Tampere University

Annukka Ojala-Salo

THE VALUE OF TACTILE SOUND IN MUSIC PERCEPTION

Exploring Haptic Music and its Influence on UX with a Multisensory Art Installation

Faculty of Information Technology and Communication Sciences
M. Sc. Thesis
May 2023

ABSTRACT

Annukka Ojala-Salo: The Value of Tactile Sound in Music Perception: Exploring Haptic Music and its Influence on UX with a Multisensory Art Installation
M.Sc. Thesis
Tampere University
Master's Degree Programme in Human-Technology Interaction
May 2023

Low-frequency vibrations (LFV) have been utilized in music throughout the ages. Usually, sensing sound and music is understood in the form of hearing. However, music can be experienced both as heard and felt. The tactile sensation of music manifests itself especially with bass frequencies. Nonetheless, the valuation of the tactile form of sound and its role in the whole user experience (UX) is not well assessed.

The purpose of this interdisciplinary study is to explore tactile bass with a multisensory art installation and find out whether users find the tactile sensation of the music valuable, and if it adds liking of the installation.

A multisensory art setup was created, where visual material was running on a big screen, audio material was outputted via small bluethooth speaker, and the vibrotactile material was derived with a subwoofer. The different sense perceptions formed together a multisensory sensation, where the audio material was produced to be perceptible also in vibrotactile form. The different soundscapes were compared in auditory and vibrotactile versions, also a no audio version was taken into account. The participants' opinions and liking were queried with semi-structured interviews.

The findings revealed the value of vibrotactile sound. Participants preferred the vibrotactile versions of the soundscapes, however the no audio soundscape gained also meaningful valuation. This research could contribute to the culture field by determining the value of tactually perceived sound [low frequency vibrations] that influence on the UX in sound related installations in culture context.

Keywords and terms: museum experience, multisensory perception, vibrotactile sound, HaXD, UX, product experience.

Acknowledgements

I'm extremely grateful to my supervisors Professor Roope Raisamo and Professor Tarja Rautiainen-Keskustalo for all their knowledge and guidance in this process.

Thanks should also go to the classmates Lauramaria and Viljami for all the peer help they gave.

I'd like to especially thank my family: Ville and boys for all the understanding you've had, and for making all this possible. Thank you also friends and relatives who supported this process and participated in the experiment (particularly Tiina).

Thank you all warmly. Without your help this dream would have not never come true.

Contents

1 Introduction

The human ability to percept different sensations has been extensively studied in recent years. Perception is a phenomenon of multiple sensories: it involves individual sensory modalities interacting with each other's (Reybrouck et al. 2019, Merchel 2014), like hearing and tactile perception. Vibration is a significant part of the perception of music (Merchel & Altinsoy 2014). For example, the quality perception of a music experience can be improved by adding vibrations to seats (Merchel 2014). However, there is a niche for testing whether the bass frequencies in presented music are actually more felt in the body, rather than just being heard (Hove et al. 2020).

These findings suggest that the phenomenon of tactile perception of music might be meaningful when applied to multisensory cultural context, such as museums and art exhibitions. Therefore, it seems that further investigations are needed in order to find the value of tactile sounds in multisensory installations. To address this gap, this thesis aims to understand how low-frequency vibrations, sensed as tactile vibrations, affect on the people's overall experience with and the valuation of a multisensory, sound utilizing art installation.

When experiencing loud musical situations, besides the audible sensations, there occurs also the related side effects: bodily experiencing of the vibrations and sound pressures. Usually, though, we do not pay attention to those, nor are we even aware of them (Merchel & Altinsoy 2014). Yet, they are highly meaningful components in the evaluation process of the musical experience (Merchel & Altinsoy 2014). Strong bass is connected especially to modern-day popular music styles, but low frequencies are an essential part of all music, also the classical genre and acoustic performances. Without the low end, something seems to be missing from the music. It is easy to think the difference between experiencing music in a live concert or via laptop's speakers. Tactile perception of bass vibrations occurs mainly unconsciously, and we are not usually aware of the stimuli nor the effects it has on us (Reybrouck et al. 2019). Interesting is, how subjective the experience seems to be; the difference between positively or negatively perceived stimulation of low frequencies can be subtle and highly personal (Reybrouck et al. 2019).

However, the coupled perception that music and vibrations form together (Merchel & Altinsoy 2014), has not been properly harnessed in use in the cultural context. Museums and art exhibitions seem to treat sounds mainly as in audible matter, and the haptic nature remains underused. Nonetheless, the interest towards multisensory experiencing is increasing, and now when haptic gadgets are becoming more common, they introduce the tactile sensing channel to an increasing extent of people. Also, understanding the importance of accessible content is increasing, which also prompts towards developing new ways of experiencing things. Therefore, it is highly timely matter to explore more the haptic nature and possibilities of sound.

Sound is the key factor for understanding the role of sensory experience in general and how it is rooted in the human body and technologies (Trower 2012). Music and sounds can be taken into consideration in vibrational terms (Reybrouck et al. 2019, Eidsheim 2015), and vibration can be conceptualized through the experience of sound (Trower 2012). The vibrational energy does not limit only to the auditory system and the sense of hearing: it also activates the sense of touch (Huang et al. 2012). Thus, sensing sound can be understood as a sensation of touch as well. Touch is one of the most important human senses, as well as the oldest, most primitive, and pervasive one (Raisamo 2019b). Notable is too, that in the case of music, we hear the melody, but the beat we feel (Phillips-Silver & Trainor 2005).

Recently, the market strategy has changed and instead of selling products the focus is now on selling experiences to the consumers: the latest studies about consumer experiences highlights the significance of embodiment (Joy & Sherry 2003). Though haptic feedback is an underused modality (Raisamo 2019b), it is increasingly studied in the market research and business strategy planning: product opinions can be improved with well-designed tactile aspects (Schneider et al., 2017). Also, research about the role of touch in aesthetics has increased in recent years, and haptic technology has become more prevalent through personalized devices and wearables.

In art practice, the exploration of touch and tactility can offer new ways of engaging with audiences and for creating sensory experiences that go beyond the purely visual (Lauwrens (2019). Touch is capable for providing such information related the work that would not be accessible with just vision; the aesthetic experiences can be enriched with touch for all individuals, regardless of visual ability Lauwrens (2019). By designing environments and experiences that engage the sense of touch, it is possible to create more diverse and dynamic aesthetic experiences for everyone.

The context where touch occurs highly determines how it is experienced (Hayes & Rajko 2017). Haptically pleasant touch is triggering a response that is emotional, and it might be the factor that is in control when evaluating that particular product (Jansson-Boyd (2011). When consumers are feeling emotionally connected with a product, they also feel close connection with them, which raises the probability to purchase and do the purchase again (Jansson-Boyd, 2011). Haptics are greatly encouraged to be added on designs (Schneider et al. (2017), and haptic feedback can enhance emotional experiences and increase user engagement with products (Jansson-Boyd (2011).

Therefore, including haptic design principles into also experience design can be an efficient method for creating a strong emotional connection with users and for ensuring they recommend the ‘experience’ (e.g. art exhibition or specific installation) to others.

All in all, sound has been started to think of as a product attribute just recently (Mayor Poupis et al. 2021). For example, in games, sound has been traditionally an inessential component, secondary factor if compared to visual material and the game graphics (Mayor Poupis et al. 2021). However, game developers have recently started creating an "immersive experience" by using audio (Frometa 2018) and the followed interest on sound design in gaming has also produced the academic research to focus on how sounds influence on the experience and evaluations of video games (Mayor Poupis et al. 2021). Players' experience and immerse in games can be enhanced with sounds (Grimshaw 2012, Fu 2015). Also, with mobile applications, the in-app experience of users can be highly influenced with utilization of sounds; intentional non-verbal sounds caused higher product evaluations and the probability for recommending the app to a friend (Mayor Poupis et al. 2021). This most likely is the case with art and museum installations too – soundscapes and the perception of sound seems not been understood as a channel that would meaningfully effect on the experience, immersion, and evaluation of the installation. However, the more enjoyable an experience is, the more one might value it and recommend it to others. Sound as a product attribute may be more valuable with tactile components. These findings will be taken into further exploration in this thesis by testing how different soundscapes (auditive vs. tactile) affect on the [user] experience with a multisensory art installation.

The museum experience, then again, is a journey of multiple layers, consisting of levels that are proprioceptive, sensory, aesthetic, intellectual, and social (Wang 2020). Making visitors to tactilely engage with the art enriches their understanding of the artwork's possible meanings (Lauwrens 2019). The deeper meanings are produced when the visual and tactile experiences are exchanged (Lauwrens 2019, Vi et al. 2017).

Tate Sensorium made a multisensory exhibition to the London's Tate Britain Art Gallery. They augmented an art peace with mid-air haptics to be a multisensory experience, and their case study was the first describing how to design work of arts by taking all the different senses, especially touch, into account (Vi et al. 2017). In Team Lab's exhibition in Amos Rex at 2018 were digital, immersive installations; large spaces whit huge projections, surfaces, soundscapes, atmospheres, and worlds where one could walk in and interfere with (Radio Helsinki 2021). Frid et al. (2019) created The Sound Forest, a Digital Musical Instrument (DMI), which utilized haptic vibrations. It enabled the visitors to interact with the installation and resulted in sonic, visual, and haptic feedback. Jung et al. (2019) made a multisensory exhibition in Gwacheon National Science Museum in South Korea. They created a device that produced multisensory stimuli (visual, auditory, and vibrotactile) for creating additional sensory experiences onto to the different artifacts in the museums. The Finnish National Opera and Ballet (FNOB) created a modern opera, Laila, which was immersive in a sense that people were literally placed inside the show:

an AI guided audiovisual experience for 6 persons at a time inside a 7,5 meter dome (Honkanen 2020).

The question of what the future of art exhibitions, museums, theatres, music concerts, and all culture-related events is highly timely. Museums should focus more on creating a connection with the visitors, and to the interaction that occurs between experience and senses (Wang 2020). The future of theatres is going to be hybrid, where utilization and integration of digitalization and augmented reality (AR) is only going to increase (Lenni-Taattola 2020). Also, museums should be active in ways that are visual, auditory, olfactory, and emotional (Wang 2020), and most of all; vibrotactile.

The main hypothesis in this thesis is that whole-body vibrations may be meaningful in the evaluation of a multisensory, sound utilizing art installation. In case the vibratory component is left out, the evaluation of the installation might change. Or, like following the example of Merchel & Altinsoy (2014), by adding vibrations the valuation of a multisensory sound utilizing installation might be improved, or even impaired.

This thesis aims to explore the effects of auditory-tactile perception of music, and whether they influence on the overall evaluation and valuation of the presentation. The goal is to find out if the appreciation of a multisensory art installation experience changes when vibrations are added. It might feel a self-evident phenomenon, but it has not been studied though from viewpoint of user experience (UX) and valuation. The insights gained from the study can be used in the developing, designing, and reproducting vibrations related to music. The results can be utilized in improving the sound reproduction systems e.g. in cultural context such as museums and art exhibitions.

Understanding human behavior requires viewpoints from diverse fields of science. Interpreting is not easy, and making an interdisciplinary study is challenging for only one researcher.

1.1 Research questions

The main research question is:

1. How does tactile bass affect on the overall experience of a multisensory art installation that utilizes also sound?

And the sub questions:

a. How does people value and experience haptic music (as part of a multisensory art installation)?
b. What are the factors that affect on the experience of haptic music?

2 Low-frequency vibrations

Low frequency vibrations (LFV) are greatly studied from versatile point of views. They are a target of interest in psychology, brain research, sound studies, haptics, therapy, computing systems, museum management, consumer research, public health, occupational safety, and even armed forces. In this thesis we discus frequency range of 20 Hz – 250 Hz as low-frequencies; so-called audible low-frequencies.

The sources generating low frequencies can be both man-made and natural. The natural origins are for example wind, earthquakes, and thunder. Man-made musical causes are for example contrabasses and cellos. Other man-made sources for LFV are example heavy vehicles like trains and busses, or stationary devices like cooling and ventilation.

The awareness and experiences of vibrations were intensified by railway trains and other technologies, which corresponded with scientific interest in detecting and calculating vibrations that would have otherwise escaped from consciousness (Trower 2012).

The interest towards different speeds of vibration known as frequencies was developed in the late eighteenth and nineteenth century by diverse and interdisciplinary professionals: e.g. physicists, engineers, mathematicians, poets, geologists, and philosophers (Trower 2012). It was important to gain and retain the awareness of vibrations for being able to manage them: vibrations were increasingly felt as a dangerous force, noise that caused pain and nervous illness, though they were noticed to be also stimulating, therapeutic and even life-giving (Trower 2012).

LFV and their effects on humans has been widely utilized throughout the times. Mainly they have been generated via music. Goudreau et al. (2008) describes how drumming has been an integral part of Aboriginal cultures since time immemorial, as the drumbeat represents to them the heartbeat of Mother Earth.

Since vibration can be simultaneously palpable-audible and visible-audible, it crosses different sensory thresholds (Trower 2012). Human being's first sense is the sense of touch (Raisamo 2019b, Hepper 2008). Sensing vibrations can be understood as a sensation of touch as well. Perhaps a fetus sensing its mother's heartbeat [low-frequency vibrations] is fundamentally a sensation of touch instead of sensation of hearing. Tactile perception is further discussed in subsection 3. Haptic perception.

Vibrations in the air are called *airborne sound*, in liquids *liquid-borne sound*, and solids *structure-born sound***.** The primary quantity with airborne sound is sound pressure, which can be measured with microphones. With structure-born sound, under determination are the displacements, velocity and acceleration of the surfaces (Muller & Moser 2013). In this thesis, structure-born sounds are under further investigation in the experiment.

2.1 Whole-body vibrations (WBV)

Human related vibrations occur when a body vibrates because of external and internal forces (Donati et al. 2008). The vibrations transfer to human body via the body parts contacting the vibrating surface: for example, a machine's handle or seat, the floor of a concert hall, or the air of loud situation (Donati et al. 2008).

Whole-body vibration (WBV) is described in the VDI standard 2057 (as cited in Merchel & Altinsoy 2014) as *'mechanical vibrations within the frequency range of 0.1 Hz to 80 Hz, which affect the whole body via the feet of the standing person, via the buttocks, feet and back of a seated person, or via the contact area of a person in a lying position'*. Following the example of Merchel & Altinsoy (2014) the term will be extended in this thesis on increased range of frequencies and broader range of excitation:

> "Whole-body vibrations are defined as mechanical vibrations, which excite large parts of the body via sound waves or vibrations of a contact surface".

According to Muller & Moser (2013), whole-body vibrations can be stochastic, meaning they are random or unpredictable, or they can contain different frequencies or shock signals. To accurately measure vibrations, vibration sensors, also known as accelerometers, must be rigidly connected to the surface or structure being measured (Muller & Moser 2013). In the experiment, a vibration meter will be rigidly connected to the floor for measuring the structure-born sounds that would transfer as WBV to the participant.

2.2 Low-frequency Noise (LFN)

The negative effects that low-frequency vibrations cause varies from disturbing to damaging. What is considered as LFN is the frequency range 10-200 Hz, and it also includes infrasound and audible noise (Maschke 2004). Usually, LFN appears in conjunction with vibrations (Maschke 2004).

The space programs from America and Russia have been sources for extreme levels of low-frequency noise and vibrations, therefore they started to examine LFN and how it effects on human's health and performance (Maschke 2004). Nowadays, LFN and vibrations are increasing in our everyday acoustic environments and thus creating a new challenge for industrialized nations (Maschke 2004).

The effects of LFN are diverse and dependent of the individual. What one experiences as noise is highly personal: the experienced noise levels are often in perception threshold, which contains significant individual differences (Maschke 2004). For people who are sensitive to LFN, it can cause extreme distress (Leventhall 2004, Maschke 2004). Natural high sensitivity level (Maschke 2004) and increased sensory response in the auditory range may result as sensitivity for LFN, and the middle age seems to be age when LFN starts to especially annoy (Leventhall 2004). In general, the secondary effects of vibrations are experienced as more disruptive than the vibrations itself: e.g. bouncing objects or glasses that rattle (Muller & Moser (2013).

Many technical sources, such as vehicles (busses, trains, airplanes) and stationary sources (building's ventilation, heating & cooling devices), relate to LFN having dominant part in the area of low frequency (Maschke 2004).

LFN is especially problematic with its ability to spread; in open air it can travel a very far distance, and even when permeating through walls and windows there occurs only a low attenuation (Maschke 2004). The low-frequency sound can significantly change due to the room resonance (Maschke 2004).

Leventhall (2004) criticizes how in assessing the annoyance of LFN, the common methods are inadequate and results the regulatory authorities to make incorrect decisions. Leventhall (2004) points that the conventional methods are usually based on sound level weighted with A, which does not estimate the LFN effects correctly and thus is inadequate. However, specific assessment methods for LFN are emerging, though they lack in providing a full assessment of fluctuations (Leventhall 2004).

Vibroacoustic decease (VAD) is a description of how LFN and vibrations may affect on humans, and it includes symptoms like depression, increasement of irritability or aggression, isolation tendency and cognitive skill decreasement (Maschke 2004). VAD has occurred with people exposing to LFN in their everyday environments: mechanical engineers, restaurant workers, disc jockeys, and pilots (Maschke 2004).

Maschke (2004) underlines, that quantifying the effects of environmental LFN with vibration are one of the future challenges in noise effect research: as per annoyance, performance, and health indicators. According to Maschke (2004), the state of knowledge about LFN's extra aural effects is unsatisfactory, and **the effects of LFN in the environment are highly underestimated**. Though this thesis is focusing on exploring the positive effects of tactile sound, these serious and negative influences of LFV must be taken into account.

3 Haptic perception

Tactile sensing is obtained from cutaneous inputs (e.g. through the skin receptors), **kinesthetic** from proprioceptors relating to the orientation of body parts, and to limb movements, and **haptic sensing** is obtained from both the tactile and kinesthetic receptors (and usually encompasses active touch) (Raisamo 2019a). **Active touch**, the act of touching, is voluntary, and self-generated movements focusing on gathering information about object properties of the environment (Chapman 2009, Raisamo 2019b). **Passive touch,** the act of *being* touched, is about the sensation experienced and not exploratory in nature and is generated by an external agent (Chapman 2009, Raisamo 2019b). Both these forms of touching are easy to do for example while speaking or listening (Raisamo 2019a). In this thesis, under focus is passive touch.

3.1 The sense of touch

From all the human senses, the sense of touch is the oldest, pervasive and most primitive one (Raisamo 2019b). As a sense, touch is proximal, and usually requires closeness or contact with the target for enabling the sensation (Raisamo 2019b). However, exceptions occur; for example, **deep bass tones** (Raisamo 2019b), and exploring them and their effects are the core of this thesis.

As a sensory channel, the sense of touch is parallel to sight and hearing: it can provide additional or redundant information (Raisamo 2019a). Multimodal interaction involves the interaction of several input and/or output modalities for interacting with a computer system (Raisamo 2019a). In this study's experiment, the different modalities utilized are sight, hearing, and the sense of touch, and the computer system is a digital multimodal (art) installation.

The touch sensitivity depends on multiple factors; for example, age, gender, individual differences, the level of attention (fatigue, mood, stress), diseases and disabilities, and also training affects on the perception (Raisamo 2019b).

There are only a limited number of studies on how a fetus reacts to cutaneous sensation because it is difficult to present the stimuli to the fetus (Hepper 2008). It seems that touch is the first of the senses that develops and starts responding to stimulation (Hepper 2008). When the fetus is 8 weeks old, it starts responding if touched; the first location to react is the lips, then cheeks, forehead, palms, and upper arms (Hepper 2008).

The fetus gets the tactile stimulus from multiple sources, like the uterus walls, umbilical cord, and the own body (Hepper 2008). However, seems that it is not yet studied is the fetus sensing its mother's heartbeat initially as vibrations via the haptic perception channel, or as audible material via the auditory sensory system.

3.2 Tactile sensing

Cutaneous inputs enable tactile sensing (Raisamo 2019b). Human's largest organ is the skin, and there are two kinds of skin types: the hairless glabrous skin covers the sole of the feet and hand palms, and rest of the body is covered with hairy skin type (Sonneveld & Schifferstein 2008). The hairless skin is suitable for active touch and the hairy skin for passive touch (Sonneveld & Schifferstein 2008).

These skin types consist of three layers: epidermis is the outermost and contains for example pigment cells, dermis is the middle layer and where majority of the skin receptors are, and subcutaneous the nethermost layer where for example fat and nerves are (Raisamo 2019b).

The different sensors that are located in the dermis are for example mechanoreceptors, thermoreceptors, and nociceptors (Sonneveld & Schifferstein 2008). Mechanoreceptors sense the skin's mechanical transformation, thermoreceptors sense the skin's temperature changes, and nociceptors are united with the sensation of pain if the skin gets damaged (Sonneveld & Schifferstein 2008). The sensory information that stimulated skin sensors obtain, is carried out to by neural fibers to the central nervous system (Sonneveld & Schifferstein 2008). The different sensors have differences in their adaptation rates, which highly influence on the duration of tactual sensations: some sensations disappear quickly when others may last for long (Sonneveld & Schifferstein 2008).

The different skin sensations can be distinguished as following (Sonneveld & Schifferstein 2008):

- **Light touch** is the sensation of touch when the skin is not deformed, and is rapidly adapted: due to the rapid adaptation it is for example possible to forget the clothes that are touching us
- **Pressure** is touch that is maintained and occurs in situations where an object presses the deforms the skin. These sensors adapt slowly, and thus, for example, it is difficult to ignore the sensations of deep and heavy pressure.
- **Vibration** is sensed when with the skin when touch sensors that adapt rapidly are rhythmically stimulated, for example when sitting on a chair and truck drives by and vibrates the floor. Receptors sensitive to low frequencies are in the skin's upper layer, and receptors sensitive to high frequencies are in the deeper layers.
- **Cold and warmth** are sensed with two different sensory systems.
- **Pain** occurs in three forms: superficial pain happens when pain is caused by stimulating the skin, deep pain relates to pain coming from muscles, bones and joints, and somatic pain occurs when the pain is a bodily kind of sensation.
- **Itch and tickle** are sensed when nonmyelinated fibers in the skin are stimulated.

- **Physical pleasure** can be considered as physical sensation in itself.

The tactual sensitivity is dependent of the body location because the sensors in the skin are unevenly spread (Sonneveld & Schifferstein 2008). Most sensors are in the fingertips and lips, whereas the back and calf have relatively small sensitivity (Sonneveld & Schifferstein 2008). The most sensitive areas in the body are the lips, tongue, hands, feet, and genitals (Raisamo 2019b).

3.3 Skin Receptors

The different receptors can be classified by their location: skin receptors (*exteroceptors*) are near the skin surface, muscle, and joint receptors (*proprioceptors*) in tendons, muscles, and joints, and visceral receptors (*interoceptors*) are connected with internal organs (Raisamo 2019b). Skin receptors percept vibration, touch-pressure, temperature and pain, whereas muscle and joint receptors relate to position and movement perception, and visceral receptors relate to heart rate and blood pressure (Raisamo 2019b). Hence, the skin receptors that detect vibrations and pressure, are under focus in this thesis.

Tactile sensing occurs due to two different types of skin receptors: free nerve endings, and encapsulated nerve endings (for example mechanoreceptors) (Raisamo 2019b). Predominantly mechanoreceptors deliver the tactile information (Raisamo 2019b).

3.3.1 Mechanoreceptors

Mechanoreceptors are skin receptors that respond to mechanical pressure and also skin's deformation (Raisamo 2019b). Mechanoreceptors are: Meissner's corpuscles, Pacinian corpuscles, Merkel's disks, and Ruffini Endings, and they have differences in their size, receptive fields, adaptation rates, locations, and physiological properties (Raisamo 2019b). These are illustrated in the Figure 1.

Usually, mechanoreceptors specialize to some particular stimuli: Meissner's corpuscles and Pacinian corpuscles are stimulated by vibrations, whereas Merkel's discs and Ruffini endings perceive contact forces (Raisamo 2019b). Meissner's corpuscles enable the sensations of light touch and vibrations, and they exist only in the hairless skin (Sonneveld & Schifferstein 2008). In consequence, subtle tactual details like differences in texture are not possible to perceive with body parts that have hairy skin (Sonneveld & Schifferstein 2008).

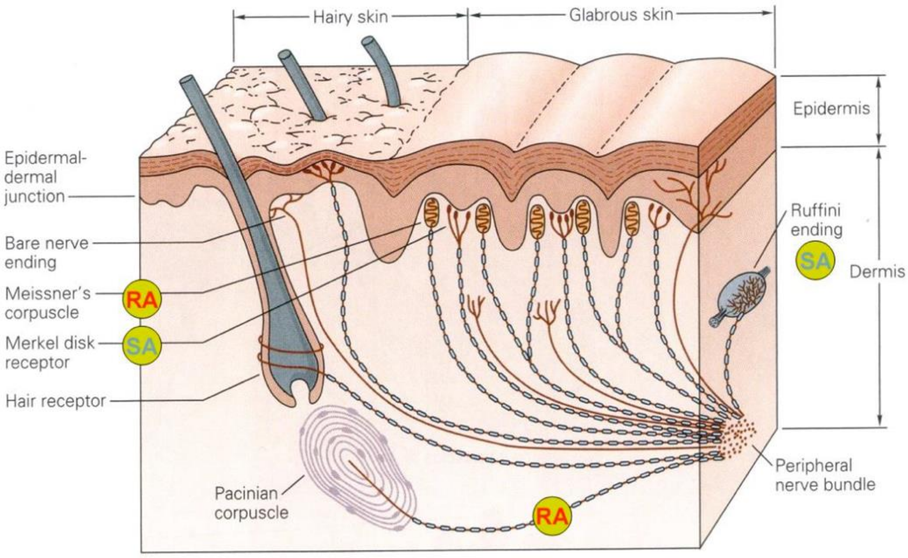

Figure 1. Mechanoreceptors are four different kinds: Meissner's corpuscles, Pacinian corpuscles, Merkel's disks, and Ruffini Endings (Raisamo 2019b).

Receptor	Rate of adaptation	Location	Receptive field	Stimulus frequency	Function
Merkel's disks	SA-I	Shallow	2—3 mm	0—30 Hz	Pressure; edges and intensity
Ruffini endings	SA-II	Deep	>10 mm	0—15 Hz	Directional skin stretch, tension
Meissner's corpuscles	RA-I	Shallow	3—5 mm	10—60 Hz	Local skin deformation, **low frequency vibratory sensations**
Pacinian corpuscles	RA-II (PC)	Deep	>20 mm	80—400 Hz	Unlocalized high frequency vibration; tool use

Table 1. Low frequency vibration sensations are perceived with Meissner's corpuscles, which are mechanoreceptor type of skin receptors. Table based on Raisamo (2019b).

The perception of vibration occurs about in the area of 0.04 – 500 Hz, whereas with hearing it is about 20 – 20 000 Hz (Raisamo 2019b). The vibration perception depends on the posture, and with the frequency range of 1-4 Hz, it is approximately proportional to acceleration's amplitudes, and with the range 10-80 Hz, the perception is relative to velocity's amplitude (Muller & Moser 2013). When the perception is above 80 Hz, the human body's interior insulation affects and the person's sensitivity perceiving vibrations decreases (Muller & Moser 2013). Frequencies over 500 Hz are experienced instead of vibrations more like textures (Raisamo 2019b).

3.4 Thresholds

Threshold denotes the exact point when the stimulation of touch is experienced consciously (Raisamo 2019b). Detection threshold (also called absolute threshold) indicates the smallest detectable level of stimulus, whereas difference threshold (also called just noticeable difference, JND) tells the smallest detectable difference between stimuli (Raisamo 2019b). There occurs a correlation between vibration thresholds and the density of cutaneous mechanoreceptors (Raisamo 2019b). In this thesis's experiment, the detection threshold for tactile and audible stimuli are measured.

3.5 Tactile acuity for vibration and pressure

The human body is extremely sensitive to vibrations (Raisamo 2019b). Vibration stimulates mainly the Pacinian corpuscles and Meissner's corpuscles (Raisamo 2019b). High frequencies (above about 60 Hz) are detected with Pacinian channel, whereas low frequencies (below 60 Hz) are perceived with non-Pacinian channel (Raisamo 2019b). The human body's sensitivity to mechanical vibration is decreasing above 320 Hz and increasing above 100 Hz: the optimum frequency is said to be 250 Hz (Raisamo 2019b). Pressure, in turn, predominantly stimulates the Merkel's disks, and the stimuli location defines the pressure sensitivity (Raisamo 2019b).

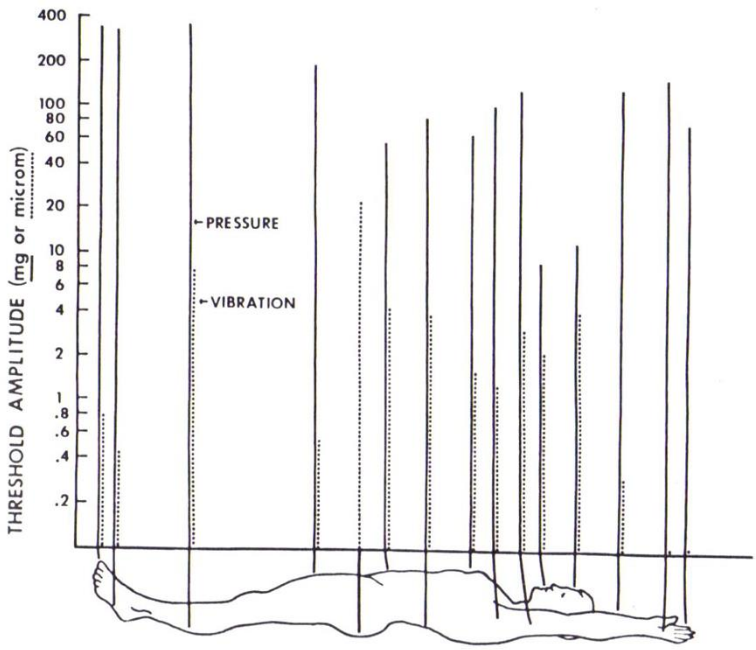

Figure 2. Different threshold responses for 200 Hz vibration (dots) and pressure (lines) (Raisamo 2019b).

How one percepts vibration depends on the personal constraints, on the activity itself, and on the environment (Muller & Moser 2013). Tactual sensitivity varies in time, and aging decreases it (Sonneveld & Schifferstein 2008). However, the vibrotactile detection in the fingertips seems not to reduce due to ageing, whereas on the contrary, pressure sensitivity overall seems to weaken with aging (Raisamo 2019b).

3.6 The parameters for tactile stimulation

The parameters that affect the tactile stimulation are for example frequency, amplitude, waveform, spatial location, duration, and rhythm (Raisamo 2019b). Also, the context where touch occurs highly determines how it is experienced (Hayes & Rajko 2017). In this thesis, the meaningful parameters are (low) frequencies, amplitude, and spatial location. The experiment context is free from unwanted interferences, and therefore does not simulate to a realistic museum or art installation situation. However, as this experiment can be seen as a pilot test, the used context enables focusing for the sensation exploration itself without surprising and disturbing interferences that could occur in a real-life situation.

Frequency

Mechanoreceptors respond when stimulating with a frequency range from 0.3 to over 500 Hz, and for sensing vibrations, the optimal range is about 150-300 Hz (Raisamo 2019b). If the frequency is changed, is tends to also change the stimulation’s perceived intensity (Raisamo 2019b).

Amplitude

When doing tactile experiments, the tactile stimulation’s amplitude should be detectable whilst low enough for not being uncomfortable (Raisamo 2019b). The amplitude perception is affected by many factors, for example the actuator contacts and body location (Raisamo 2019b).

Spatial location

The vibration can travel on the skin like a wave even for many centimeters (Raisamo 2019b). Thus, if placing actuators on sensitive body parts, like arms, the distance should be at least 2-3 cm, but with less sensitive body parts, like legs or back, the distance should be even more (Raisamo 2019b).

4 Sensing sound – Beyond the ear

4.1 What is sound

For understanding the role of sensory experience in general, and how it is rooted in the human body and technologies, sound[1] is the key factor (Trower 2012). As Trower (2012) describes, vibration can be conceptualized through the experience of sound.

Helmholtz (1895) pointed, that *"aerial vibrations do not become sound until they fall upon a hearing ear*". Helmholtz (1895) compared the ear to the eye, meaning that like sound, also light consists of frequencies of vibration. Frequencies of light are visible as different colors - like sonic frequencies are audible as musical tones, while the vibratory consistency of light and sound itself tends to be unconscious (Trower 2012).

What ear hears as sound is about the frequency range 20-32 000 in a second (Trower 2012). Ultrasounds are frequencies above the range of human hearing, and its lower limit is about 20 kHz (Muller & Moser, 2012).

Sound wave occupies a space and is a three-dimensional quantity (Howard & Angus 2017). In reality, sound from a source does not propagate in one direction but propagates in three dimensions: it spreads out while travelling away from the source (Howard & Angus 2017).

The methods for examining what sound wave's amplitude in a certain point is are for example sound intensity, pressure amplitude, or the velocity component being associated (Howard & Angus 2017). For measuring sound wave's amplitude, pressure, with the quantity *sound pressure*, is used since it's easier to measure and due to the human ears' sensitivity for it (Howard & Angus 2017).

Commonly, there are more than one sound sources present, and it can result from surface reflections in a room, or from other musical instruments (Howard & Angus 2017.

As Howard & Angus (2017) describes, for human existence communication via sound is fundamental, and yet majority take sound for granted.

4.2 The effects of music

Music and sound have the ability to impinge into our bodies and mind, which causes us to react either in positive or negative ways (Reybrouck et al 2019). According to the brain researcher Minna Huotilainen, listening to music affects to our body and brain fast and strong, and creates a personal listening experience (Huotilainen 2021). Listening to relaxing music has effects on the stress hormone excretion (Khalfa et al. 2003), whereas speedy music inspires, lifts the state of alertness, and produces more optimal state of

1 The Canadian Northern College says that the first sound heard in the world was the heartbeat of Mother Earth (northernc.on.ca).

learning experience (Huotilainen 2021). Music activates the pleasure system in our brain and listening to music has both cognitive impact and strong effect on physiological states (Huotilainen 2021). Music activates exactly those brain areas which regulates the physiological state: breathing, muscle tension, heart function, circulatory, eye movements and blinking (Huotilainen 2021).

How we set music apart from noise is dependent on the spectrum of frequency, and sound stimuli's level (Reybrouck et al. 2019). Reybrouck et al. (2019) separates them as the sounds physical-acoustic description, and as the listener's subjective-psychological reactions.

Reybrouck (2019) describes how music has an existential structure and meaning; rather than solely reasoned and decoded, the involvement with music is *experienced*. The effects of music are triggered by human psychobiology and mediated also by the listener's choices and mental states (Reybrouck 2019). Similarly, Eidsheim (2015) criticizes, how the rich event of music is narrowed down when understood through the restricted and fixed concepts like pitch, durational schemes, and genres. Hence, the sound's multisensorial phenomenon is reduced into something static, fixed, limited and multidimensional (Eidsheim 2015).

According to Reybrouck et al. (2019), musical experience could be described as 1) the relationship between sound's vibrational properties and the listener's body, and 2) the more conscious evaluation of music in the traditional forms and parameters. Thus, in this view, **music and sounds can be taken into consideration in vibrational terms**: they are transferable energy impinging into our body and senses (Reybrouck et al. 2019, Eidsheim 2015).

From acoustical point of view, music is considered as an energy that pulsates via mediums (Reybrouck et al. 2019). Huang et al. (2012) points, that the vibrational energy does not limit only to the auditory system and the sense of hearing: **it activates also the sense of touch**. How one experiences music involves activation of several sensory modalities simultaneously (Reybrouck et al. 2019). First the sensory system processes the sound, following the preconscious responses which activates the autonomic nervous system that is in control of the physiological functions like heart function, the hormonal and immune systems, and respiration (Maschke 2004).

Therefore, it becomes relevant to study what kind of role also tactile and haptic perceptions have in the perception of sound and music, and how they affect on the overall experience and sensation of music.

With live music experiences, the perception of sound and vibration are always coupled (Merchel & Altinsoy 2014). When in rock concert, or even in a classical concert, the kettle drums and double basses are heard but also sensed in other ways. The air-borne sound vibrates the seats and excites the skin surface, whereas some instruments transmit directly the vibrations from the instrument to the listener as structure-born sound (Merchel & Altinsoy 2014). The figure 3 shows the overlapping between the frequency ranges of auditory and tactile perception. Particularly some instruments excite sound and vibrations, for example the double bass (Merchel & Altinsoy 2014).

Typically, when concert records are being played back with a multimedia hi-fi system, the vibratory information lacks (Merchel & Altinsoy 2014). That is because of the low quality of the reproduction system or due to the narrow frequency range the speakers can output (Merchel & Altinsoy 2014). Soundtracks have an supplementary channel for low frequency effects (LFE), and they are reproduced with a subwoofer (Merchel & Altinsoy 2014).

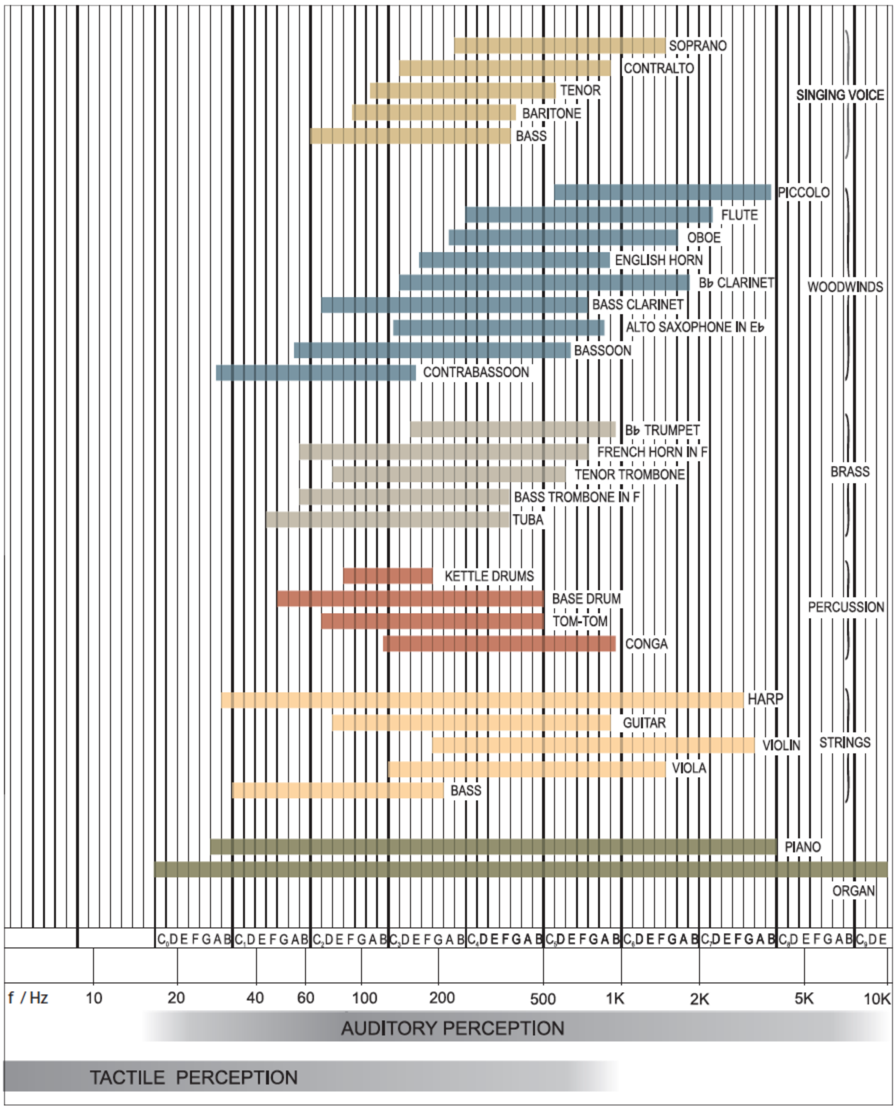

Figure 3. Auditory and tactile perceptions' frequency range, and the primary frequencies for different instruments (Merchel 2014).

Phillips-Silver & Trainor (2005) says we hear the melody in music, but the beat we feel. The human tendency to move the body to music is pervasive and seem biologically congenital (Phillips-Silver & Trainor, 2005). The desire of moving to the beat is termed as *'groove'* in the literature (e.g. Lustig & Tan, 2020 and Guy, 2006).

Tactile perception of bass vibrations occurs mainly unconsciously, and we are not usually aware of the stimuli nor the effects it has on us (Reybrouck et al. 2019). Interesting is how subjective the experience seems to be; **the difference between positively or negatively perceived stimulation of low frequencies can be subtle and highly personal** (Reybrouck et al. 2019).

How one experiences the aesthetic quality of music, forms from the musical information being balanced in a way that one hears the relevant musical information in a distinct way (Reybrouck et al. 2019).

Contrarily, how noise is experienced is not so constrained and seems mainly uncontrolled (Reybrouck et al. 2019). Noise is often negatively associated, relating either to the acoustical descriptions or the to the subjective evaluations (Reybrouck et al. 2019). However, an increasement in the scope of music's frequency spectrum and dynamic area is emerging: if musical sounds considered as traditional are in the optimal stimulation range, **there seems to be an increasing trend in what is considered acceptable at the extremes of loudness levels and frequency spectrum** (Reybrouck et al. 2019). Habits and likings are evolving via developing technology and new ways of enjoying music. Factors like music taste, ability to hear and sense influence on how we orientate on listening and precepting sounds: what is music to some can be noise to others.

4.3 The impacts of loud sounds and noise exposure

The physicist Herman von Helmholtz has described (1895) how a sounding body is in a state of vibration, and the vibration is possible to see and feel; with loud sounds one can feel the trembling air without needing to touch the vibrating body. Helmholtz (1895) describes how in the perception of loud sound the trembling of the air can be perceived with skin:

> *"In this way deaf mutes can perceive the motion of the air, which we call sound. They do not hear, they feel the motion by the nerves of the skin, producing that peculiar description of sensation called 'whirring'."*

According to Reybrouck et al. (2019), it seems, that listening to loud music activates a primitive mechanism related to experiencing and evokes an amodal perception by surpassing boundaries between sensory modalities. Reybrouck et al. (2019) hypothesizes, the sensation of loud music is either, as Freud suggests: a return to the *'oceanic feeling'*[2], or like the threshold of rock and roll, and the high levels of vibrotactile and haptic stimulation it has, implies: *'a desire to be surrounded by a cocoon of sound'*.

Like Reybrouck et al. (2019) and Trower (2012) points, what people experiences as pleasurable might be very unusual stimulation, and even play with the threshold of pain.

On the other hand, Howard & Angus (2017) indicates how the Western society generates noise that has long-term effects: when comparing the hearing of Westerners and other cultures, at a given age Westerners had a meaningfully lower threshold for hearing.

Permanent hearing damages may occur from exposure to noise over 90 dBA, thus e.g. the European legislation demands a noise exposure less than 85 dBA for workers (Howard & Angus 2017). In case the work environment has greater noise levels, employers must provide hearing protection for workers.

However though, it is common in musical context that for short periods the noise level can be greater than 90 dBA: a concert audience might expose to peaks above that (Howard & Angus 2017). A method called integrated noise dose can be utilized for evaluating the possible effects of short exposures to a sound of 96 dBA (Howard & Angus 2017).

Hearing loss is permanent and can happen insidiously: when it is measurable it is already too late (Howard & Angus 2017). Therefore, for protecting the hearing sensitivity and acuity, avoiding exposure to excess noise is essential. Damage may occur even if the sound level is less than 85 dBA (Howard & Angus 2017).

Potential hearing damage is probable in following situations (Howard & Angus 2017):

- Listening to music via headphones can produce damaging sound levels
- Playing acoustic or electrical music instruments can produce damaging sound levels particularly in small rooms

When exposed to a large noise dose, like nightclubs, concerts, or power tools, the hearing acuity can take days or even weeks to recover (Howard & Angus 2017). Therefore, daily exposure to these should be avoided, and one should restrict the noise dose and use hearing protection. From the given point of view, the sensitivity of the ears should take into careful consideration when creating tactile sound and utilizing loud sounds.

4.4 Therapeutic possibilities of tactile sound

Music has been utilized as a method for improving mood and even pain. Campbell et al. (2019) has found out that for treating psychological and physical symptoms, the tactile

2 "The oceanic state has often been depicted simply as a transient and regressive feeling of oneness with the universe." (Saarinen 2012) form of music has resulted in beneficial and promising way: Vibroacoustic (VA) therapy is beneficial for relieving mood or even pain. In vibroacoustic therapy, the patient listens to preferred music accompanied with low-frequency sinusoidal vibration and therapeutic interaction (Campbell et al. 2019). With the help of VA treatment, participants experienced decreased pain, depression, and anxiety levels, increasement in relaxing, improvement in the quality of sleep, and the whole treatment was experienced as empowering (Campbell et al. 2019).

5 Experience creation

5.1 Product experience

Experience and interaction are bound together, and for exploring how people experience products it is essential to understand how human-product interaction forms (Schifferstein & Hekkert 2007). In this study, the concept of product is extended to include also non-physical products, such as art installations. The reacts of people to work of arts has been widely studied by philosophers and psychologist (Schifferstein & Hekkert 2007).

How human interact with the environment they are in, relies on multiple biologically innate systems: motor system enables acting with the environment; sensory system enables perceivement of the environment and changes in it; cognitive system enables making sense of the environment and action planning (Schifferstein & Hekkert 2007). Products are included in an environment (Schifferstein & Hekkert 2007). The motor system is needed for exploring, interacting, and operating with a product, and the sensory system for perceiving and evaluating the product (Schifferstein & Hekkert 2007). These determine is a sensation (visual, tactual, auditory, gustatory, or olfactory) pleasurable or need to avoid (Schifferstein & Hekkert 2007). The cognitive system combines the perceived information with stored knowledge and enables interpretation: they arouse remembering previous usage and similarities with other products (Schifferstein & Hekkert 2007).

How people experience products is depended on how they interact with the product (Schifferstein & Hekkert 2007). For example, the aesthetic experience forms from feelings of (dis)pleasure which bases on the object's sensory perception: does the object look beautiful, sound nice, or **feel pleasurable** (Schifferstein & Hekkert 2007).

The research about product experience crosses multiple scientific disciplines and subdicplines (see figure 4), but since the research of product experience is focused on peoples' subjective experiences, it goes under the discipline of psychology (Schifferstein & Hekkert 2007).

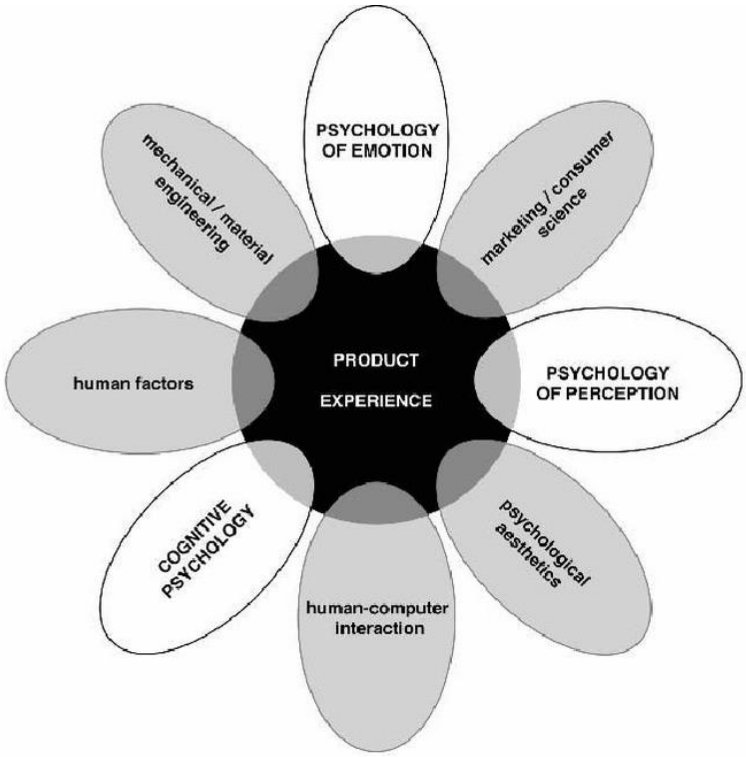

Figure 4. The field of product experience involves diverse disciplines (Schifferstein & Hekkert 2007).

Tactual experiences are an ordinary element of our everyday life. However, people do not really talk about them, nor do they discus about how do objects feel (Sonneveld & Schifferstein 2008). This most likely is the case with immaterial objects, such as art installations and museum experiences, aswell.

5.2 Sonic experience

Multiple factors affect on the quality evaluation of a sound utilizing experience. The vibrations, sound, and images are perceived with different senses, creating a multimodal perception which is then reflected by the brains, following the recognition and designation of the qualities and features (Merchel 2014). Then takes place the comparison of those features with expectations: the experience gains good quality when the expected characteristics fulfills or exceeds (Merchel 2014).

The average frequency range for human hearing system is 20-20 000 Hz, but high individual differences occur (Howard & Angus 2017). The frequency range what one hears changes alongside the human aging process: usually the high end reduces (Howard & Angus 2017). How the ear senses sounds depend on the frequency range and the sound pressure level: with 4 kHz the averagely minimum heard sound pressure level is 10 micro pascals, and the maximum combination (what is experienced as hearing and not painful) is 64 Pa (Howard & Angus 2017). It is difficult to measure how ear senses sounds, and it also depends on the listener's own interpretation and experience (Howard & Angus 2017).

The ear is an organ sensitive to pressure. How a sound wave's loudness is perceived is not directly related to the sound wave's pressure amplitude: due to our hearing sensitivity varies when the frequency varies, and because sounds being on different frequencies, a sound wave with higher pressure amplitude may sound more quiet than a sound wave with lower pressure amplitude (Howard & Angus 2017). To sound equally loud, different frequency tones should occur on sound pressure levels differing to each other's (Howard & Angus 2017).

5.2.1 Sound absorption

When sound and physical object interacts, the sound gets absorbed: by hitting an object, the vibrational energy transfers from the sound wave to the object (Howard & Angus 2017). Partial absorption of the energy happens due to the inner frictional loss of the object material, and due to the sound wave travelling via porous material: because of the fibers and holes in a material, there exists a very large surface area for interaction (Howard & Angus 2017). Frictional loss will happen on any material's surface due to the interaction between sound wave's velocity component and the material's surface: high loss occurs with large surface areas; therefore clothes, rock, wool or other porous materials have the ability to strongly absorb sound waves (Howard & Angus 2017). Thus, for minimizing sound and vibration absorption in the experiment, participants are seated on wooden chair with their sole of feet placed on wooden floor.

5.2.2 Acoustics and Psychoacoustics

For analyzing acoustical phenomena, acoustic measurements are an important tool. van den Bosch et al. (2018) suggests that for evaluating an acoustic environment, audible safety could be the key factor. Typically, the measurement happens with components of source and receiver: the receiver is a 'sound level meter' or 'sound analyzer' and shows the total sound level in frequency-dependent data, for example in decibels (Muller & Moser, 2012).

Usually, microphones are used for converting the sound pressures into form of electrical signals, which enables the sound pressures to be displayed, saved, and analyzed (Muller & Moser, 2012). Also, other forms of transducers, e.g. electromechanical and electro acoustical ones, may be called as microphones: hydrophones are transducers for measuring underwater sound, and accelerometers are sensors for measuring structural vibrations (Muller & Moser, 2012). In this thesis, microphones and accelerometers (vibration meter) are the measurement tools used for detecting decibels and vibrations.

5.2.3 Speaker systems

Surround systems: The room and its walls influence on how we perceive a sound from loudspeakers (Howard & Angus 2017). 5.1 surround is a form of spatial reproduction, and it is utilized in video and film presentations (Howard & Angus 2017). In recent years, additional speakers have been added to this 5.1 surround systems, like 7.1, 9.1, 11.2 and so on, to designate the extra speakers (Howard & Angus 2017). The purpose of these extra channels is to improve the surround-sound experience for the listener so that they have more consistent localization all the way around themselves (Howard & Angus 2017).

Low-frequency effects: In the 5.1 system the channel "0.1" is required due to the substantial low-frequency and *subsonic* content that exists in the sound effects (such as punches and explosions) in film and video (Howard & Angus 2017). Therefore, for being able to reproduce properly these sounds, a specialized speaker is needed. Howard & Angus (2017) points out, how originally this low-frequency speaker was not intended for reproducing musical signals, and now, in many surround music systems their presence is used to provide general low-frequency content as a "*subwoofer*" (Howard & Angus 2017).

Its advantage is enabling a means of dealing with the effects of low-frequency modes on the sound, as these speakers can be placed in an "optimum" position (Howard & Angus 2017). It also allows the use of multiple bass speakers and appropriate processing to combat the effects of modes and can permit the use of more compact speakers for the other channels, as they do not have to handle the lowest frequencies (Howard & Angus 2017).

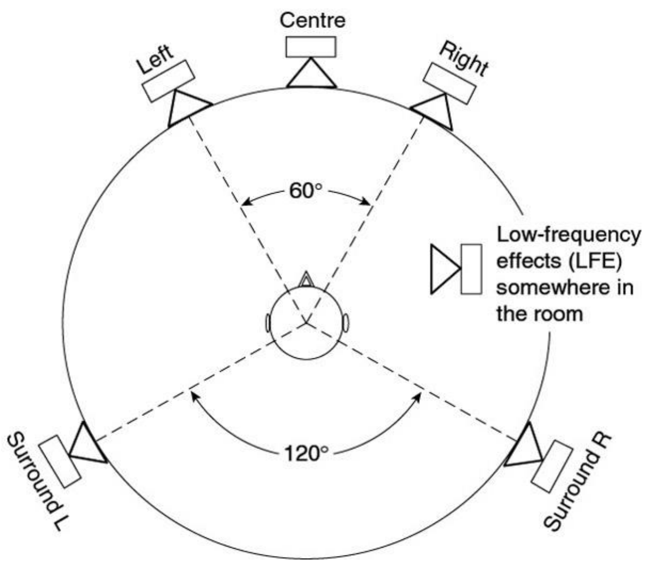

Figure 5. Typical Speaker Layout for 5.1 Surround (Howard & Angus 2017).

In many cases, the extra low-frequency channel is a duplicate of the existing low-frequency channel, and not a different low-frequency feed (Howard & Angus 2017). Having two low-frequency speakers allows one to place them in a way that deals with the inevitable modal issues that happen in real rooms at low frequencies (Howard & Angus 2017). The necessary signals for these extra speakers may e.g. be derived from an existing 5.1 system via the technique of matrixing, or they can be provided by separate dedicated channels (Howard & Angus 2017).

Spatial sound: Spatial and so-called 3D audio reproduction is an essential aspect of the enjoyment of sound, whether it's on a personal player via headphones at home, or in the cinema (Howard & Angus 2017). These reproduction systems utilize acoustics and psychoacoustic for mimicking the real sound sources, like musical instruments and singers, and for presenting the illusion of those specific sound directions (Howard & Angus 2017).

With the help of these "phantom images" the listener is tried to provide with an illusion of being in a space (Howard & Angus 2017). Ambisonics is a three-dimensional spatial sound reproduction system for simulating the sound field in a specific point in a room (Howard & Angus 2017).

5.2.4 Subwoofing

In her book about vibrations' history, Trower (2012) describes how sound is composed of repeated physical sensations; vibrations make up the sound. She also points out how especially bass vibrations (LFV) are an essential element in most forms of dance music, and how **subwoofers have become standard part of sound systems both at home and in public places**. According to Trower (2012) music is *"no less palpable than audible"* and may even be as painful as it is intensively pleasurable. Trower (2012) describes how in dance music, there occurs an "extra-auditory experience" that relates to the perception of the bass: **instead of just heard by ears it is experienced "*through the whole body*".**

Sub-woofers have been designed to transmit sound through the air and to vibrate floors and furniture in order **to add effect on our bodies as a tangible** and also audible phenomenon (Trower 2012). At some dance clubs they have created 'bodysonic dance-floors' where the bass speakers are targeted on the floor to vibrate the dancers also through their feet along the rest of their bodies (Trower 2012).

Speaker technologies are developing into multisensory purposes. For example, 'Butt-Kicker' sub-woofer enables 'Feel Bass Without Volume' when their low frequency transducers 'shake' the couch in synchronization with the audible material from a movie, music, or game (Trower 2012). According to Trower (2012), this opportunity to oscillate the human body results in way that a sound is experienced as more intense, louder, or quieter, which means that **it is rather felt than heard**.

The vibrating nature of sound can be experienced as palpable and audible but also visible (Trower 2012). We can feel, hear, and see the subwoofer vibrating and see its effect on other bodies and things: a glass that bounces on top of a speaker is good example of the visual occurrence. The cultural prominence of vibrating speakers seems real in the multiple ways in which they are adapted for musical, commercial, and artistic purposes or other forms of entertainment (Trower 2012).

Auditory technologies (phonographs, subwoofers) have brought the hundredths of a second into consciousness, like photography does to moving image, and made it possible to detect vibrations of sound, and to see and feel them as never before (Trower 2012).

Trower (2012) indicates, how all technologies that explore, exploit, direct and harness the potential of vibration, and seeks to manage its movement between pleasure and pain, may be seen as antecedents of the subwoofer.

In their experiment, Lustig and Tan (2020) applied audio filters on basslines with electronic dance music (EDM) and studied how timbre effected on liking ratings and groove. Their study suggest that **people find basslines preserving and low-frequency energy providing music groovier and more likeable**.

Van Dyck et al. (2013) conducted study with motion-capture in club-like environment where they played newly composed EDM songs. They found out that participants moved their bodies more when the bass drum was louder, which means that bass drum's role in modern dance music is meaningful: it has a positive impact on dancer movement. The louder the bass, the more people dance. The louder the bass, the stronger are also the low-frequency vibrations and the tactile perception of the sound.

5.2.5 Sonic accessibility

Renel highlights (2019) the importance of sonic accessibility in cultural institutions such as museums. He points how sound has a pivotal role when determining the inclusivity of a space, thus it is essential to consider the diverse needs of visitors when designing, measuring, and maintaining the acoustics of these institutions.

It is especially important to take into consideration the needs of d/Deaf and disabled visitors, who may face sonic barriers that prevent them from fully experiencing cultural institutions; issues may occur with navigation and orientation, as well as with overstimulation in noisy or reflective environments (Renel 2019). To address these challenges, Renel (2019) suggests museums and other cultural institutions to take steps such as providing assistive listening systems, embedding audio descriptions, and offering information and wayfinding via multimodal channels, including audible, tactile, and visual cues.

From this point of view, providing individual augmenting methods related to audible material would be one way for making a sonic space more accessible. For example, in the context of museums, instead of creating one loud, and for some maybe chaotic, soundscape, people could wear individual bone-conducting speakers, which would allow them to be collectively presence in the space while still being able to thoroughly and bodily (and in tactile way) to experience the soundscape.

Designing acoustic environments that balance the need for clear communication with a space's physical dimensions and properties can help to create a more inclusive environment for all visitors. As Renel (2019) points, the need for sonic accessibility in cultural institutions is an important consideration for ensuring social equity and inclusivity for all visitors.

5.3 Vibrotactile and Haptic Experience

HaXD refers to Haptic Experience Design, which involves creating a haptically pleasurable experience for users. Schneider et al. (2017) defines haptic experience design (HaXD) as following:

> *"The design (planning, development, and evaluation) of user experiences deliberately connecting interactive technology to one or more perceived senses of touch, possibly as part of a multisensory experience."*

Jansson-Boyd (2011) studied, how consumers experience haptically pleasant products. They found out that haptically pleasant touch is triggering a response that is emotional, and it might be the factor that is in control when evaluating that particular product. When consumers are feeling emotionally connected with a product, they also feel close connection with them, which raises the probability to purchase and to do the purchase again (Jansson-Boyd, 2011). Jansson-Boyd (2011) also pointed how in majority of consumer scenarios visual sense appears to be sense that guides the consumer at least in the beginning. Hence products should be congruent in their visual and haptic appearing; *"products should feel the way they look"* (Jansson-Boyd 2011).

Therefore, providing a product that is haptically pleasant, may trigger an emotional kind of response and make the user feel more connected to the product. When a product provides a pleasant haptic experience, such as a smooth and soft texture, it can bring out positive emotions such as happiness, comfort, and pleasure (Jansson-Boyd, 2011). This positive emotional response can create a lasting impression in the user's mind, which can increase their likelihood of purchasing the product again and recommending it to others (Jansson-Boyd, 2011). Therefore, including HaXD principles into also experience design can be an efficient method for creating a strong emotional connection with users and for ensuring they recommend the 'experience' (e.g. art exhibition or specific installation) to others.

5.3.1 Embodied experience

Recently, the market strategy has changed and instead of selling products the focus is now on selling experiences[3] to the consumers: the latest studies about consumer experiences highlights the significance of embodiment (Joy & Sherry 2003). Because the nature of our body and bodily interactions are defining the conceptual systems and the ability for critical reflection, success is dependent of the aesthetic experience and its memorability (Joy & Sherry 2003).

Joy & Sherry (2003) explored what connections movement, embodiment, and multisensory experience have, because they are helping in defining the factors of valuation related to a museum. They emphasize the value that *somatic experience* [4] has in aesthetic appreciation and highlights the coexistence between perception and imagination and how they are fully embodied.

Joy & Sherry (2003) suggests that the process of embodiment can be comprehended in these levels of awareness: conscious and cognitive unconscious. The conscious level enables person to be aware their body while thinking and being active, whereas the cognitive unconscious level involves all the activity that remains unrecognized, like the neural processing related to transmitting messages and learning, which enables thinking and being active.

Joy & Sherry (2003) critiques that research should study the somatic nature of consumption experience: the ways how consumers interact with the material and immaterial stuff on the marketplace should be grasped holistically.

5.3.2 Aesthetic touch

In recent years, the interest towards touch and tactile experiences has increased in various fields, including sensory studies, psychology, and art practice. This interest is partly a response to the longstanding dominance of vision and visuality in academic discourse, which has often resulted in the neglect or marginalization of other senses, particularly touch (Lauwrens (2019).

The study of touch has important implications for our understanding of human perception, cognition, and communication (Lauwrens (2019). It is also relevant to a range of practical fields, including product design, architecture, and healthcare (Lauwrens (2019). In art practice, the exploration of touch and tactility can offer new ways of engaging with

---

3 The American Heritage Dictionary defines experience as "the apprehension of an object, thought, or emotion through the senses or mind" and the verb. to experience as "to participate in personally; undergo". https://www.ahdictionary.com/

4 Somatic experience, "thinking bodily", how the logic of thinking about art is communicated by the body (Joy & Sherry 2003).

audiences and for creating sensory experiences that go beyond the purely visual (Lauwrens (2019).

Hayes & Rajko (2017) highlights the role of touch in modern aesthetics and the challenges of understanding and identifying standard aesthetic principles of touch. The context where touch occurs highly determines how it is experienced, as does the past experiences and sociocultural practices (Hayes & Rajko 2017).

Research into the role of touch in aesthetics has increased in recent years, and haptic technology has become more prevalent through personalized devices and wearables. However, there is still much to be explored in the field of touch, particularly in relation to how it interconnects with the sensitivities of the proprioceptive, kinaesthetic, and vestibular senses (Hayes & Rajko 2017).

Eric Gunther and Sile O'Modhrain suggested the concept of *tactile composition* or *aesthetic composition* for the sense of touch: the tactile sensation itself could be aesthetic goal (Gunther & O'Modhrain 2003). Gunther & O'Modhrain (2003) studied how the tactile stimuli could be an aesthetic artifact and the skin an analogous receptor like the ear is a receptor for music.

Related experiments in theme are also Kaffe Matthews' *Sonic Bed* and STiMULiNE by Lynn Pook & Julien Clauss, which both mediate the sonic wave via different types of technical applications, and intent conveying the sound into the body (Satoshi 2014). In STiMULiNE the audience wore earplugs for receiving the sound only via tactile transducers that were contacted to the body and via bone conduction. In *Shake-ousmonium* Otso Lähdeoja experimented how bass frequencies were haptically perceived: they were enabled by driving the audiotactile vibration into the seats of the audience by structure-born sounds (Lähdeoja 2016). Hayes (& Rajko 2017) experimented enhancement of the physical experience with electronically produced sounds by applying haptic feedback directly to the skin of the performer.

Hayes & Rajko (2017) suggest that an interdisciplinary approach can lead to the development of an aesthetics of touch, which would take into account the rich and varied range of tactile experiences that can be evoked in artistic and everyday contexts. They criticize the fact that much of the research on touch has focused on relatively homogenous sensations, like *experiencing the reinforced bass frequencies in music*.

Instead, Hayes and Rajko (2017) recommends utilizing somatically-informed performers like dancers or musicians; they could offer valuable viewpoints with their extremely tuned sense of the body for drawing attention on the variety of felt experiences that could be brought along to the show. These practices involve a deep awareness and sensitivity to bodily sensations, which may be utilized for creating and arousing the diverse variation of tactile experiences (Hayes and Rajko 2017).

The role of touch in contemporary aesthetics is an important area of research, and it is necessary to consider the context and past experiences when exploring aesthetic principles related to touch (Hayes & Rajko 2017). Hayes & Rajko (2017) points that as an aesthetic experience, it is troublesome to consider touch, since it is complicated as a sensory modality, and because of the complex sociocultural perceptions of touch.

Due to touch being still dominantly excluded from galleries and museums, and for what commonly is counted as aesthetic experience, it has resulted in a way that there does not exist as language that could adequately describe the complex experiences related to touch (Lauwrens 2019). However, touch is capable to providing such information about the world that may be inaccessible for vision (Lauwrens (2019). This can have important implications for aesthetic experiences. While sight is often considered to dominant sense for aesthetic experience, also touch can have a remarkable role in enriching the experiencing of the world: ***"aesthetic experience may be as much tactile as visual"*** (Lauwrens 2019).

Lauwrens (2019) highlights the need for greater awareness of the needs and interest of blind people in aesthetic viewpoint; they rely heavily on touch to navigate and understand the world around them. Blind individuals often have highly developed tactile senses and can experience aesthetic pleasure through the tactile qualities of objects and materials (Lauwrens 2019).

Nonetheless, Lauwrens (2019) also emphasizes that touch can enrich aesthetic experiences for all individuals, regardless of visual ability. By focusing more attention on the tactile qualities of objects and materials, and by designing environments and experiences that engage the sense of touch, it is possible to create more diverse and dynamic aesthetic experiences for everyone.

6 Multisensory Culture Experiences: Museum as a sensory place

The interest for understanding the haptic encounters is also increasing in the art context (Lauwrens 2019). Wang (2020) describes the museum experience as a journey of multiple layers, consisting of levels that are proprioceptive, sensory, aesthetic, intellectual, and social. According to Wang (2020), museums are not just archives of passed times cultural relic for future, they are diverse centers where people come to learn, gather, wander, reflect, relax, sensory stimulate, create new social ties, create lasting memories, reminisce, and they are also places where one can heal and contemplate (Wang 2020).

In the 1600-1700 centuries, it was common that museum visitors were touching, shaking, smelling, and tasting the displayed objects and paintings (Lauwrens 2019). To profoundly understand and gain the aesthetic experience of the object, it was deemed necessary to handle them (Lauwrens 2019). However, in 1800s touch got evicted from art galleries and museums because of the upper class thought the working class would damage the artworks and were incompetent to aesthetically experience art (Lauwrens 2019).

Nonetheless, slowly the senses have started returning to art galleries and museums and gained increasing interest among experiential visitors (Lauwrens 2019). The multisensorial body was allowed back to museums mainly due to programs that were designed for visually impaired or blind visitors (Lauwrens 2019).

Lauwrens (2019) says that making visitors to tactilely engage with the art, it enriches their understanding of the artwork's possible meanings. The deeper meanings are produced when the visual and tactile experiences are exchanged (Lauwrens 2019). The same conclusion was drawn also by Vi et al. (2017) with their artwork experiments at the Tate Sensorium Exhibition in 2015 by utilizing haptic and tactile devices. They enhanced the emotional experiencing and meaning of abstract paintings with technology of mid-air haptics. Their research revealed how experiencing art can be done more meaningful and the viewer's imagination can be awakened with sensory augmentation (Vi et al. 2017).

6.1 Utilization of music, sound, and soundscapes

Many art installations and museum exhibitions utilize sounds, soundscapes, and music alongside visual material. A soundscape is dependent on 1) how the environment influences on the senses (particularly hearing), and on 2) the meaning defining process for the sensations from the influences (perception), and on 3) the cognitive-emotional reactions to the perceptions (van den Bosch et al. 2018). Hence, the soundscape is depending on cues from the acoustical environment, and produces psychological replies like feelings, affective states, and cognition (van den Bosch et al. 2018). There is a close connection between the auditory nervous system and the arousal and emotion related parts of the brains (van den Bosch et al. 2018).

Mayor Poupis et al. (2021) studied the usage of intentional non-verbal sounds with mobile apps and found out that those sounds caused higher product evaluations and the probability for recommending the app to a friend. These sounds also increased purchase intentions, meaning willingness-to-pay. Mayor Poupis et al. (2021) indicates that sounds are non-verbal and non-musical, and does not have special meaning or emotional connotations, are able to create a sense of connection and therefore may fulfill the need for belonging. That happens by awaking the feeling of being socially presence (Mayor Poupis et al. 2021).

Especially game developers have recently started creating an "immersive experience" by using audio (Frometa 2018) and the followed interest on sound design in gaming has also produced the academic research to focus on how sounds influence on the experience and evaluations of video games (Mayor Poupis et al. 2021). For example, Grimshaw (2012) and Fu (2015) indicate how players experience and immerse in games can be enhanced with sounds.

Mayor Poupis et al. (2021) points out how sound has been started to think of as a product attribute just recently. For long, academia and industry has treated sound as an inessential component in games, secondary factor if compared to visual material and the game graphics (Mayor Poupis et al. 2021). However, according to Mayor Poupis et al. (2021), the in-app experience of users can be highly influenced with utilization of sounds.

This most likely is the case with art and museum installations too – soundscapes and the perception of sound may not be understood as a channel that effects on the experience, immersion, and evaluation of the installation. The more enjoyable an experience is, the more one might recommend it to others.

On the other hand, van den Bosch et al. (2018) argues how the existing habitats are not supporting the evolutionary auditory warning systems, but hampers creating the audible safety. This derives in moods and emotions more negative and aroused, which in the end, results in stress (van den Bosch et al. 2018). Therefore, van den Bosch et al. (2018) suggests, that in order to provide human optimized environments, the soundscapes should be more natural, or if that is not possible, then less threatening and less improved by their qualities.

6.2 Modern museums and Art Exhibitions

The question of what the future of art exhibitions, museums, theatres, music concerts, and all culture-related events is highly timely. Lenni-Taattola (2020) examined the future of theatres and suggest that the future is going to be hybrid – meaning that utilization and integration of digitalization and augmented reality (AR) is only going to increase. Lenni-Taattola (2020) highlights how digital theatre and "traditional" theatre should not be thought of as excluding each other's, but on the contrary – they can walk side by side, complementing one another's strengths and even substituting each other.

This idea can be taken also in other culture fields, for example in the form of augmenting what already exists with new sensory experiences and with new forms of experience ensembles.

Wang (2020) points out how museums should focus more on creating a connection with the visitors, and to the **interaction that occurs between experience and senses**. For the viewpoint of what is future of museums, **museums should be visually, auditorily, olfactorily, and emotionally active (**Wang 2020). Museums are trying to reach their communities via the collections by providing conversations that are meaningful and relevant, and by enabling the objects in forms that are accessible and meaningful for a broad and diverse user base (Wang 2020).

Tate Sensorium, an interdisciplinary collaboration, made a multisensory exhibition to the London's Tate Britain Art Gallery. They augmented an art peace with mid-air haptics to be a multisensory experience, and their case study was the first describing how to design work of arts by taking all the different senses, especially touch, into account [5] (Vi et al. 2017). Their production was the first who used mid-air haptics in museum context for improving the painting experience by combining it with sound (Vi et al. 2017). Their study revealed how the compound of sound and mid-air haptics was experiences as immersive and providing an experience of *touching without touch* (Vi et al. 2017). The results indicate that by utilizing mid-air haptics, it is possible to add emotional engagement and stimulation to the art [6].

Frid et al. (2019) created The Sound Forest, a Digital Musical Instrument (DMI), which utilized haptic vibrations. It enabled the visitors to interact with the installation and resulted in sonic, visual, and haptic feedback. They found out that since multimodal feedback stimulates several senses at once, if designed properly, multimodal feedback is able to generate sensorial experiences that could go beyond of what would be possible with unimodal stimulus.

Accessibility was one of the key elements in their design, and they wanted to provide easy access for people with impairments and ensure the that the experience itself is rich for them too. The findings from Frid et al. Sound Forest study (2019) suggest that relating to musical experiencing, using a multisensory platform that utilizes whole-body vibrations, could be used for providing similar associations among people with diverse ages

5 "Art is inspired by, made, and exists in, refers or relates to a multisensory world." Tate Sensorium project's findings, Tony Guillan, (Vi et al. 2017).

6 "What does it make me feel, and what does that make me think?" Tate Sensorium project's findings, Tony Guillan (Vi et al. 2017).

and abilities. Their findings also indicate positive reactions towards the haptic feedback while in context.

Though the tactile sound and vibrations were experienced as very positively in their experiment, they had not designed the haptic experience consciously. By also studying and designing the tactile aspects of sound, they might have created even more meaningful sensory experiences.

However, Frid & Lindetorp (2020) made a follow-up study and examined how to aid the composers by introducing them how whole-body vibrations may be perceived. They found out, that due to the haptics training, the composers improved their haptic composition task, and with training the awareness of the diverse possibilities of haptics with multisensory installations can be enhanced. They also pointed how the sound stimulus resulted in relatively diversely perceived sensations, and therefore it should be more studied how people percepts whole-body vibrations in artistic music.

The Finnish National Opera and Ballet (FNOB) created a modern opera, Laila, which was part of the Opera Beyond- project, that aimed to develop open-minded new ways of creating opera and ballet by combining different art forms and technologies (Honkanen 2020). In Laila they had a 7,5 meter dome with modern presentation technique (see figure 6), which inside they presented an AI guided audiovisual experience for 6 persons at a time. There were 40 speakers placed in the dome, and one subwoofer, and the participants also got a personal wireless speaker placed on their chest (Honkanen 2020). The experience was immersive, in a sense that people were literally placed inside the show (Honkanen 2020). It was also interactive, so that people could affect on how the show proceeded: how people moved affected on the behavior of sound and image (Honkanen 2020). The makers indicated it was a challenge to think what sense takes control of the human at what point (Honkanen 2020).

Laila won the international Fedora Digital price, which encourages to artistic innovation in opera and ballet especially with the help of digitalization (Lehmusvesi 2020). The price also inspires to find new interaction methods with the audience utilizing digital tools (Lehmusvesi 2020).

Figure 6. People were experiencing the multisensorial Laila opera literally inside the show (Lehmusvesi 2020).

This encourages further utilization and research on the use of tactile sound in similar projects. In Laila they had placed one subwoofer in the dome, and the speaker that visitors wore on their chest seemed not been utilized in bone-conduction way but as in common audible manner. Though this work of art was multisensorial and utilized essentially sound, the haptic nature of sound was not harnessed for utility. By exploiting the tactile possibilities with the soundscape, they might have gained even more immersive, richer, and modern sensory experience for the visitors.

6.3 Added vibrations: Reinforced experiences

Merchel & Altinsoy (2014) studied how audio-induced vibrations affect to the quality perception with a live music experience. They highlight how there occurs a naturally strong correlation between sound and vibrations in the casual situations. In their experiment they represented a concert situation: they played music DVDs for participants and added vibrations into seats in order to simulate a live music experience. Their studies revealed that in many cases people preferred the added vibrations; if the vibrations were turned off participants reported something was missing. Different complaints were reported too, e.g., some vibrations were too strong or too tingling, especially with the high frequencies. The outcome of their study is that with vibrations added to seats, the overall experience of music listening may be meaningfully improved. They point how by inserting vibrations, it is possible to affect on the quality perception of concert halls or common audio reproduction systems.

Merchel & Altinsoy (2014) also suggest that since participants generally preferred high levels of acceleration, similar that commonly occurs in a concert venue, it would be beneficial for real halls to amplify vibrations in the auditorium too. Merchel & Altinsoy

(2014) points, that for creating a proper multisensory concert experience, all the different sensory system inputs have to be combined in a way they form a one uniform perception, and thus there should not be any delays between different sensory inputs.

In another study, Merchel (2014) also found that at low-frequencies, vibrations influence on the perceived intensity of a sound, and creates the *'auditory-tactile loudness illusion'*. This means the perceived loudness is higher due to the vibrations (Merchel 2014). The phenomenon could be harnessed into use by providing the extra sensory level via deriving vibrations onto body, which would enable lowering the overall sound pressure levels and thus ease the sensing burden that ears have to go through.

Jung et al. (2019) made a multisensory exhibition in Gwacheon National Science Museum in South Korea. They created a device that produced multisensory stimuli (visual, auditory, and vibrotactile) for creating additional sensory experiences onto to the different artifacts in the museums.

7 Experiment

The objective of this test is to measure and compare the perceiving and valuation of the amplified low-frequencies of music samples in a multisensory context with different types of users without revealing to users that the test is related to vibrotactile bass. Additional objective is to gather data about the acceptance of vibrotactile bass with a questionnaire. The design of the vibrotactile stimuli experiment is described in table 2.

The goal of the experiment is to find out how participants perceive and value tactile low-frequencies in a multisensory culture context. In this thesis there is tested auditive and hypothetical tactile versions of the same music samples. Also, a just visual version (no audio) is included in the comparison. Following the example of Jung et al. (2019), the different sample versions are referred in the thesis as: *visual*, *auditory*, and *vibrotactile*.

	Control group	Experimental conditions	
		Auditory	**Vibrotactile**
Vibrotactile (using a bass speaker)	No vibrotactile stimulus	No vibrotactile stimulus	Vibrotactile stimulus
Auditory (using a speaker)	No auditory stimulus	Auditory stimulus	Auditory stimulus
Visual (using a TV)	Video of the art peace		

Table 2. The design of the vibrotactile stimuli with sound was created by following the example of Jung et al. (2019).

However, this thesis is not focusing on the objective measurements of the vibrotactile occurrence, but instead on the subjective evaluation of participants: how they experience the different sample versions, especially the vibrotactile one.

7.1 Participants

There were altogether 10 participants in the experiment; test was completed with 8 participants, 2 tests were excluded. The participants were selected using several parameters: age group, music consumption habits, musical background, diversity in hearing abilities, culture consumption habits, and presumptive variations in likingness of loud music. The aim was to create a heterogenous sample of people with diverse appreciation towards sound utilizing culture context. None of the participants had participated before into a psychophysical experiment. All participants participated voluntary and were unpaid, though they received a small gift afterwards.

The participants' ages ranged from 7 to 71 (mean age 38 years). The age distribution is visualized in table 3. 5 participants were male and 3 females. One of the test participants reported having minor hearing problems with left ear, but the stronger ear (right) was naturally towards and nearer to the test setup's audio sources.

The exclusion of the two tests was due to one participant's inability to focus and pursue with the tasks (the participant was 6 years old), and due to the other participant's hearing impairment (participant was 72 years old male with hearing aids in both ears; participant had major problems in perceiving the demonstrated tactile samples). Thus, these tests were aborted, and the collected data from those tests are not included in the analysis.

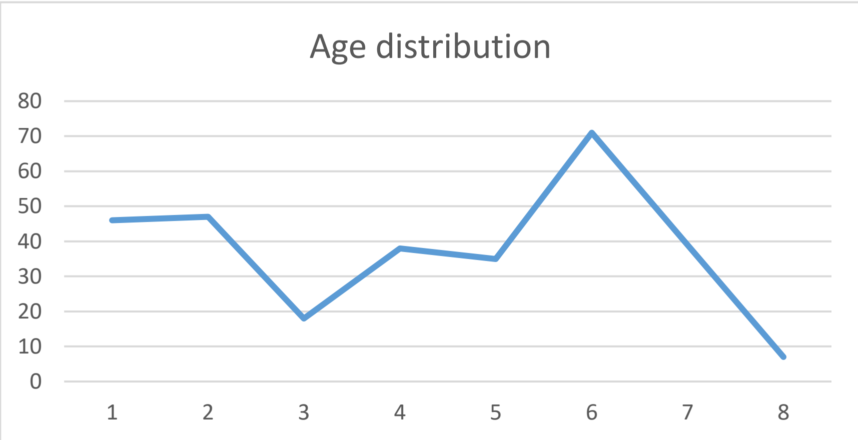

Table 3. Age distribution was wide, varying from 7 to 71 years.

2 participants had musical experience with instruments; 1 had played piano for 4 years, and 1 participant violin and trumpet for one year per instrument. 61 % of the participants goes to concerts or gigs about once per year, 13 % goes twice, 13 % five times and 13 % said there don't go to concerts or gigs at all. 60 % of participants visits museums and art exhibitions 1-3 times per year, 40 % said they visit them very rarely. 50 % of the participants goes to movies to movie theatre about 1 per year, 25 % goes 2-3 time per year, and 25 % 4-6 times per year.

75 % of the participants listens to music nowadays mainly at home with a simple home stereo system, 1 listen mainly with in-ear headphones while bicycling and 1 participant with a laptop at work. The sound loudness varied, but 63 % said they listen mainly with a normal volume, 13 % said listen mainly with a loud volume, and 25 % said they listen mainly with a quiet volume. 88 % of participants listens to music also while travelling in a car, and then the sound volume ranges from quiet to loud but was mainly loud

(see figure 7). 1 participant noted having a proper audio system in their car, including a subwoofer, and in previous life had also a proper audio stereo system at home.

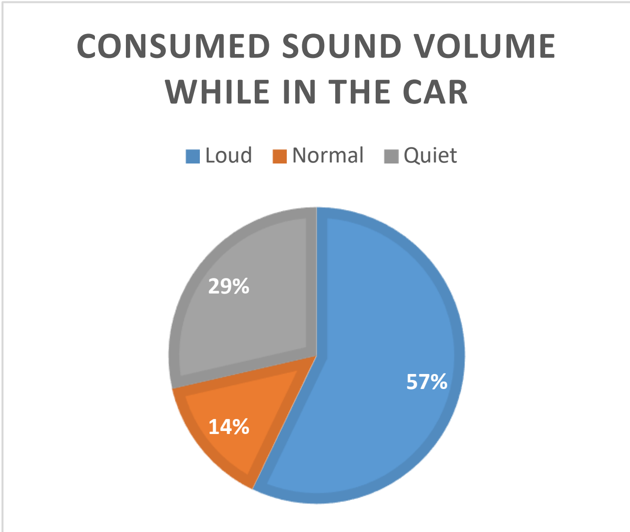

Figure 7: How loud participants listens to music while in a car.

7.2 Experimental setup

Due to the covid-19 pandemic, the experiment had to be planned as doable and feasible as possible, considering the existing healthy limitations and restrictions. Thus, the experiment was planned to be executed at writer's home setting, in which case the test could have been executed though public places, e.g., museums, would have been closed.

Nevertheless, the test environment and setup were built as laboratory-like as possible, meaning that all possible environment variables were eliminated. Sensing music can occur in almost any position, but in this test, the focus is on sitting position, and e.g., standing position is left out. Sitting position was chosen due to the visual source in the setup being so low in the room that seeing the visual content in a sitting position would have been more natural and ergonomic than in a standing position. Also, while sitting, it was possible to maximize the direct contact areas of participants' body for the vibrations: in addition to the sole of the feet on the floor, also the gluteal muscles were in contact with the chair.

Also, the acoustical factors were considered: the carpet was removed under participant's location for enabling direct contact with feet to the wooden floor and for minimizing the sound and vibration absorption (that was discussed in Chapter 5.2.1 Sound Absorption). Participants were also sitting on a wooden chair. These features were chosen for optimizing the vibration movement from subwoofer to participant, that is, making the acoustical parameters as good as possible and minimizing any possible irrelevant sound absorbers between the sound sources and participants.

The test setup consisted of a 48” TV (Samsung LED-TV (type UE48H6290)) on participants’ eye height, JBL Flip Essential speaker in front of the participant at the height of 45 cm from the floor level, a Genelec F TWO (B) Subwoofer on participants right side on the floor 50 cm away of them.

SPLnFFT Sound Meter v7.0 app was used for measuring the sound levels in decibels (dB(A)) next to participants’ right ear. Laptop with Spotify and Youtube were used for sending the audio and video materials into output devices (speakers and TV). Remote controller for subwoofer were used for applying the different test modes. Figure 8 shows an illustration of the experiment setup.

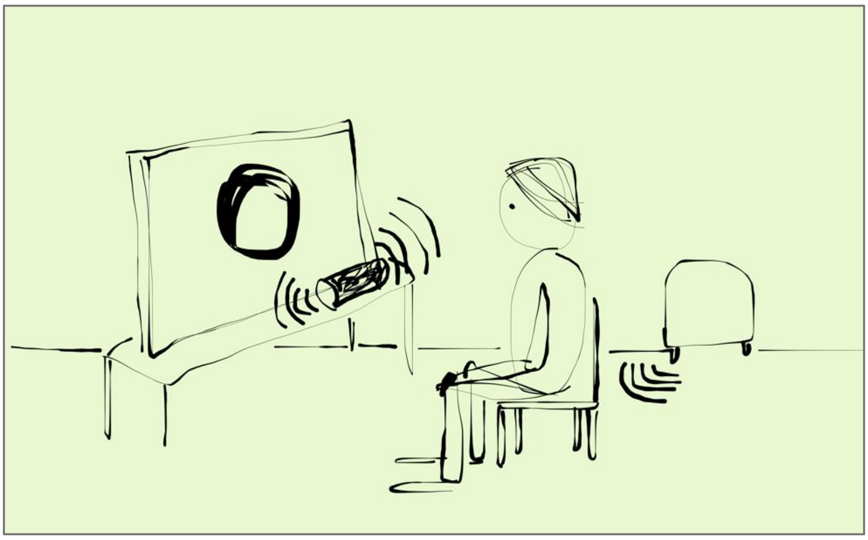

Figure 8. Rough illustration of the experiment situation. Participants were sitting on a wooden chair, their feet soles on the wooden floor. In front of the participants were TV showing the visual material. Also, the speaker outputting auditive material was in front of the participants. The subwoofer outputting the vibrotactile material was in participants’ right side on the floor.

7.2.1 Experiment’s sample materials

The experiment’s sample materials consisted of visual and auditory elements. Visual material was a video, and the auditory elements were 1 test tone and 3 different soundscapes (music songs).

The visual material used in the experiment was the international art collective teamLab's Enso in version Gold light. The artwork Enso represents the Zen practice of drawing a circle with a single brush stroke and it is represented in the form of Spatial Calligraphy (teamLab 2017).

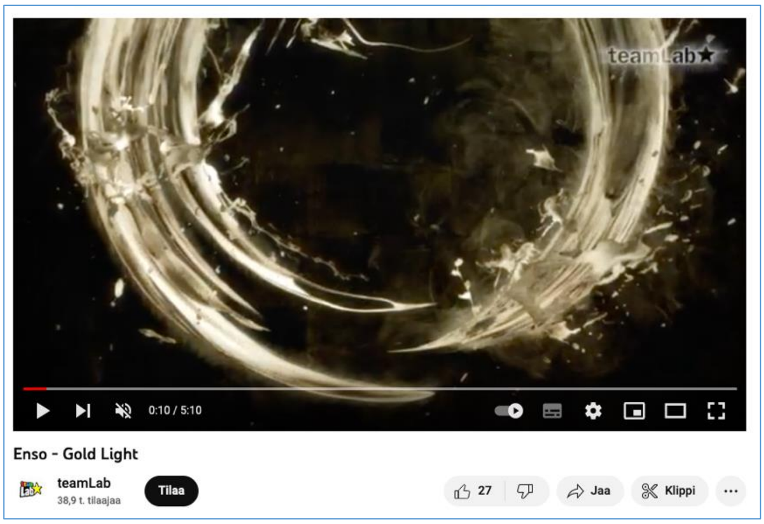

Figure 9. The visual material used in the experiment was teamLab collective's spatial calligraphy artwork Enso[7]. Figure 9 is a screenshot from the video (teamLab 2019).

The test tone was chosen to 60 Hz as it is perceivable both in auditory and tactile senses. The test tone was tested with 2 variations: (just) auditory, and (auditory with) vibrotactile. The sound samples utilized in the experiment were tested with 3 different conditions: **no audio**, (just) **auditory**, and (auditory with) **vibrotactile**. Visual stimulation was running in the background with all the different audio condition variations.

					Visual
		Auditory	Visual	Visual	Auditory
Sound samples	**Auditory**	**Vibrotactile**	**No audio**	**Auditory**	**Vibrotactile**
60 Hz test tone	x	x	-	-	-
Bass meditation	-	-	x	x	x
Greenland	-	-	x	x	x
Crush	-	-	x	x	x

Table 4. Table of the used sound samples and different condition variations they were tested with.

[7] *teamLab. (28.8.2019). Enso – Gold Light. [Youtube]. Viewed 15.10.2022* *https://www.youtube.com/watch?v=bgtzB-WreiM.*

The different sound samples were chosen based on their richness in the bass frequencies. Also, difference in the musical genres were taken into consideration; one sample was classical, and the two were modern electro ambient music but differing in their tone and beat.

The sound samples were:

- 60 Hz test tone by Sonic Electronix[8]
- Bass meditation by Kuuninjatar *Q*[9]
- Greenland by Emancipator[10]
- Crush by Metaform[11]

7.3 Procedure

Introduction & pre-interview: The test started with an introduction about the test and test procedure. Participants were informed to tell whether any unpleasant sensations occurred, and if they wanted to stop the whole test. After introduction followed a pre-interview where participants' background information was asked. Asked questions related to clarifying participants' sound listening habits and preferations, and possible hearing impairments.

Test tone: The testing started with a test tone, where a 60 Hz sound sample was evaluated first as an auditive sample (audio sample from speaker) and then as a tactile sample (audio sample from speaker + vibrotactile layer from subwoofer). In both variations the new sound was slowly increased from 0 dB to onwards. The evaluation was done with a 5 point Likert scale, where 1 was Strongly Disagree and 5 Strongly Agree.

---

8 Sonic Electronix, (1.1.2016). 60 Hz test tone. [Youtube]. Viewed 15.10.2022. https://www.youtube.com/watch?v=GqwFimG3X3w.

9 Kuuninjatar Q (26.2.2020). Bass meditation. [Youtube]. Viewed 15.10.2022. https://www.youtube.com/watch?v=mCcVb3W979o.

10 Emancipator. Greenland. [Spotify]. Viewed 15.10.2022. https://open.spotify.com/track/2SPTGg9SC5MT1FwNX4IYfx?si=bc445b08c6ac43dd.

[11] *Metaform. Crush. [Spotify]. Viewed 15.10.2022. https://open.spotify.com/track/2oQ2fiNCn5Ei8wdXOMFkny?si=eae4ceabbbf54541*

Actual test: After assessing the test tone, the actual test started. The visual material was evaluated with four different soundscapes where three were with auditive and vibrotactile versions.

Post-interview: After evaluating the different samples, participants were post-interviewed and specifying questions related to subwoofers and strong bass tones were asked.

8 Results

The results from the experiment are presented in the following chapters. In the tables 5, 6, 7, 13, 14, 15, 16, and 17 the participants are in the same order. This way the differences between individual participants can be observed from the tables.

8.1 Perceiving and experiencing the test tone

Participants perceived the 60 Hz test tone auditory sample from the speaker rather easily, averagely on 28,7 dB, and variations from 26,7 dB between 30,8 dB occurred. When adding the vibrotactile sample from subwoofer on the context, some participants had difficulties in distinguishing the slowly increasing sound layer. However, when accidentally testing an on-off comparison (subwoofer on-off with ~50 dB and the speaker still playing the test tone in the background) the distinguishment was easier for participants. Averagely participants perceived the added subwoofer for the 60 Hz test tone at 45,3 dB, with variations from 38,5 to 53 dB.

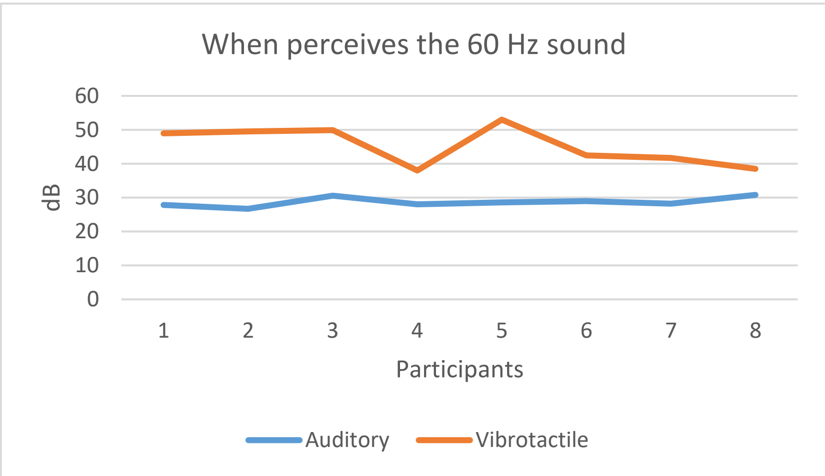

Table 5 shows at what volume participants perceived the slowly increasing test tone.

The auditory test sample was averagely experienced as loud but not yet intolerable loud at 48,2 dB. Participants noted the vibrotactile sample to be loud but not yet intolerable loud at 54,4 dB, varying from 46 dB to 59,7 dB. One participant would have accepted even higher amplitudes, but for safety reasons facilitator refused doing so.

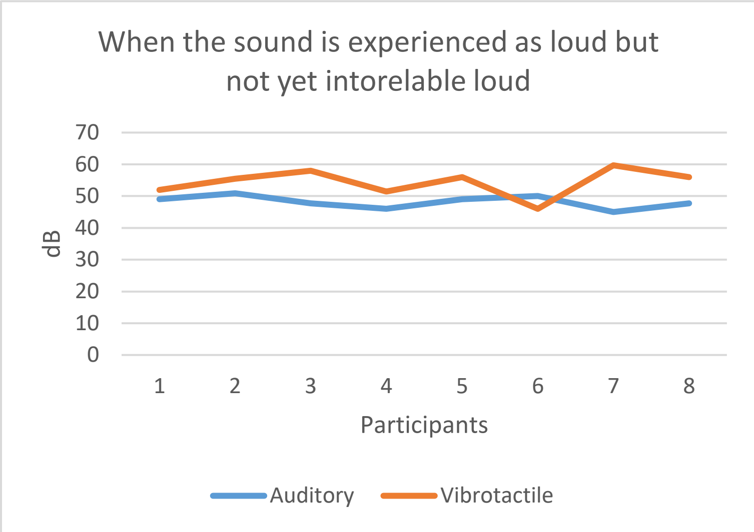

Table 6 shows how the subwoofer version of the test tone was accepted louder than the just speaker version.

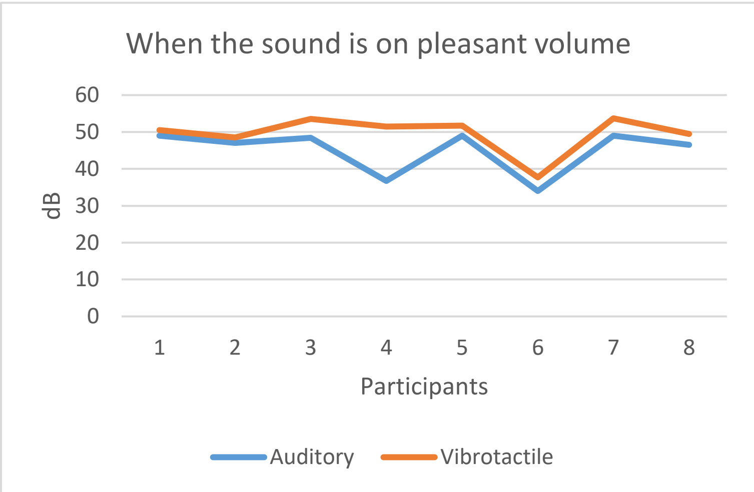

Table 7 also shows how the vibrotactile version of the test tone was wanted louder than the just auditive version.

One participant described the auditory sample as *"annoying in the long run",* one would have wanted to close their eyes for preventing the aching feeling it caused, one said "*it was a new kind of sound they haven't heard before*", one said it was "*basic humming*", and one described it "*similar to the buzzing that occurs when the radio channel goes out of space",* one noted it was "*a bit unpleasant humming*", and one said it was "*trembling in the ear*".

The vibrotactile version participants described as disturbing, calm, difficult to describe, background noise, “*bass has always been nice, but in the long run this of course will become boring*”, “*a bit pleasant than the previous one, but in a long run this is also annoying*”, “*a bit unpleasant rumbling, feels more than the previous sample, goes somehow deeper*”, one did not notice any difference to the previous [only auditory] sample. One participant described the vibrotactile sample being “*similar to previous one* [only auditive sample]*, but this as stronger*” and “*here's something more*”. One participant said they “*didn't notice the added subwoofed layer with slow increasement, but when it was on-off they noticed it felted also in the body*”.

On a scale of 1-5 (where 1 is the least and 5 is the highest value), participants graded the auditory sample to be 2,2 distressing, votes varying from 1 to 4. On a scale of 1-5 (where 1 is the least and 5 is the highest value), participants graded the vibrotactile sample to 2,2 by its distressing, values varying from 1 to 4.

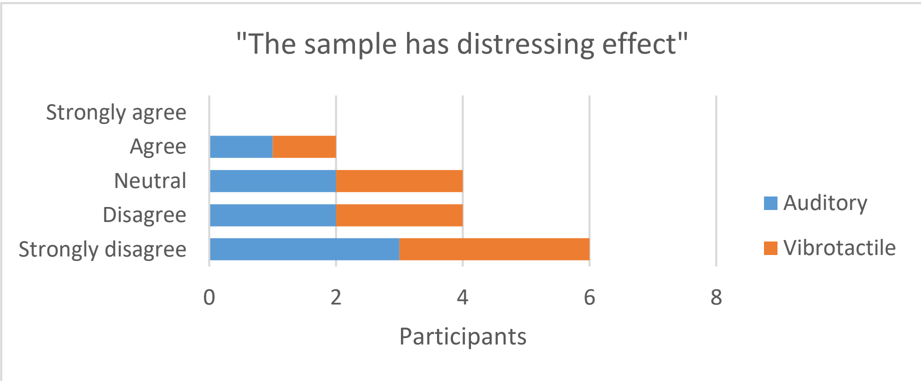

Table 8 indicates the 60 Hz sample had no meaningful difference in the distressing effect between auditory and vibrotactile sample versions.

When asked about the auditory sample's pleasantness, it got a grade of 2,5, votes varying from 2 to 4. The pleasant volume for vibrotactile sample was averagely experienced at 49,6 dB, measurements varying from 37,7 to 53,7 dB. When asked about the vibrotactile sample's pleasantness, participants graded it to 2,2, with variation from 1 to 3. One participant said about the vibrotactile sample: *“This is quite nice for a short period, but in the long run this will become less pleasant”*.

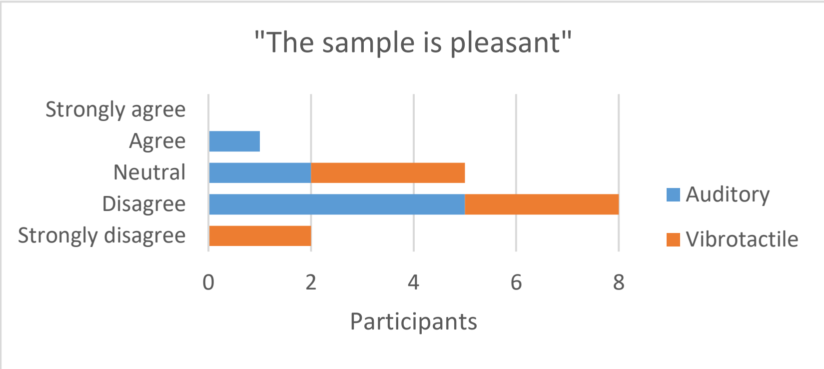

Table 9 shows how pleasant the auditive and vibrotactile samples were experienced.

88 % of the participants described the perceiving of the auditory sample as hearing, one noted it would cause a headache if the sound would go on for long. 88 % said they felt the auditory sample in their ears, one noted feeling it in the head and forehead, and one also noted feeling the auditory sample in their chest.

Also, the vibrotactile sample was experienced mainly as hearing: 88% mentioned sensing the sample in their ears, but **38% mentioned also perceiving the sample in their chest, 25% mentioned feeling it in their feet (**either in the sole of the feet or just feet**), and 1 in their body**.

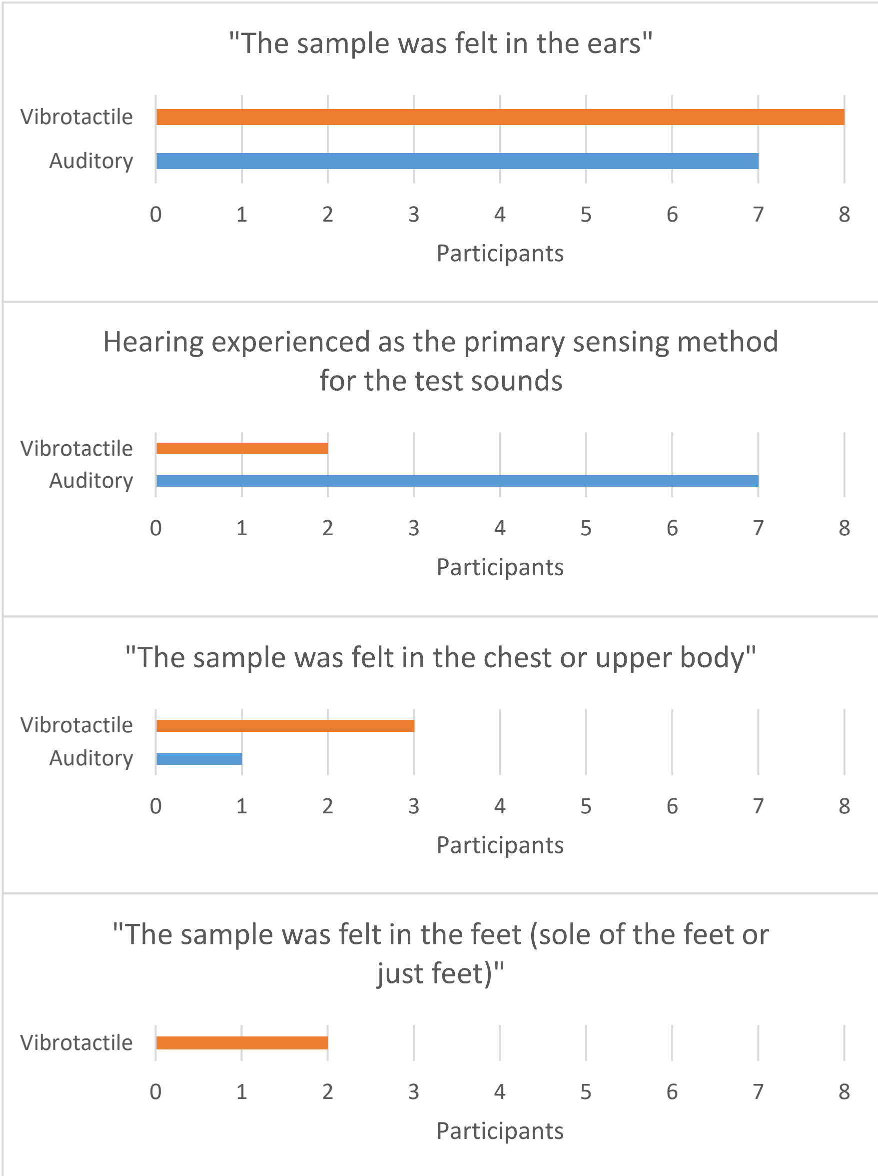

Table 10. The 60 Hz test tone was mainly perceived by hearing both in auditory and vibrotactile versions, but especially the vibrotactile version produced sensations also in e.g. chest and sole of the feet.

Overall, the test tone was experienced, both in auditory and vibrotactile versions, rather negatively and unpleasant; something that one would not want to be exposed to for long. **The vibrotactile sample was experienced as more thorough than the just auditory version: "*goes somehow deeper*".**

Participants had difficulties in describing and wording the vibrotactile sample, which is align with the findings of Lauwrens (2019) and Sonneveld & Schifferstein (2008). However, **several participants did mention that "*here's something more [than in the just auditory version]*".**

Description of the sounds					
Auditory			**Vibrotactile**		
Negative reactions	annoying in the long run	1	Negative reactions	disturbing	1
Negative reactions	would have wanted to close their eyes for preventing the aching feeling it caused	1	Negative reactions	pungent	1
Negative reactions	similar to the buzzing that occurs when the radio channel goes out of space	1	Negative reactions	annoying in the long run	2
Negative reactions	a bit unpleasant humming	1	Negative reactions	a bit unpleasant rumbling	1
Negative reactions	aching	1	Neutral reactions	doesn't notice much difference to the previous sample	3
Negative reactions	sound causes a headache if it would go on for long	1	Neutral reactions	difficult to describe, its like trembling but wihtout trembling	1
Neutral reactions	a new kind of sound they haven't heard before	1	Neutral reactions	background noise	1
Neutral reactions	basic humming	1	Positive reactions	feels more than the previous sample, goes somehow deeper",	1
Neutral reactions	trembling in the ear	1	Positive reactions	stronger than previous sample, this has something more	1
Positive reactions	fulfilling, strong	1	Positive reactions	bass has always been nice	1
			Positive reactions	a bit more pleasant than the previous one	1
			Positive reactions	calm	1

Table 11 shows how participants described the auditive and vibrotactile versions of the 60 Hz test tone. The vibrotactile version gained more positive descriptions than the just auditive sample.

8.2 Validation of test tone's vibrotactility

The 60 Hz test tone's vibrotactile sample was measured with a FAG Detector 3 for validating whether there truly occur vibrations. The measuring device is for measuring vibration in industrial machines. Values in mm/s are measured according to the ISO-10816 standard, which is for measuring the total vibration levels for rotating machines. The standard was integrated in the device, and due to the standard, the frequency range of the measurement was 10 – 1000 Hz.

Therefore, the standard and the frequency range were not originally meant for measuring vibrations that are relevant for humans. Nonetheless, the device and the setup were able to indicate that **there occurred differences in the vibration levels between auditory and vibrotactile samples**.

The vibrations were measured from the location where the participants sole of the feet were. The measurement is demonstrated in the figure 10. In the auditory sample, the test tone came from a speaker. In the vibrotactile sample, the sample came both from the speaker and from a subwoofer; the vibrotactile layer was added on top of the auditory sample.

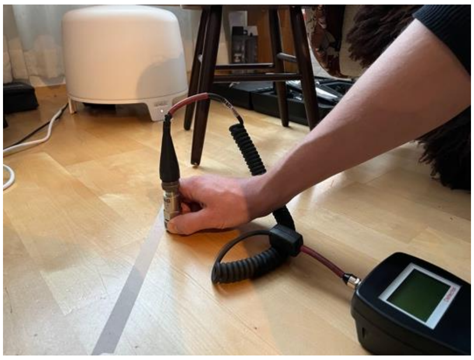

Figure 10. Measuring with a vibration meter from the floor the vibrations that subwoofer produced at a 60 Hz test tone.

Vibration measurements for 60 Hz test tone		
Auditory	0.017 mm/s	56,5 dB
Vibrotactile	0.027 mm/s	57,2 dB

Table 12. Measurements show there existed differences between the auditory and vibrotactile samples with the 60 Hz test tone.

As mentioned above, the ISO-10816 standard is used to evaluate the vibrations of rotating machines in different industries. Thus, the standard is not very feasible in evaluating vibrations sensed by humans, as it is more made to tell about the condition and structural sturdiness of the machines. However, as this measuring device was available, it was used for measuring, and that way verifying that the samples with the subwoofer truly produced more mechanical vibration than the samples without the subwoofer.

In the ISO-10816 standard these values are very small, but proportionally the difference is meaningful. Since the device measure vibrations from frequencies 10-1000 Hz, which are a great part of the tactile perception range (as was shown in the figure 3 'Auditory and tactile perceptions' frequency range' in chapter 4.2), it also **supports the interpretation that there occurred vibrotactile sensations**.

Based on this validation, it can be assumed that the other audio samples used in the experiment also produce vibrotactile sensations. Their musical content is rich in low frequencies, especially around the frequency 60 Hz and above. Due to the samples varying in their frequencies, and the vibration meter being able to meter only continuous and steady vibrations, the structure-born vibrations were not measured with the other soundscape samples.

8.3 Evaluation of the just visual sample

After the test tone, participants were asked to evaluate the just visual component (no audio) of the installation. Participants wondered what the video is presenting, and proposed topics like space, abstract visual arts, a 90's screensavers, temperature differences, and water vortex. Some wondered what it is, and some said, *"the video was beautiful"* and *"it was pleasant to look at"*. Image of the video can be seen in figure 9 in chapter 7.2.1 Experiment's Sample Materials.

When asked about how engaging the installation, participants voted on a scale of 1-5 (where 1 is the least value and 5 the highest value) the just visual version (no soundscape) to be averagely 3.0. When asked about how pleasant the installation was, participants voted on a scale of 1-5 the just visual version (no soundscape) to be averagely 3.75.

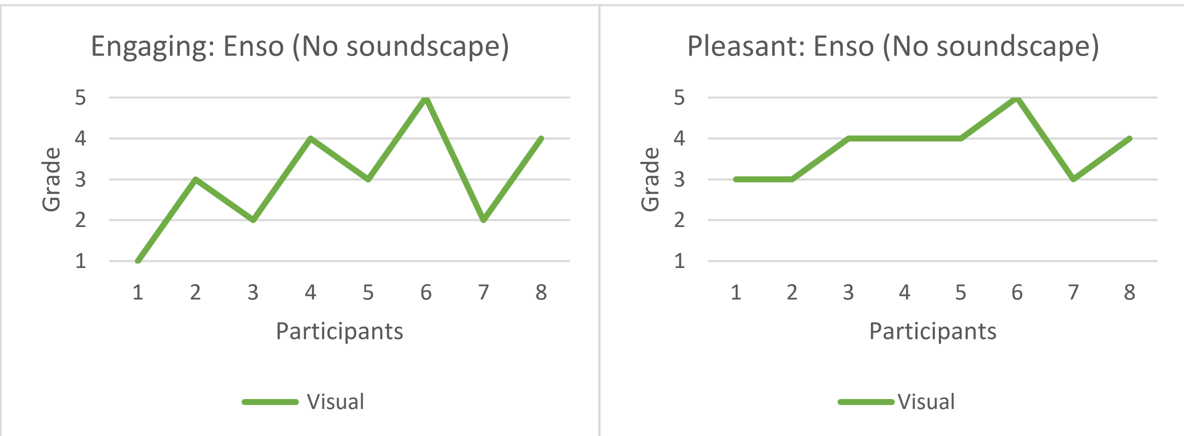

Table 13 representing how engaging and pleasant participants experienced the just visual part of the illustration (without any soundscape).

8.4 How engaging different soundscapes were

When asked about how engaging the installation was with different soundscapes, participants voted on a scale of 1-5 (where 1 is the least value and 5 the highest value) the Bass meditation auditory version 2.6; Bass meditation vibrotactile 3.1; Greenland auditory 3.0; Greenland vibrotactile 2.9; Crush auditory 2.5; and Crush vibrotactile 2.5.

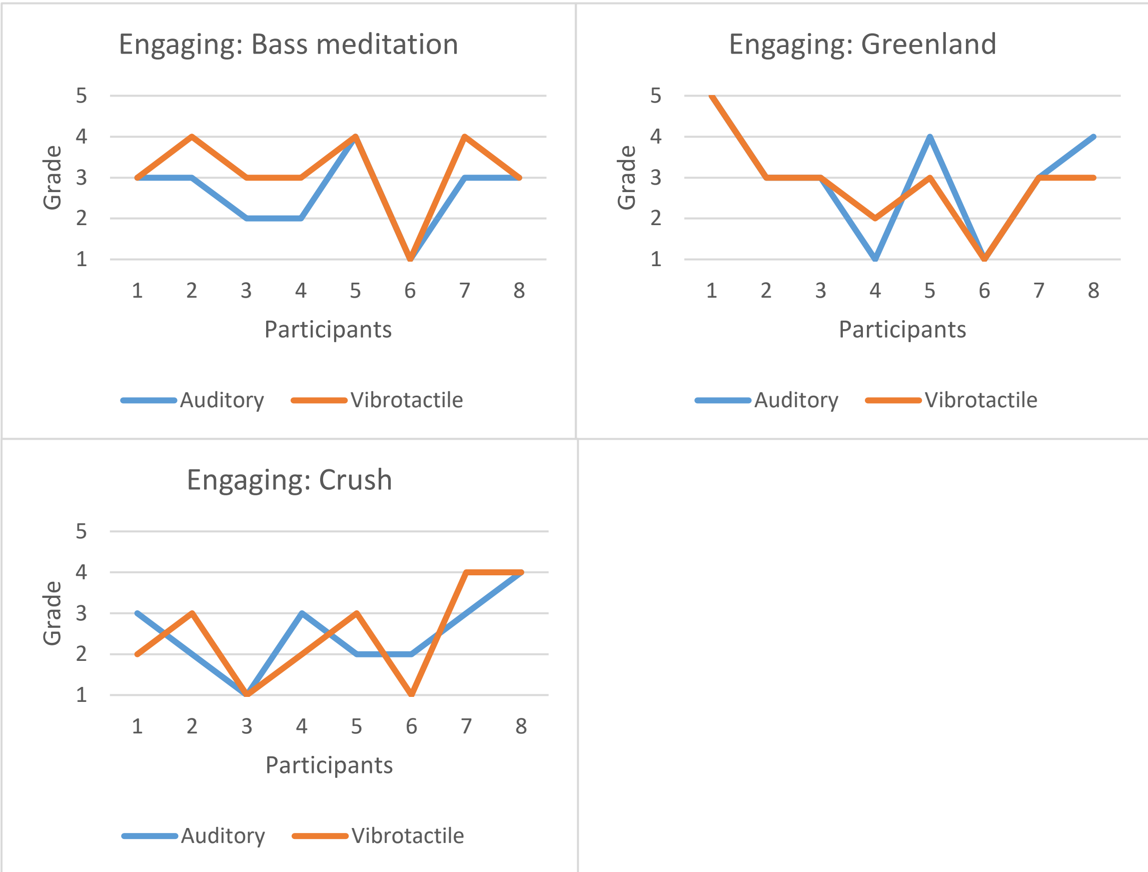

Table 14 shows how engaging participants found the different soundscapes with the visual component of the installation.

8.5 The pleasantness of different soundscapes

When asked about how pleasant the installation was with different soundscapes, participants voted on a scale of 1-5 (where 1 is the least value and 5 the highest value) the Bass meditation auditory to averagely 2.8; Bass meditation vibrotactile 3.0; Greenland auditory 3.0; Greenland vibrotactile 2.9; Crush auditory 2.9; and Crush vibrotactile 2.5.

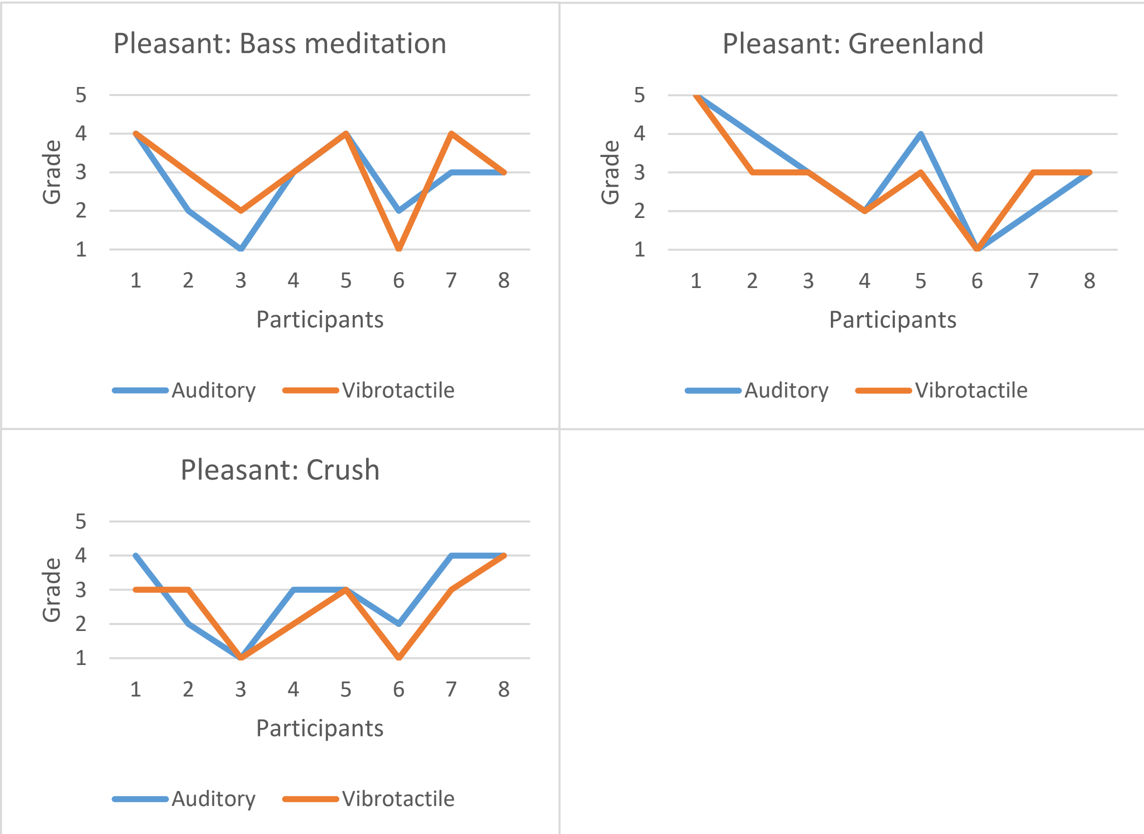

Table 15 shows how the pleasant the different soundscapes were experienced.

8.6 How the soundscapes fit with the installation

When asked about how compatible the installation was with different soundscapes, participants voted on a scale of 1-5 (where 1 is the least value and 5 the highest value) the Bass meditation auditive to be averagely 2.8; Bass meditation vibrotactile 3.1; Greenland auditory 2.3; Greenland vibrotactile 2.8; Crush auditory 2.1; and Crush vibrotactile 2.3. (The no audio version was not asked in this question.)

Notable is, that **all these soundscapes were averagely evaluated more compatible in vibrotactile version** with the visual component of the installation. This result is in align with the findings of Merchel (2014), where the perceived quality of a music experience found out to be improved by adding vibrations to seats.

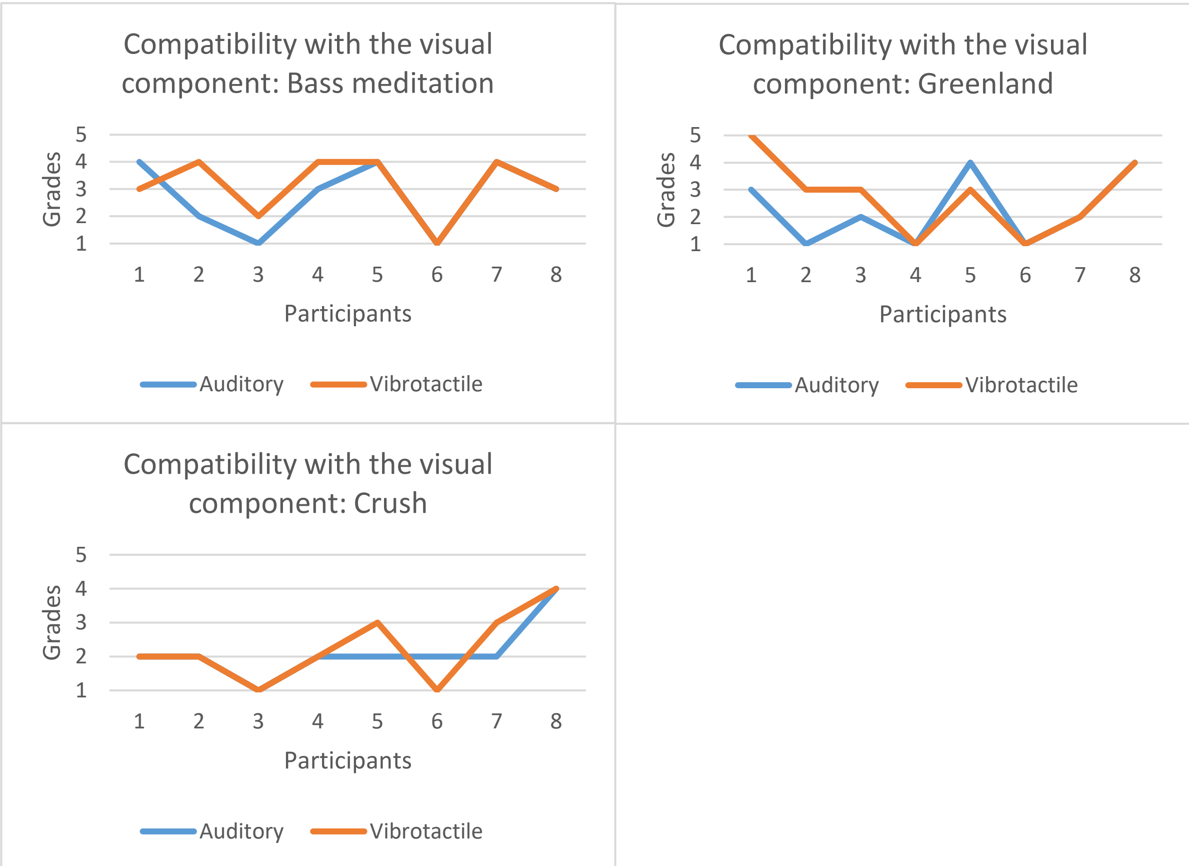

Table 16 shows that the vibrotactile sample versions was experienced as more compatible with the visual component of the installation, than the auditory soundscapes.

8.7 What soundscape the installation needs

When asked which of the different soundscapes the installation needs, participants voted on a scale of 1-5 (where 1 is the least value and 5 the highest value) the Bass meditation auditive to be averagely 2.8; Bass meditation vibrotactile 2.6; Greenland auditory 2.1; Greenland vibrotactile 2.8; Crush auditory 1.8; and Crush vibrotactile 1.9.

The just visual (no audio) version was not taken into consideration in this question. However, it would have been useful to take that alternative in the direct evaluation too. With the classical Bass mediation sample, the auditory version was preferred, but with the two electro pop samples the vibrotactile versions were preferred.

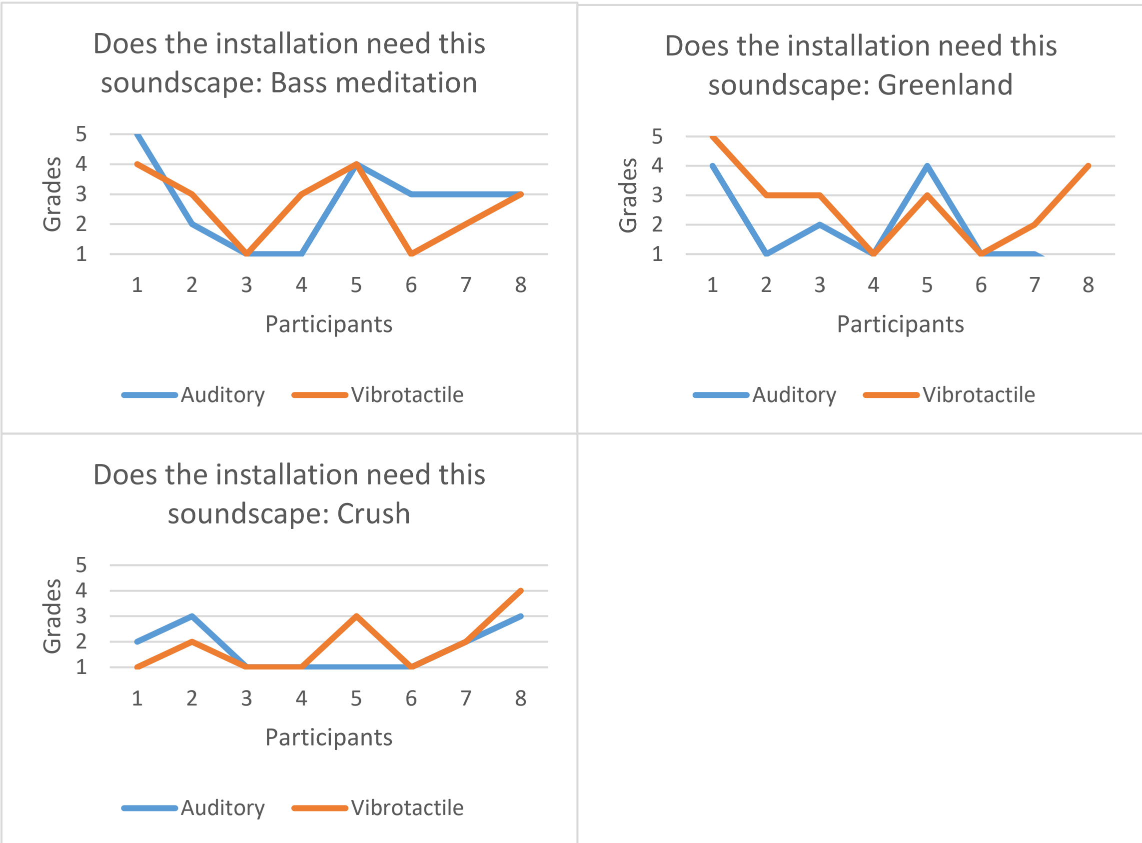

Table 17 shows that in Bass meditation, the auditory sample version was preferred, but with the other two soundscapes the vibrotactile samples gained better valuation.

8.8 How people commented about the different soundscapes

The Bass meditation: Three participants said the auditory version of Bass meditation was not compatible with the visual component, one pointed the sample was too loud, one said it was too fast when compared to the speed of the visual material, and some said *"beautiful, smoothing, pleasant", "maybe a bit ghost-like, cool",* and *"a bit different"*.

The vibrotactile version of Bass meditation was commented by two as strong, one noted it did not make the installation any better, one said it did make it better, one said *"the installation is now a bit darker",* and one says *"it is still too loud*", one said "*pleasant, strong*", and one said "*cool*". One said about the vibrotactile version "*This somehow feels more*", and one said: "*the bass gives a sense of power"*, whereas one said the loud sound is annoying. Two mentioned the vibrotactile sample feeling deeper.

One participant commented "*It was nicer to just look at it [the visual material] without any sounds,* ***because the sounds change the installation****. Some other kind of music or sound would have been better."*

The Greenland: The auditory version of Greenland was described as more cheerful, beautiful, and two said light, one said nice and ok. Three mentioned the auditory sample was not compatible with the visual installation. One said it was a bit more pleasant now than with Bass mediation, one said Greenland brought speed and happy feeling to the installation. One said it took away the mystic feeling from the installation, and one said it brought livelihood to the installation.

The vibrotactile version of Greenland was described by two as "*beautiful*", one said "*not so light anymore*", two said the vibrotactile was worse than auditory version, one said the vibrotactile brought fullness, two said the vibrotactile was better, one said "*the soundscapes had wrong tempos compared to the visual material's tempo*". One participant pointed also these samples being too loud. One said: "*that low sound made the installation more complete*", one said: "*it is now more atmospheric*", and one said it brough power and calmness.

The Crush: The auditory version of Crush gained several complaints and was not experienced very compatible with the visual part of the installation: "*The music does not illustrate what is seen on screen*". This finding is aligned with the findings of Jansson-Boyd (2011) who found out that in majority of consumer scenarios visual sense appears to be sense that guides the consumer at least in the beginning (discussed in chapter 5.3 Vibrotactile and Haptic Experience). Similarly, one participant also said: "*That image looks strong, and with the subwoofer it also* ***sounds*** *strong*".

Some experienced the vibrotactile version as better, but some said it was even worse than the auditory version of Crush.

8.9 Summary of results

Most engaging soundscape: The Bass mediation in vibrotactile version was graded as the most engaging soundscape. The second most engaging was Greenland's vibrotactile version.

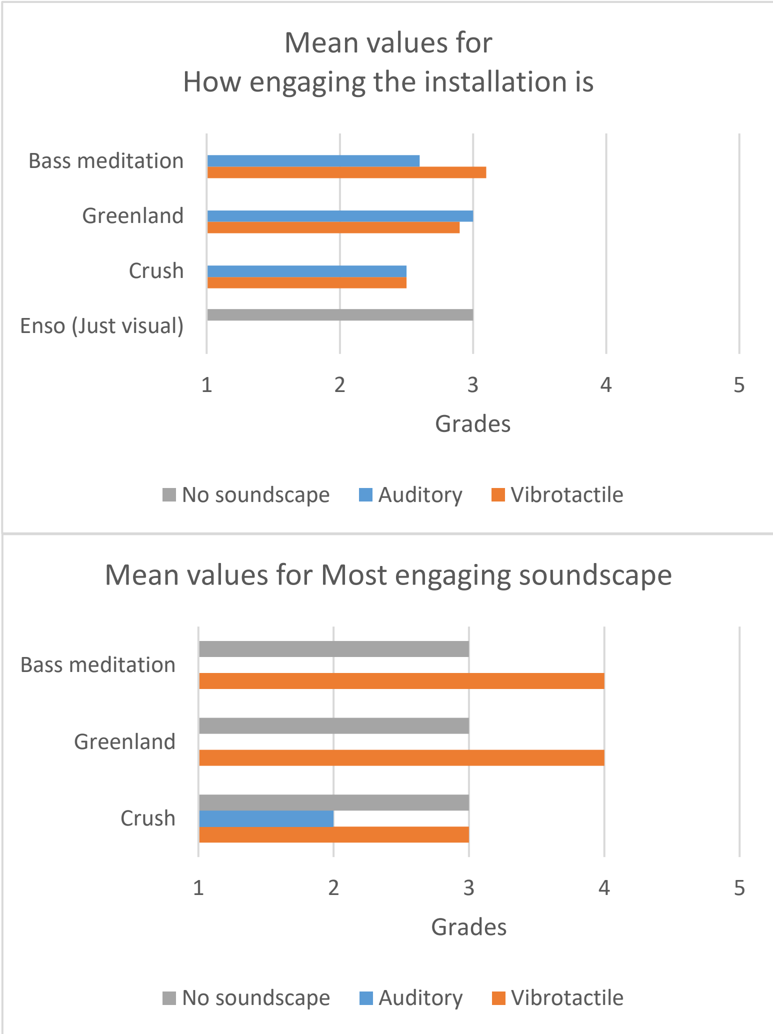

Table 18. The Bass meditation's vibrotactile version was valued as the most engaging soundscape.

Most pleasant soundscape: Participants graded as the most pleasant soundscape the Greenland's vibrotactile version. The second most pleasant was the no audio soundscape.

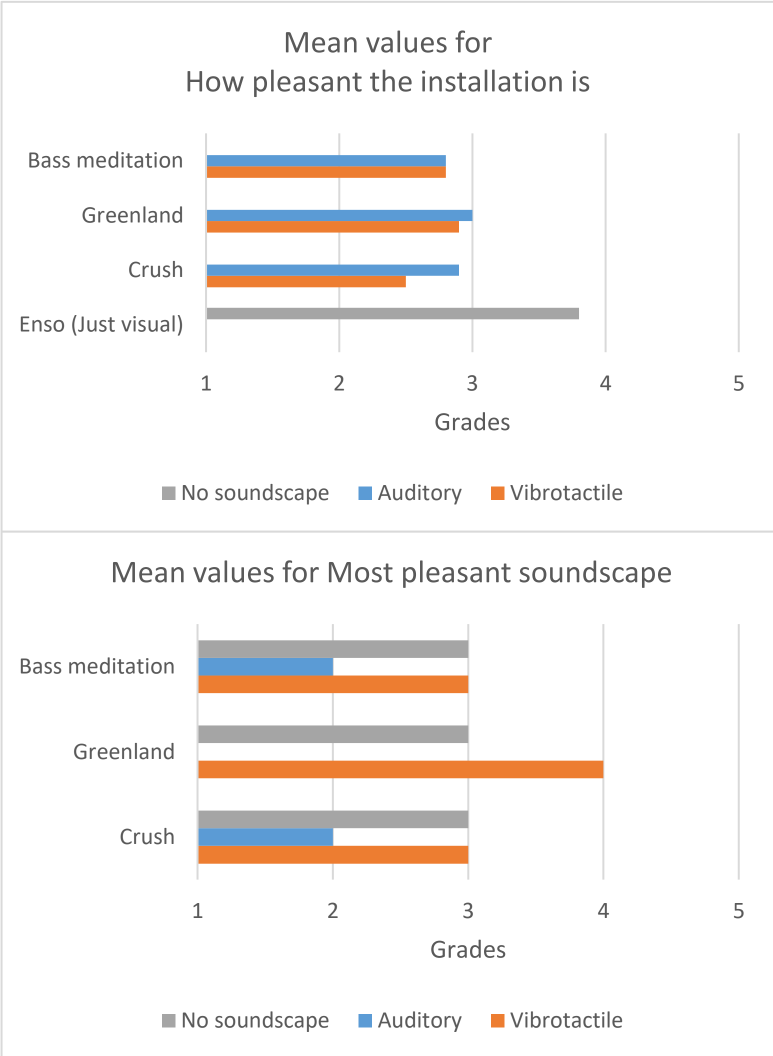

Table 19. The most pleasant soundscape was Greenland's vibrotactile version.

Which (auditory or vibrotactile) soundscape fits best: Participants evaluated the Bass meditation's vibrotactile version as the most compatible soundscape with the visual component of the installation. The second most valued was the Greenland's vibrotactile version. The no audio soundscape was not included in this question.

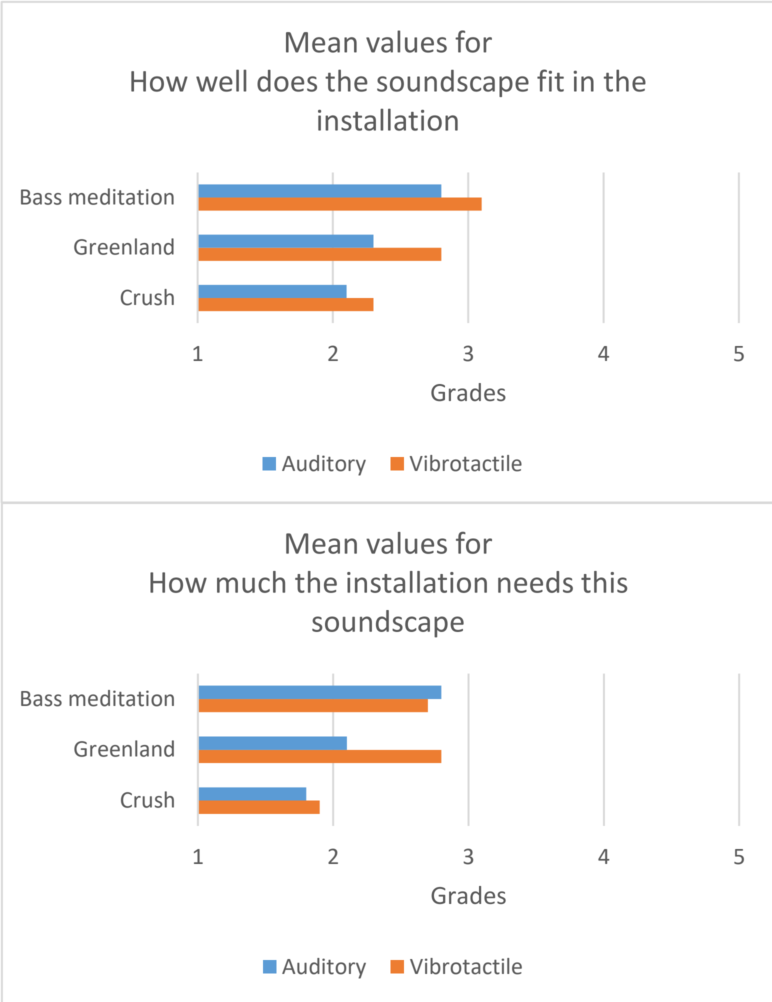

Table 20. From the auditory and vibrotactile samples, the Bass meditation's vibrotactile version was graded as the most compatible soundscape with the installation.

Which soundscape is the most compatible: However, when asked directly, from all the soundscapes participants voted the no audio version as the most compatible soundscape with the visual component of the installation. Those who valued more some of the auditory/vibrotactile version, valued more the vibrotactile versions.

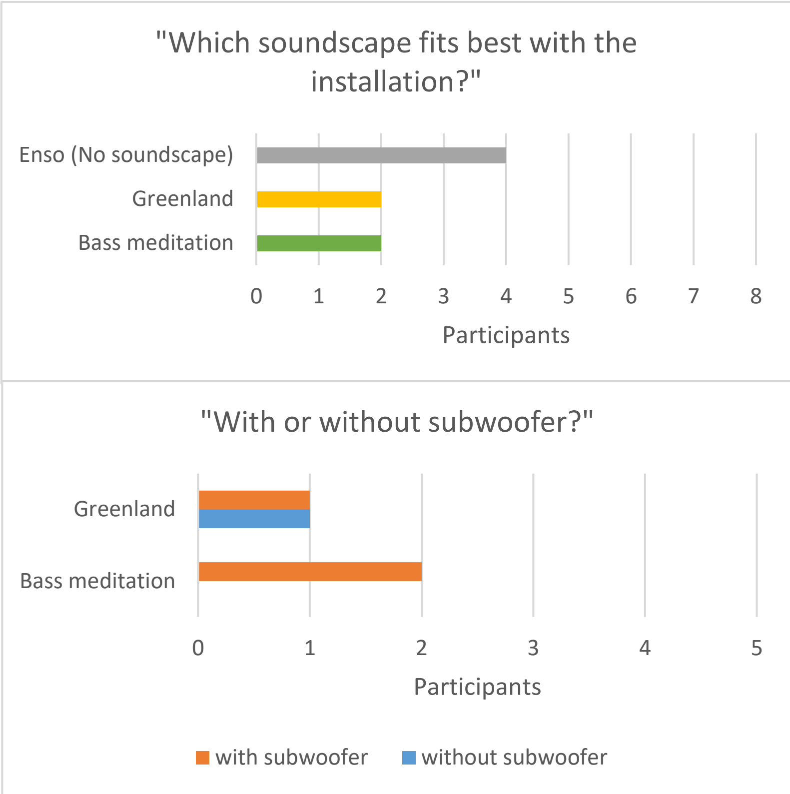

Table 21. From all the soundscapes, the no audio version was valued the most. But those who preferred the audio material, wanted it in vibrotactile format.

9 Discussion

9.1 Findings

These results show how utilizing sounds either in audible or vibrotactile manner is not that simple and easy. Multiple diverse factors influence on the overall experience, and the vast number of relating components can either impair or improve the created installation and experience.

Participants were not fully consistent in their replies and seemed answering slightly differently at different phases of the experiment. However, some results can be drawn from the experiment. The variation in the results also indicates how relative and sensitive the experiencing, and experience creation, is. How one feels [experiences something] at one moment may be totally different in the second moment, due to for example fatigue or habituation to the stimuli (Raisamo 2019b).

Several participants had problems distinguishing the vibrotactile output when it was slowly increased from 0 dB to higher amplitude, but when testing it with a on-off comparison where the vibrotactile version was running alongside the auditory sample, participants immediately noticed the difference between the samples. This showed that sudden changes or appearances in the high amplitudes of subwoofered material are easier to perceive than slow changes. Also, these sudden appearances seemed to cause more surprised reactions than the slowly progressed ones; the sudden spikes seemed to be experienced as more negative than the steady ones.

Though the occurred vibrations were verified only in a simplistic way, the participants' experiences revealed their existence: some participants perceived the vibrations derived from the subwoofer in their chest and legs. This came out especially with the unintentional on-off comparison.

The results from the experiment show on one hand that the music involving soundscapes were not as pleasing as the just visual version of the installation. This may indicate the individual differences in music taste. Also notable is, how the presenting order of the different soundscape samples may have affected on the evaluation. The no audio version turned out in surprisingly meaningful role, but it remains unexplained how meaningful the order of presenting was for the evaluation process.

On the other hand, **all soundscapes that involved auditive material were evaluated as most compatible in the vibrotactile version** with the visual component of the installation. This result is in align with the findings of Merchel (2014), who found out that the perceived quality of a music experience can be improved by adding vibrations to seats.

Participants also described the soundscapes verbally a bit differently as how they rated them with the 1-5 scale. They could give more negative description in words as what they gave in grades. This can be interpreted in a way that people do not know how to describe these experiences and sensations, especially the vibrotactile ones. That finding is in align with the outcome of Lauwrens (2019) and Sonneveld & Schifferstein (2008), and with Reybrouck et al. (2019), who indicates that the tactile perception of bass vibrations occurs mainly unconsciously, and we are not usually aware of the stimuli.

However, several participants did mention with different vibrotactile samples that **"*here's something more [than in the just auditory version]".*** This is also supported by the findings of Lauwrens (2019) and Vi et al. (2017) who point how making visitors to tactilely engage with the art enriches their understanding of the artwork's possible meanings, and how the deeper meanings are produced when the visual and tactile experiences are exchanged. Vi et al. (2017) also indicate how experiencing art can be done more meaningful with sensory augmentation. In this experiment, participants described the vibrotactile sample version as **"*somehow deeper"*** and ***"fuller*"** than the auditory version, which corresponds with the Vi et al.'s (2017) finding.

Some participants mentioned how the soundscapes were not representing the same matter as what the visual material was: the soundscapes were not compatible with the visual material. Also, Jansson-Boyd (2011) found out that products should feel how they look, since in majority of consumer scenarios visual sense appears to be sense that guides the consumer at least in the beginning. Similarly, this finding rose from this experiment's results. The visual sense was the first sensation given for precepting the installation, and it might have been very dominating factor for creating the first impressions about the installation. If the starting point would have been with some auditive or vibrotactile sample version, the evaluation results for different soundscapes might have been totally different.

Then again, van den Bosch et al. (2018) indicates how the existing habitats are deriving in moods and emotions more negative and aroused, which in the end results in stress. This also appeared in the experiment with some participants with some samples, as they experienced high irritation towards some auditory or vibrotactile samples. Perhaps the soundscapes should have had also more natural variations, like van den Bosch et al. (2018) suggests.

However, also the contrary point of view was found from this experiment's results. Some participants experienced increased valuation of the installation due to the vibrotactile, and the auditory, soundscape versions. This again is a corresponding result with the findings of Grimshaw (2012) and Fu (2015), who found out that player experience and immerse in games can be enhanced with sounds, which might be interpreted in the current context of multisensory art installation as well.

These opposite findings from the experiment indicate the importance of finding the appropriate soundscapes for a particular situation: the musical and/or sound material should be suitable with the context and user groups. The results also revealed how individual the perceptions and experiencing is, which also correlates with the findings of

Reybrouck et al. (2019) who found out that the difference between positively or negatively perceived stimulation of low frequencies can be subtle and highly personal.

Nevertheless, this experiment revealed the value of vibrotactile soundscapes in multisensory context. Essential is to find the correct audio material and reproduce it with a right kind of and a quality setup. This experiment and thesis indicate that vibrotactile soundscapes may enhance the overall experience of a multisensory, sounds utilizing, art installation.

9.2 Research questions

The answers to the research questions are:

1. Tactile bass seemed to influence on the overall experience of a multisensory, sound utilizing art installation in enhancing way. However, some participants experienced it as too loud or too strong [for the particular soundscapes], mut majority experienced it bringing [positively] "*something more*" to the overall experience.
    a. People highly valued the vibrotactile version of music involving soundscapes as part of the multisensory art installation. However, it turned out that in a very meaningful role was the musical content itself, not the vibrotactile format of it.
    b. The factors that affected on the experience of haptic music in this experiment were for example the context itself, the setup and its components (e.g. the chair, the position of the speaker and subwoofer, the occurred decibel levels), the occurred vibrations (their frequencies, amplitudes, rhythms), the participants' individual physical (in)abilities, and most of all: the participants' preferences (towards the musical content, volume levels, and bass toned audio material.

9.3 Limitations and Future work

Limitations came for example from the Covid-10 pandemic which caused planning the experiment in a minimalistic way. Optimally, the test would have been executed in real life setting, e.g., in a museum or art exhibition, with a real, ongoing exhibition and artwork. However, this experiment can be thought as a MVP or a pilot test, that is done before the real-environment experiment.

Other limitations in the experiment related for example to the poor quality of the sound reproduction systems. The speaker caused unwanted whirring which might have biased in the perception of detection threshold for the auditory sample of the test tone. One participant experienced all the auditory and vibrotactile samples as meaningfully too loud, and one got irritated due to the low quality of the sound reproduction: the audio was for example too loud compared to the subwoofer, and they were positioned wrongly compared to the listening place. Also, other participants said the soundscape samples were too loud.

Also, the soundscapes turn out being too homogenous and alike. Since people have so diverse preferences, the musical material should have been more diverse too. Now there was only one classical sample, and the two others were too similar among themselves (both modern electro ambient). For example, some natural soundscape could have been implemented too.

The physical setup caused also discomfort for some participants, since the chair in the experiment was children's chair and thus caused uncomfortable position for the adult participants: the seat was too small, the chair too low, and it was difficult to place and hold the sole of the foot on the exact marked point on the floor.

Limitations occurred also with acquiring the appropriate measurement devices for the experiment. Measuring how humans perceive vibrations would have been more straight forward with devices meant for detecting human-related vibrations. It was also difficult to verify the psychoacoustic viewpoint and for example record and display the sound spectrums of the soundscape samples. Thus, collaboration with an interdisciplinary team could provide more effective, fruitful, and better-quality results.

Future work: Though in this experiment, the participants accepted higher decibels with subwoofer with the 60 Hz test tone than what they accepted with just the speaker, the findings do still indicate that *utilizing subwoofer brings something more to the overall experience*. Because the vibrations influence on the perceived intensity of a sound, the perceived loudness is higher due to the vibrations (Merchel 2014). Thus, more research on finding the appropriate decibel levels should be done, so that the overall decibel levels may be lowered. This phenomenon could be harnessed into use by providing the extra sensory level for example via deriving vibrations directly onto body, which would enable lowering the overall sound pressure levels and thus ease the sensing burden that ears have to go through.

In the future experiments, the setup should be more uniform in its quality, meaning for example that the sound samples and video clips should cut and run similarly (without any differences). Also, the sound reproduction should be executed with better quality. The installation itself could be more immersive, in a sense that participants could for example go inside the installation, like in the modern opera Laila (Honkanen 2020) (see Figure 6 in chapter 6.2 Modern Museums and Art Exhibitions).

Also, the participants could be selected more appropriately. Now they were mainly "novice users", people who do not consume hi-fi audio nor visit museums or art exhibitions (only one participant were hi-fi audio hobbyist and only few participants said they might occasionally visit museums or art exhibitions).

As mentioned in the Limitations chapter, the future work should be executed in collaboration with an interdisciplinary team. It could provide more effective, fruitful, and better-quality results.

10 Conclusions

This thesis aimed at exploring the value of tactile music in a multisensory art installation context, and whether it influences on the overall experience in that particular situation.

The observed immaterial object here is the so-called museum experience. The relevant physical components are video as the visual material, sounds, and vibrations. As pointed in the chapter 8.2 Validation of vibrations occurrence, measurements indicate the occurrence of vibrations during the music containing installation. If the soundscape involved high amplitudes of low frequencies, it caused the floor and seat to vibrate. The intensity of vibrations and their frequency spectra depended on multiple factors, e.g. mode of the room or the floor's construction parameters.

The low frequencies in music and soundscapes are highly meaningful for the evaluating and valuating the overall experience. The haptic and tactile nature of these low frequencies should be better acknowledged and measured, and their meaning should be studied more thoroughly. The meaning and value of haptic sounds might be much more important for evaluating the overall experiences as what we have previously understood. Essential is to recognize the limits in order for being able to create safe and high-quality experiences. This can be thought also from the point of views of accessibility and inclusive design, and from the viewpoint of utilizing and grasping into use new multimodal ways of experiencing and doing things.

Most of all, in this way, the experience of remote, digital, and VR concerts could be meaningfully enhanced. Also, in live concerts the experience could be augmented with amplified vibrations, which would enable lowering the overall decibel levels and thus protect ears from high volumes.

Relating to the future of museums and art exhibitions, for example the modern museum Amos Rex in Helsinki is interested especially about that sort of immersive art experiences where one doesn't need any additional accessories (like VR glasses or headphones) (Radio Helsinki 2021). In this view, **providing haptic music and augmenting exhibitions with vibrotactile sounds could be exactly what is wanted and needed in the cultural context**. However, what a modern person awaits from an art experience might be a matter of generations: it is easier to approach youth through and with digital means, whereas the elder people appreciate more traditional art forms (Radio Helsinki 2021).

Similarly, also Wang (2020) points out how museums should focus more on creating a connection with the visitors, and to the **interaction that occurs between experience and senses**. For the viewpoint of what is future of museums, **museums should be visually, auditorily, olfactorily, and emotionally active (**Wang 2020), and most likely in haptic and tactile ways aswell. As Lauwrens (2019) indicates, it is important to identify the role of touch in aesthetic experiencing.

This research could contribute to the culture field by determining the value of tactually perceived sound [low frequency vibrations] that affect on the UX in sound related installations in culture context. This study could also provide guidelines for what attributes to consider when creating a multisensory installation that utilizes haptic sensation of sound.

References

Brochard, T. (2008). Evidence of beat perception via purely tactile stimulation. Brain Research, 1223(1223), 59–64. *https://doi.org/10.1016/j.brainres.2008.05.050*

Campbell, E., Hynynen, J., Burger, B., & Ala-Ruona, E. (2019). Exploring the use of Vibroacoustic treatment for managing chronic pain and comorbid mood disorders: A mixed-methods study. Nordic Journal of Music Therapy, 28(4), 291–314. *https://doi.org/10.1080/08098131.2019.1604565*

Chapman, C. (2009). Active Touch. *In Encyclopedia of Neuroscience (Vol. 1, pp. 35–41).*

Donati, P., Schust, M., Szopa, J., Starck, J., Iglesias, E., Senovilla, L., Fischer, S., Flaspöler, E., Reinert, D., Beeck, R. (2008). Workplace exposure to vibration in Europe: an expert review. European Agency for Safety and Health at Work. *https://osha.europa.eu/en/publications/reports/8108322_vibration_exposure*

Dyck, E. & Moelants, D & Demey, M. & Deweppe, A. & Leman,. (2010). The impact of the bass drum on body movement in spontaneous dance. *Proceedings of the 11th International Conference on Music Perception and Cognition (ICMPC11).*

Eidsheim, N. (2015). Sensing Sound: Singing and Listening as Vibrational Practice. Duke University Press.

Florian, M. (2017). Deaf people feeling music rhythm by using a sensing and actuating device. Sensors and Actuators. A. Physical., 267, 431–442. *https://doi.org/10.1016/j.sna.2017.10.034*

Frid, E., Lindetorp, H., Hansen, K., Elblaus, L., & Bresin, R. (2019). Sound Forest: Evaluation of an Accessible Multisensory Music Installation. Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, 1–12. https://doi.org/10.1145/3290605.3300907

Frid, E., & Lindetorp, H. (2020). Haptic Music : Exploring Whole-Body Vibrations and Tactile Sound for a Multisensory Music Installation. Proceedings of the Sound and Music Computing Conference (SMC) 2020, 68–75. Retrieved from *http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-283651*

Frometa, R. J. (2018). How Music Helps To Make Games More Immersive. Retrieved February 2021, from *https://ventsmagazine.com/2018/08/15/how-music-helps-to-make-games-more-immersive/*.

Ghislaine Goudreau, Cora Weber-Pillwax, Sheila Cote-Meek, & Helen Madill. (2008). Hand Drumming: Health-Promoting Experiences of Aboriginal Women from a Northern Ontario Urban Community. Journal of Aboriginal Health, 4(1), 72–.

Grimshaw, M. (2012). Sound and player immersion in digital games. In The Oxford Handbook of Sound Studies. Oxford University Press

Gunther, E., & O'Modhrain, S. (2003). Cutaneous Grooves: Composing for the Sense of Touch. *Journal of New Music Research*, *32*(4), 369–381. *https://doi.org/10.1076/jnmr.32.4.369.18856*

Halata, Z. & Baumann K. (2008). Anatomy of receptors. In In Grunwald, M. *Human Haptic Perception* (pp. 85–92). Birkhäuser Boston. https://doi.org/10.1007/978-3-7643-7612-3_6

Hayes, L., & Rajko, J.J. (2017). Towards an Aesthetics of Touch. *Proceedings of the 4th International Conference on Movement Computing.*

Helmholtz, H. (1895) On the Physiological Causes of Harmony in Music. *In Popular Lectures on Scientific Subjects. 1st series, trans. E. Atkinson. (London: Longmans, Green % Co), 53-93, 56*

Hepper, P. (2008). Human Haptic Perception Basics and Applications. In Grunwald, M. *Human Haptic Perception* (pp. 149–154). Birkhäuser Boston. *https://doi.org/10.1007/978-3-7643-7612-3_11*

Honkanen, Velimatti. (2020). Uusi diiva on syntynyt – Kansallisoopperassa estettävä virtuaalinen Laila vie oopperan uusiin ulottuvuuksiin. *Tekniikan maailma 22.8.2020. Viewed 13.2.2021. https://tekniikanmaailma.fi/uusi-diiva-on-syntynyt-kansallisoopperassa-esitettava-virtuaalinen-laila-vie-oopperan-uusiin-ulottuvuuksiin/*

Hove, M., Martinez, S., & Stupacher, J. (2020). Feel the Bass: Music Presented to Tactile and Auditory Modalities Increases Aesthetic Appreciation and Body Movement. Journal of Experimental Psychology. General, 149(6), 1137–1147. *https://doi.org/10.1037/xge0000708*

Howard, D., Angus J. (2017). Acoustics and Psychoacoustics. In Acoustics and Psychoacoustics (5th ed.). Routledge. https://doi.org/10.4324/9781315716879

Huang, J., Gamble, D., Sarnlertsophon, K., Wang, X., & Hsiao, S. (2012). Feeling music: integration of auditory and tactile inputs in musical meter perception. PloS One, 7(10), e48496–e48496. *https://doi.org/10.1371/journal.pone.0048496*

Huotilainen, M. (2021). *Musiikki ja aivot – Miksi aivotutkija suosittelee musiikkiharrastusta? (Lecture video). Retrieved from Youtube https://www.youtube.com/watch?v=BD3sJWVoUVY at 16.3.3021.*

http://www.northernc.on.ca/indigenous/the-drum/ Northern College, Indigenous Services & Initiatives, The Drum. Viewed 16.2.2021.

Jekosch, U. (2005). Voice and Speech Quality Perception: Assessment and Evaluation. Springer Berlin Heidelberg. https://doi.org/10.1007/3-540-28860-0

Joy, A., & Sherry, J. (2003). Speaking of Art as Embodied Imagination: A Multisensory Approach to Understanding Aesthetic Experience. The Journal of Consumer Research, 30(2), 259–282. https://doi.org/10.1086/376802

Jung, D., Kim, J., Lee, J., Yang, H., & Ryu, H. (2019). Lessons Learned from an Auditory-vibrotactile Sensory Experience in the Museum. Proceedings of the 2019 ACM International Conference on Interactive Surfaces and Spaces, 373–378. *https://doi.org/10.1145/3343055.3360754*

Lauwrens, J. (2019). Touch as an aesthetic experience. Journal of Visual Art Practice, 18(4), 323–341. *https://doi.org/10.1080/14702029.2019.1680510*

Lehmusvesi, Jussi. (2020). Korona-aika on siivittänyt Kansallisoopperan luovaan lentoon. *Helsingin Sanomat 18.11.2020. Viewed 15.1.2021. https://www.hs.fi/kulttuuri/art-2000007626092.html*

Lenni-Taattola, J. (2020). Tulevaisuuden teatterit -selvitys 2020 : Tulevaisuus on hybrid. Tampereen yliopisto

Leventhall, H. G. (2004). Low Frequency Noise and Annoyance. Noise & Health, 6(23), 59–72.

Lustig, E. & Tan, I. (2020). All about that bass: Audio filters on basslines determine groove and liking in electronic dance music. Psychology of Music, 48(6), 861–875. *https://doi.org/10.1177/0305735619836275*

Lähdeoja, O. (2016). Composing for an Orchestra of Sonic Objects: .e Shakeousmonium Project. In Proceedings of the International Computer Music Conference. Utrecht.

Madison, G.. (2006). Experiencing Groove Induced by Music: Consistency and Phenomenology. Music Perception, 24(2), 201–208. *https://doi.org/10.1525/mp.2006.24.2.201*

Maschke, C. (2004). Introduction to the Special Issue on Low Frequency Noise. Noise & Health, 6(23), 1–2.

Mayor Poupis, L., Rubin, D., & Lteif, L. (2021). Turn up the volume if you're feeling lonely: The effect of mobile application sound on consumer outcomes. Journal of Business Research, 126, 263-278. DOI:*https://doi-org.libproxy.tuni.fi/10.1016/j.jbusres.2020.12.062*

Merchel, S., & Altinsoy, M. (2014). The Influence of Vibrations on Musical Experience. Journal of the Audio Engineering Society, 62(4), 220–234. *https://doi.org/10.17743/jaes.2014.0016*.

Merchel, S. (2014). Auditory-tactile music perception. (ISBN: 978-3-8440-3161-4), Shaker Verlag, Germany.

Muller, G., & Moser, M. (2013). Handbook of Engineering Acoustics. Springer Berlin / Heidelberg. *https://doi.org/10.1007/978-3-540-69460-1*

Phillips-Silver, J. & Trainor, L. (2005). Feeling the Beat: Movement Influences Infant Rhythm Perception. Science (American Association for the Advancement of Science), 308(5727), 1430–1430. https://doi.org/10.1126/science.1110922

Raisamo, R. (2019a). Introduction to haptics. (Lecture slides). Retrieved from *tuni.moodle.fi at 31.8.2020.*

Raisamo, R. (2019b). Tactile sensing, stimulation and haptic perception. (Lecture slides). Retrieved from *tuni.moodle.fi at 31.8.2020.*

Radio Helsinki. (28.10.2021). Taide vai Teknologia. [Podcast]. Viewed 4.5.2022 *https://www.radiohelsinki.fi/ohjelma/taide-vai-teknologia/.*

Renel, W. (2019). Sonic Accessibility: Increasing Social Equity Through the Inclusive Design of Sound in Museums and Heritage Sites. Curator (New York, N.Y.), 62(3), 377–402. https://doi.org/10.1111/cura.12311

Reybrouck, M. (2019). Experience as cognition: musical sense-making and the "in-time/ outside-of-time" dichotomy. Interdisciplinary Studies in Musicology, 19, 53–80. *https://doi.org/10.14746/ism.2019.19.4*

Reybrouck, M., Podlipniak, P., & Welch, D. (2019). Music and Noise: Same or Different? What Our Body Tells Us. Frontiers in Psychology, 10, 1153–1153. *https://doi.org/10.3389/fpsyg.2019.01153*

Saarinen, J. A. (2012). The oceanic state: a conceptual elucidation in terms of modal contact. International Journal of Psychoanalysis, 93(4), 939–961. *https://doi.org/10.1111/j.1745-8315.2012.00620.x*

Satoshi, M. (2014). Sonic art for intersensory listening experience. Proceedings of the Electroacoustic Music Studies Network Conference Electroacoustic Music Beyond Performance.

Schneider, O., MacLean, K., Swindells, C., & Booth, K. (2017). Haptic experience design: What hapticians do and where they need help. International Journal of Human-Computer Studies, 107, 5–21. *https://doi.org/10.1016/j.ijhcs.2017.04.004*

Schifferstein, H. N. J., & Hekkert, P. (2007). Product Experience. Elsevier Science & Technology. https://doi.org/10.1016/B978-0-08-045089-6.X5001-1

Sonneveld, M. H., & Schifferstein, H. N. J. (2008). 2 - The tactual experience of objects. In Product Experience (pp. 41–67). Elsevier Ltd. https://doi.org/10.1016/B978-008045089-6.50005-8

teamLab. (26.10.2017). Enso in the Qing Dynasty Wall, Beijing. [Website]. Viewed 4.4.2023 *https://www.teamlab.art/e/enso-templehotel/.*

teamLab. (28.8.2019). Enso – Gold Light. [Youtube]. Viewed 15.10.2022 https://www.youtube.com/watch?v=bgtzB-WreiM.

Trower, S. (2012). Senses of Vibration: A History of the Pleasure and Pain of Sound. In Senses of Vibration. Bloomsbury Academic & Professional.

Turchet, W. (2020). Touching the audience: musical haptic wearables for augmented and participatory live music performances. Personal and Ubiquitous Computing. https://doi.org/10.1007/s00779-020-01395-2 van den Bosch, K. A. M., Welch, D., & Aninga, T. C. (2018). The Evolution of Soundscape Appraisal Through Enactive Cognition. *Frontiers in Psychology*, *9*, 1129–1129. https://doi.org/10.3389/fpsyg.2018.01129

Vi, C. T. Ablart, D. Gatti, E. Velasco, C. Obrist, M. (2017). Not just seeing, but also feeling art: Mid-air haptic experiences integrated in a multisensory art exhibition. International Journal of Human-Computer Studies, 108, 1–14. https://doi.org/10.1016/j.ijhcs.2017.06.004

VDI 2057, Human exposure to mechanical vibration: Whole-body vibration (2002)

Wang, S. (2020). Museum as a Sensory Space: A Discussion of Communication Effect of Multi-Senses in Taizhou Museum. Sustainability (Basel, Switzerland), 12(7), 3061–. *https://doi.org/10.3390/su12073061*

Xiaoqing Fu, J. (2015). The Influence of Background Music of Video Games on Immersion. Journal of Psychology & Psychotherapy, 5(4). *https://doi.org/10.4172/2161-0487.1000191*