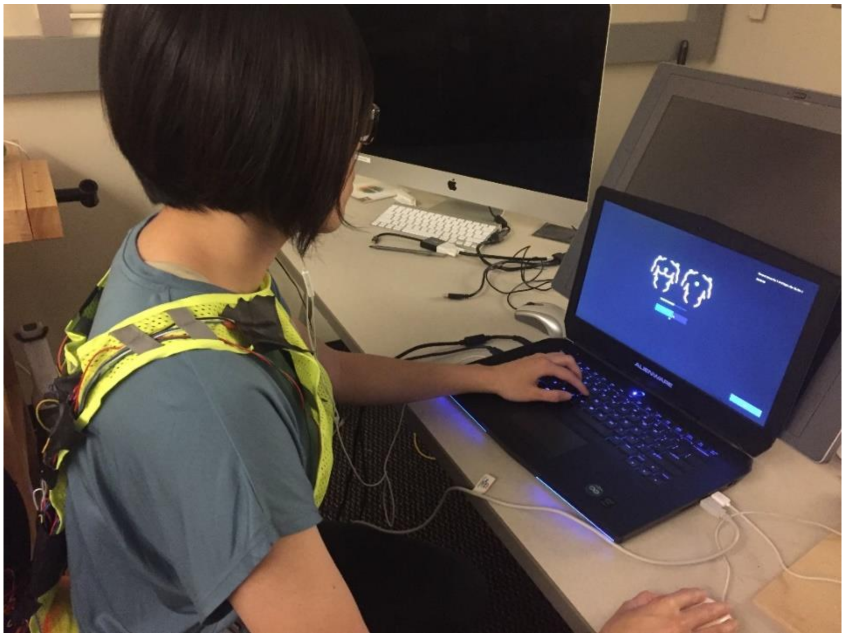


Figure 17. Participant A is doing the experiment

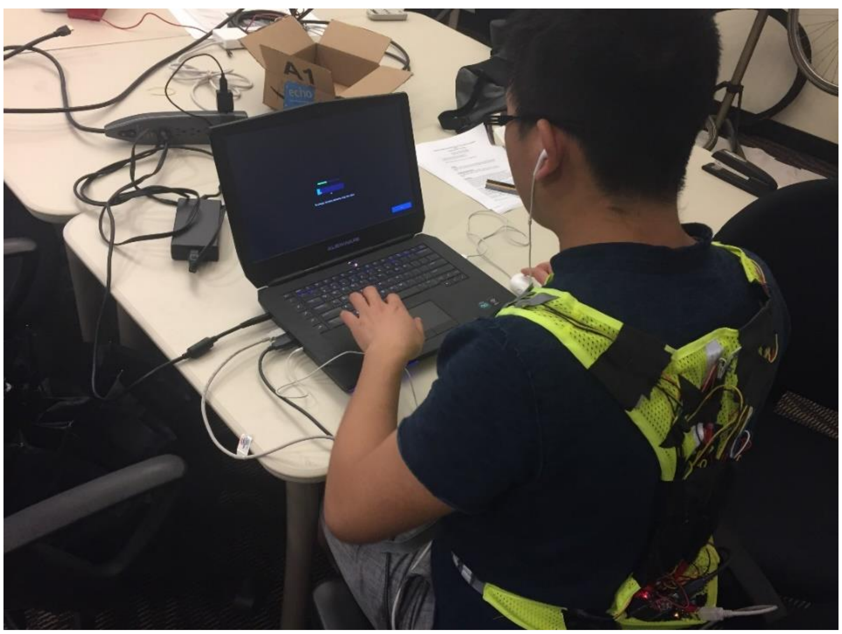


Figure 18. Participant B is doing the experiment

4 CONCLUSIONS

What is the correlation, if any, between vibration intensity and emotional responses? Below is the time-series version of the data. The red and blue ones are Schubert’s subjects’ emotional responses (mean of 63 subjects) to the music pieces over time. The yellow one is my subjects’ (mean of 10 participants) tactile responses.

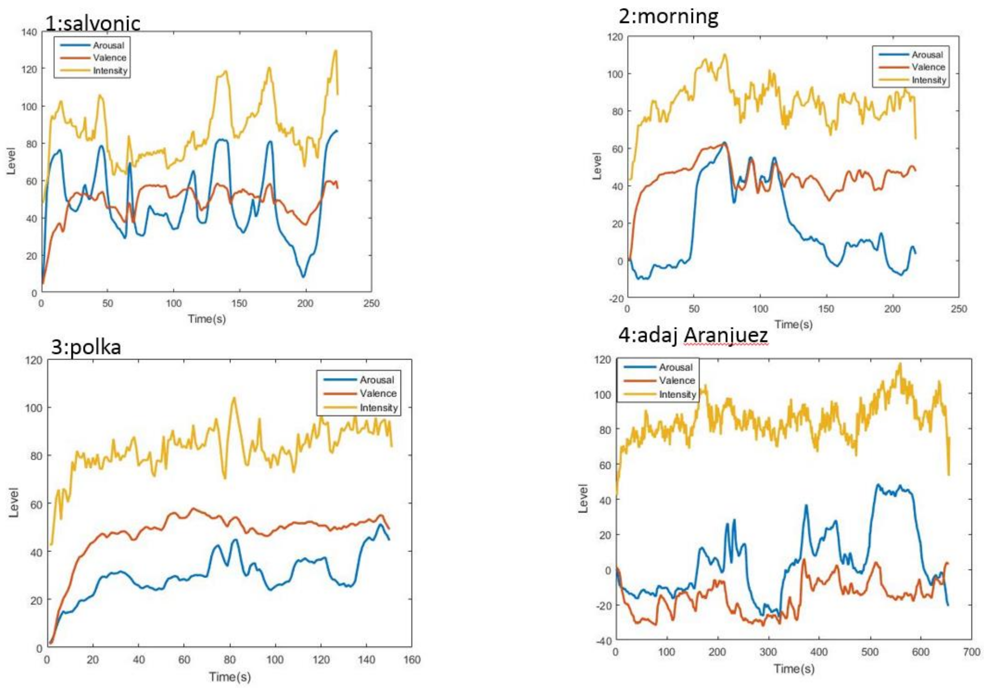


Figure 19. Time-series data of participants’ emotional responses and, tactile responses of vibration intensity to 4 music pieces

There seem to be correlations between those variables. Therefore, for clarity, scatter plot version of my data was also drawn. Ideally, a clear correlation in a scatter plot graph is indicated by the data spots lining up in a linear form. Nevertheless, my scatter plot graphs indicate that the correlations are not positively clear for any of the 4 music pieces (figure 20, 21, 22, 23).

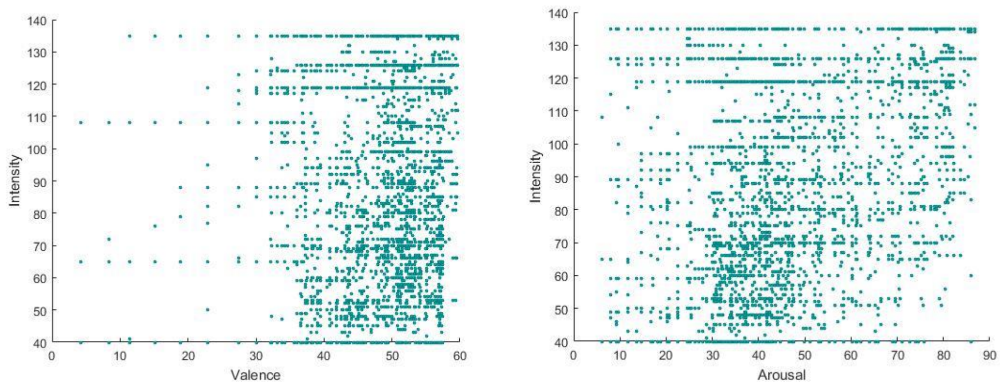


Figure 20. Scatter plot graphs of participants' emotional responses and, tactile responses of vibration intensity, to Slavonic Dance

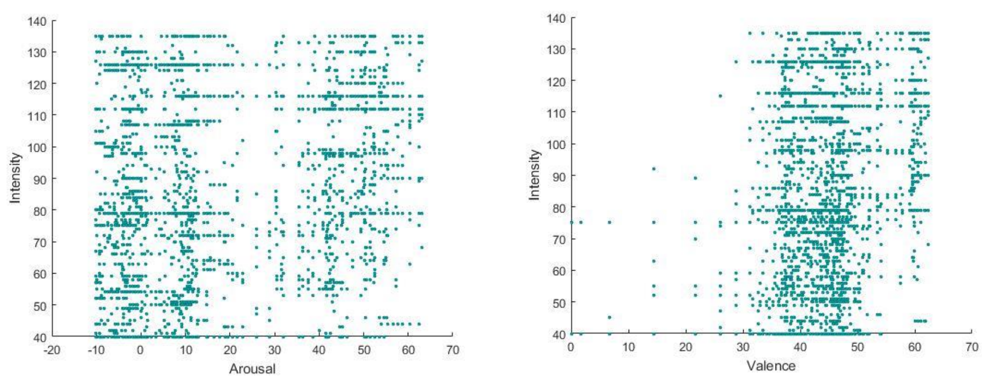


Figure 31. Scatter plot graphs of participants' emotional responses and, tactile responses of vibration intensity, to Morning

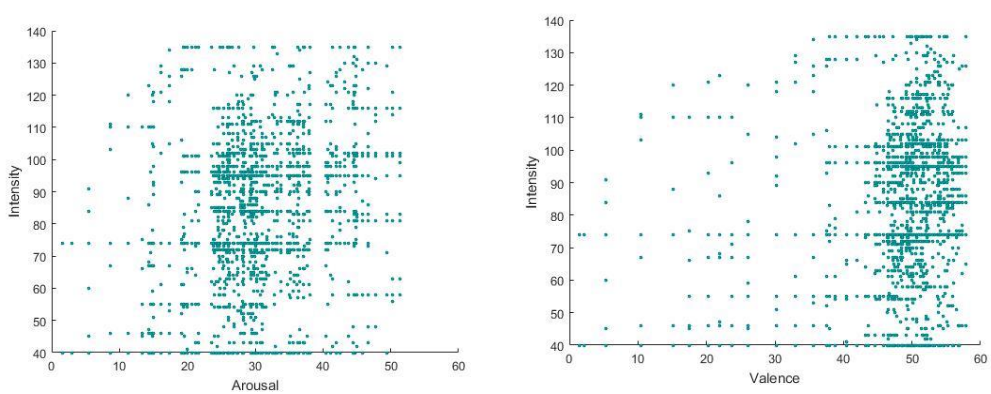


Figure 42. Scatter plot graphs of participants' emotional responses and, tactile responses of vibration intensity, to Pizzicato Polka

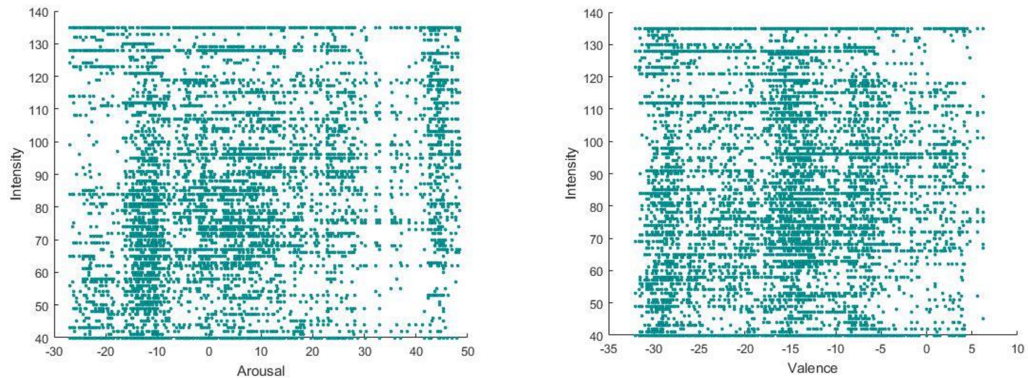


Figure 53. Scatter plot graphs of participants' emotional responses and, tactile responses of vibration intensity, to Adagio

The results tell us that there might not be a significant correlation between subjects' tactile responses of vibration intensity and their emotion. I argue that these results may happen when most participants' emotions were not influenced by the music pieces. Instead, subjects were more inclined to express the musicality (tempo, pitch, music patterns, etc) through tactile variables. Another interpretation of the results could be different people might hold different meanings for the same vibration pattern. Another potential factor could be the way participants interacted with the vibration. 4 out of 10 participants reported that the keys mapping to the vibration locations were hard to remember which is which. They thought the interaction was somewhat "disordered", "not intuitive" so that they might random turn on/off the motors during some parts of the playing music pieces.

Then what is the significance, if any, of the relationship between vibration locations and emotional responses? By comparing the means of participants' emotional responses when motors are on with off, we can draw a conclusion that, at some spots, turning vibration there on or off is not significant. For example, for the cheering song, Slavonic dance, vibration at most spots of the torso are significant, in terms of affecting participants' emotion arousal, except for both sides of back's downside (figure 24). All t-test results for 4 music pieces are visualized below (figure 26, 27, 28, 29, 30, 31). Note that the spots marked green in figure 26, 27, 28, 29, 30, 31 are significant spots while red are insignificant ones.

Motor	Arousal mean_off	Arousal mean_on	T-test passed
1	45.27308	50.08818	1
2	45.62029	50.02258	1
3	45.11066	50.15292	1
4	44.93911	50.36698	1
5	46.19396	48.88272	1
6	46.06465	48.96867	1
7	46.7828	48.80137	1
8	47.95065	48.22292	0
9	47.95057	48.21306	0
10	46.21452	48.97346	1

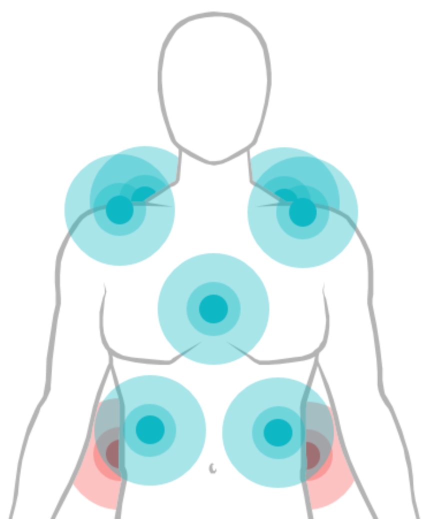


Figure 24. T-test result of emotion arousal and vibration location for Slavonic Dance

Motor	Valence mean_off	Valence mean_on	T-test
1	49.96442	47.42974	1
2	50.28155	47.08362	1
3	49.70434	47.62921	1
4	49.92251	47.43683	1
5	48.98755	48.25936	0
6	49.05414	48.22303	1
7	49.48039	47.94863	1
8	49.51253	47.82511	1
9	49.64779	47.81166	1
10	50.20518	47.68645	1

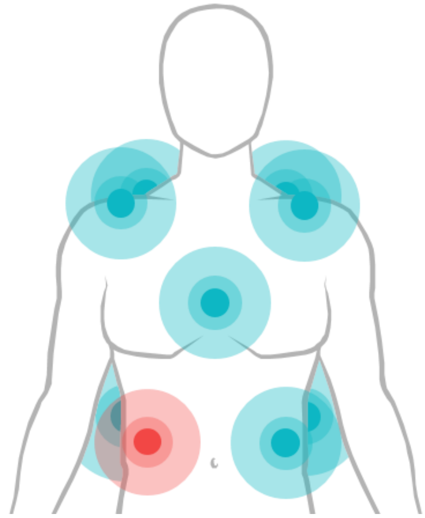


Figure 25. T-test result of emotion valence and vibration location for Slavonic Dance

Motor	Arousal mean_off	Arousal mean_on	T-test
1	12.0628	22.48862	1
2	14.11939	20.2507	1
3	16.99023	17.08351	0
4	15.04604	19.07952	1
5	18.44426	15.856	1
6	19.52859	14.68709	1
7	18.9307	16.14888	1
8	19.46385	14.77833	1
9	19.91996	14.49644	1
10	21.77515	14.37403	1

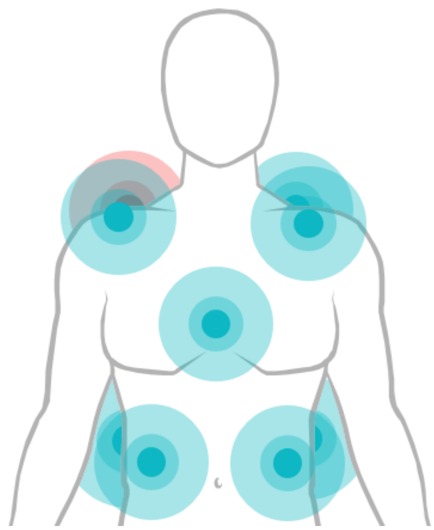


Figure 26. T-test result of emotion arousal and vibration location for Morning

Motor	Valence mean_off	Valence mean_on	T-test
1	43.96626	44.82611	1
2	44.48211	44.25857	0
3	44.46493	44.2594	0
4	44.13975	44.61985	0
5	45.53245	43.41506	1
6	45.78202	43.05687	1
7	45.23169	43.97888	1
8	45.30781	43.51343	1
9	45.39316	43.48382	1
10	45.37501	43.81659	1

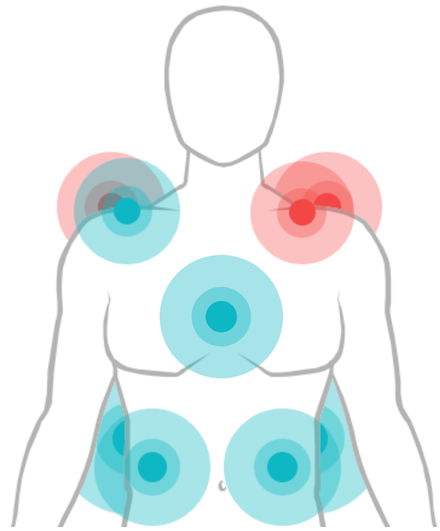


Figure 27. T-test result of emotion valence and vibration location for Morning

Motor	Arousal mean_off	Arousal mean_on	T-test
1	30.36468	29.47831	1
2	30.5104	29.45793	1
3	29.54855	30.27496	0
4	29.67075	30.12824	0
5	31.68802	29.01629	1
6	31.53127	29.12217	1
7	31.01686	29.43461	1
8	31.05486	29.40394	1
9	31.60377	29.15712	1
10	31.78242	28.31823	1

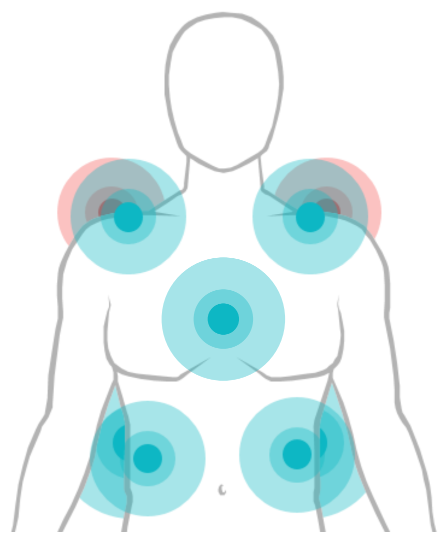


Figure 28. T-test result of emotion arousal and vibration location for Pizzicato Polka

Motor	Valence mean_off	Valence mean_on	T-test
1	49.31623	45.74685	1
2	49.74142	45.79627	1
3	49.4064	45.90305	1
4	49.5999	46.01258	1
5	49.16922	46.73294	1
6	49.03905	46.82304	1
7	49.55722	46.65844	1
8	49.28242	46.76337	1
9	49.41596	46.71192	1
10	50.6057	44.92128	1

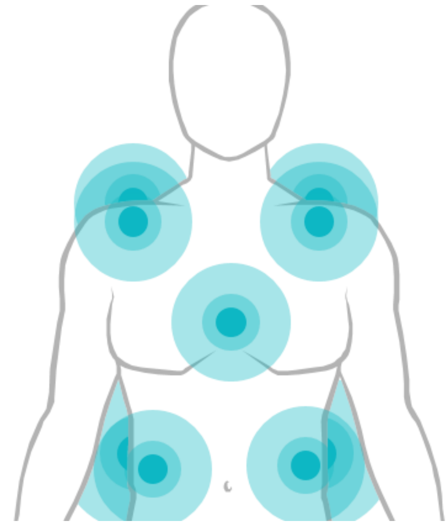


Figure 29. T-test result of emotion valence and vibration location for Pizzicato Polka

Motor	Arousal mean_off	Arousal mean_on	T-test
1	3.356773	7.340499	1
2	2.950811	8.214145	1
3	3.174267	6.669177	1
4	1.286333	8.317637	1
5	2.941087	6.552693	1
6	4.872272	5.095864	0
7	7.076919	3.837107	1
8	4.365631	5.460099	1
9	4.780248	5.139051	0
10	1.744145	6.723557	1

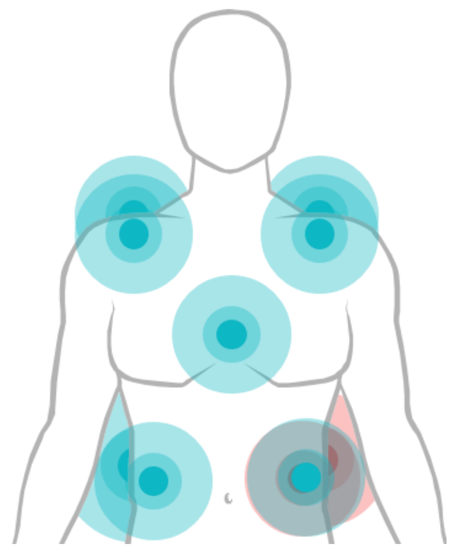


Figure 30. T-test result of emotion arousal and vibration location for Adagio

Motor	Valence mean_off	Valence mean_on	T-test
1	-16.2776	-14.8054	1
2	-16.2486	-14.7694	1
3	-15.7087	-15.6532	0
4	-16.8787	-14.593	1
5	-16.2295	-15.2532	1
6	-15.9704	-15.3299	1
7	-13.6487	-16.7777	1
8	-15.817	-15.5705	0
9	-15.7121	-15.6527	0
10	-16.2049	-15.3957	1

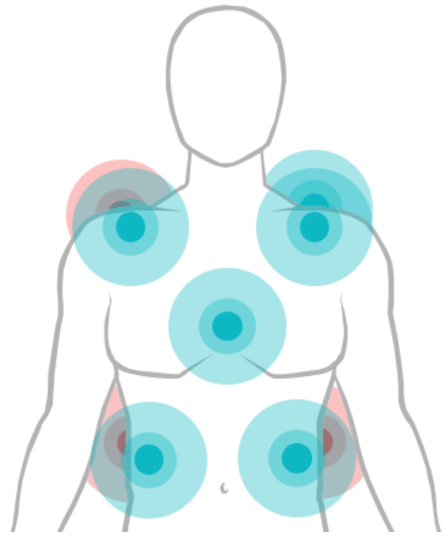


Figure 31. T-test result of emotion valence and vibration location for Adagio

Based on the t-test results for 4 music pieces, the overall visualizations of the significance of the relationship between different vibration locations and emotion arousal/valence are drawn as well (figure 32, 33). Note that different circular sizes refer to different significance levels in figure 32 and 33 with the front of a torso on the left and back on the right.

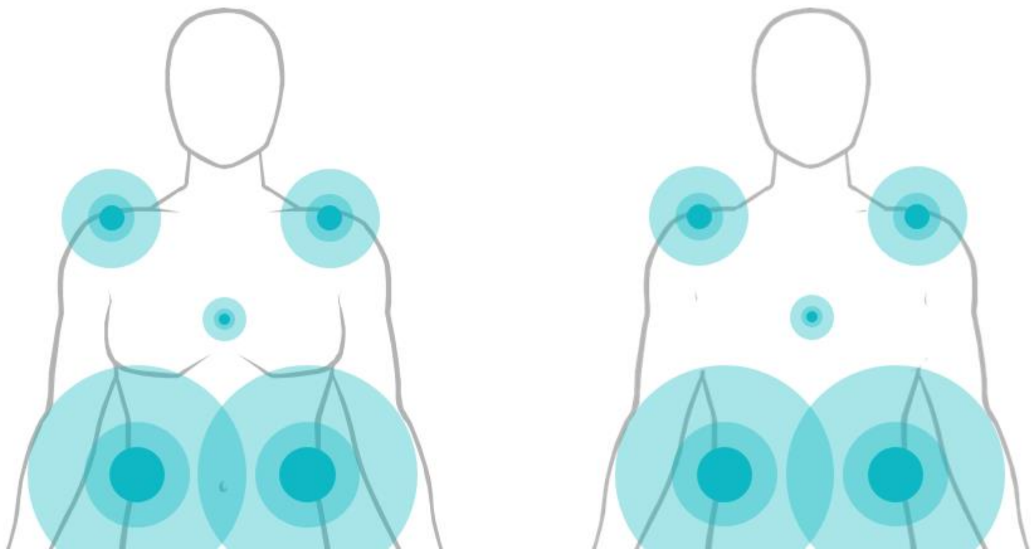


Figure 32. Different Significance of relationship between different vibration locations and emotion arousal

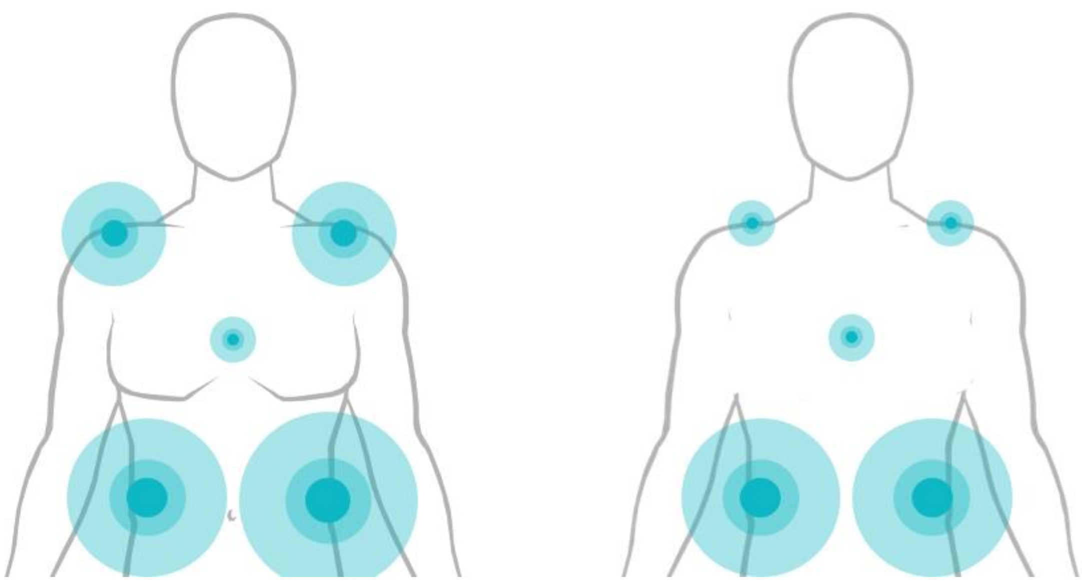


Figure 33. Different significance of relationship between different vibration locations and emotion valence

Figure 32 and 33 indicate that significance level varies from spot to spot in general. Torso’s downside (front and back) seems to have the strongest relationship with participants’ emotion (arousal and valence). The overall upper part of a torso is less related to participants’ emotion. The upper back is even more insignificant than the overall upper torso regarding influencing participants’ emotion valence. The chest and back’s centers influence participants’ emotion the least.

5 FUTURE WORK

Tactile interfaces, as a digital medium, can not only be an expansion of users' visual and auditory channel, more importantly, they can also be developed to an independent library, comprising their own principles, conventions and disciplines, by millions of artists, scientists and hobbyists. Therefore, these patterns inside the tactile library are capable of forming (a) more intuitive, universal language(s) for interpretation of emotions, literature plots, scientific logics and for communication among tribes and communities. What I discovered from this project is just a sneak peak of dimensions and principles of tactile design.

Given the constraints of time and budget, some problems embedded in our study are also obvious. Here we list a few that are worth considering for directing our future work.

New tactile variable

The tactile variables we choose are not very practical to map all the complicated variations of emotion during the experiment, given our accessibility to the state-of-art vibro-tactile stimuli. Thus in our later work, we will focus on some abstract variables such as complex waveform (sinusoid amplitude modification), rhythm (group of different durations) and vibration pattern (combination of frequency, amplitude and location). For example, I would pre-created several vibration patterns. Participants recruited will be asked to use the patterns to give respond to music.

By doing so, dimensions other than basic ones (such as intensity and location in this project) can be checked. Multilayered conclusions thus can possibly be drawn.

Musicality > Emotion

Since both our experiment and experiment by Schubert are designed for a better generalizability of a certain framework across different music listeners, the music-emotion mapping model can be used as a valid method in our experiment as well. However, 7 out of 10 participants reported that they didn't think the music pieces in the experiment could arouse their emotions. Instead of expressing emotions through changing vibration intensity and location, they spent most of their time on expressing the music features in order to accomplish the experiment. Therefore, it is better for participants to select the music pieces that they think are relevant to expressing typical emotions of the 4 quadrants of 2DES.

The strategy of qualitative mapping

Even our project aims to propose a framework out of generalizability, designers should always bear the “ultimate particular” in mind. Thus using qualitative methods to structure a library of tactile effects for enhancing media consumption, communication and navigation is scheduled in our following work. An experiment I am planning to conduct is to pre-define several vibration patterns for participants to identify under some certain scenarios instead of letting them manipulate the basic vibration variables along an experiment. Another experiment comes across my mind could be letting participants define certain vibration effects based on the descriptive, or qualitative, information they are given.

A more intuitive interaction for better data

4 out of the 10 participants reported that the strategy of key mapping and mouse dragging was so exhausting that sometimes

they gave up responding to parts of a fast-paced music piece. In my next project, I probably will use TouchOSC as the user interface. The multi-touch and user-defined mobile app will provide participants with a more smooth, efficient and intuitive experience thus will improve the quality of data collected.

6 REFERENCE

1. Mohamad A. Eid, Hussein Al Osman. 2016. *Affective Haptics: Current Research and Future Directions.* http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7320966
2. Emery Schubert. 1999. *Measurement and Time Series Analysis of Emotion in Music.* Ph.D Dissertation. University of New South Wales, Kensington, Australia. http://unsworks.unsw.edu.au/fapi/datastream/unsworks:500/SOURCE01?view=true
3. Ramachandran, V. S. and Brang, David. 2008. *Tactile-emotion synesthesia.* Neurocase, 14: 5, 390 — 399. First published on 27 September 2008 (iFirst) http://dx.doi.org/10.1080/13554790802363746
4. Russell, J. A. 1979. *Affective space is bipolar.* Journal of Social Psychology, 37, 345-356.
5. Russell, J. A. 1989. *Measures of emotion.* In R. Plutchik & H. Kellerman (Eds.), *Emotion: Theory research and experience.* Vol. 4 (pp. 81-111). New York: Academic Press.

6. Asmus, E. P. 1985. *The development of a multidimensional instrument for the measurement of affective responses to music.* Psychology of Music, 13, 19-30.
7. Collins, S. C. 1989. *Subjective and autonomic responses to Western classical music.* Unpublished doctoral dissertation, University of Manchester, U.K.
8. Thayer, J. F. 1986. *Multiple indicators of affective response to music.* Unpublished doctoral dissertation, New York University.
9. Wedin, L. 1972. *Evaluation of a three-dimensional model of emotional expression in music.* Reports From the Psychological Laboratories, University of Stockholm, 349, 20.
10. Luis-Manuel Garcia. 2015. *Beats, flesh, and grain: sonic tactility and affect in electronic dance music.* Sound Studies, 1:1, 59-76, DOI: 10.1080/20551940.2015.1079072.
11. Goodman Steve. *2010. Sonic Warfare: Sound, Affect, and the Ecology of Fear.* Cambridge, MA: MIT Press.
12. Gatti E. Caruso G. Bordegoni M. Spence C. 2013. *Can the feel of the haptic interaction modify a user's emotional state.* WHC 2013, 247-252, DOI: 10.1109/WHC.2013.6548416.
13. Katri Salminen. Jussi Rantala. Pauli Laitinen. Veikko Surakka. Jani Lylykangas. Roope Raisamo. 2009. *Emotional responses to*

haptic stimuli in laboratory versus travelling by bus contexts. ACII 2009, DOI: 10.1109/ACII.2009.5349597

14. Mohamed Yassine Tsalamlal. Nizar Ouarti. Jean-Claude Martin. Mehdi Ammi. 2013. *EmotionAir: Perception of Emotions from Air Jet Based Tactile Stimulation*. Humaine Association Conference on Affective Computing and Intelligent Interaction, DOI:10.1109/ACII.2013.42

15. L. M. Brown, S. A. Brewster, and H. C. Purchase. 2005. *A first investigation into the effectiveness of tactons.* In Eurohaptics Conference, 2005 and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, *2005.* World Haptics 2005. pp. 167-176. 2005.

16. M. Chen. D. Katagami. K. Nitta. 2010. *An Experimental Investigation of Haptic Interaction in Online Negotiation*. World Automation Congress.

17. A. Israr. S. Zhao. K. Schwalje. R. Klatzky. J. Lehman. 2014. *Feel Effects: Enriching Storytelling with Haptic Feedback*. ACM Trans. Appl. Percept. 11, 3, Article 11, 17 pages.

18. S. Yohanan. K.E. MacLean. 2011. *Design and Assessment of the Haptic Creature's Affect Display*. ACM/IEEE International conference on Human-Robot Interaction.

19. K Salminen. J Rantala. P Laitinen. V Surakka. J Lylykangas. R Raisamo. 2009. *Emotional responses to haptic stimuli in laboratory versus travelling by bus contexts.* 3rd International Conference on Affective Computing and Intelligent Interaction and Workshops, pp. 1-7.

20. J. Raisamo. R. Raisamo. V. Surakka. 2013. *Comparison of Saltation, Amplitude Modulation, and a Hybrid Method of Vibrotactile Stimulation*. IEEE Transactions on Haptics, vol. 6, no. 4, pp. 517-521, 2013.

21. S. Krishna. S. Bala. T. McDaniel. S. McGuire. S. Panchanathan. 2010. *VibroGlove: an assistive technology aid for conveying facial expressions.* Extended Abstracts on Human Factors in Computing Systems, CHI EA '10, 2010.

22. Cholewiak R.W. Wollowitz M. 1992. *The design of vibrotactile transducers*. Tactile Aids for the Hearing Impaired, I. Summers, ed, Whurr Publishers Ltd: London, 1992. pp 57-82.

23. Kryssanov V.V. Mori H. Matsumito Y. Makino S. Rutkowski T.M. 2012. *Vibrotactile Stimulus Frequency Optimization for the Haptic BCI Prototype.* CoRR, abs/1210.2942.

24. Lecture Notes in Computer Science - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/225125163_fig1_Fig-1-A-two-

dimensional-emotion-space-with-a-valence-and-an-arousal-axis-Basic [accessed 17 Apr, 2017]

25. M. Nakamura L Jones. 2003. *An actuator for the tactile vest - a torso-based haptic device.* 11th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, 2003. HAPTICS 2003. Proceedings.

26. Spirkovska, L., 2005. *Summary of tactile user interfaces techniques and systems.*

27. Frid, E., Giordano, M., Schumacher, M.M. and Wanderley, M.M., 2014. *Physical and perceptual characterization of a tactile display for a live-electronics notification system.* In ICMC SMC 2014. McGill University.

28. Yui, K., Yoshimasa, I., 2014. MatchAtria e x t e n d e d. https://www.youtube.com/watch?v=ySUowqNJAeE.

29. *Vibration Motors - Voltage vs Frequency vs Amplitude.* https://www.precisionmicrodrives.com/application-notes/ab-029-vibration-motors-voltage-vs-frequency-vs-amplitude