

# HAPTIC MUSIC - EXPLORING WHOLE-BODY VIBRATIONS AND TACTILE SOUND FOR A MULTISENSORY MUSIC INSTALLATION

Emma Frid

KTH Royal Institute of Technology  
emmafrid@kth.se

Hans Lindetorp

KMH Royal College of Music  
hans.lindetorp@kmh.se

## ABSTRACT

This paper presents a study on the composition of haptic music for a multisensory installation and how composers could be aided by a preparatory workshop focusing on the perception of whole-body vibrations prior to such a composition task. Five students from a Master's program in Music Production were asked to create haptic music for the installation *Sound Forest*. The students were exposed to a set of different sounds producing whole-body vibrations through a wooden platform and asked to describe perceived sensations for respective sound. Results suggested that the workshop helped the composers successfully complete the composition task and that awareness of haptic possibilities of the multisensory installation could be improved through training. Moreover, the sounds used as stimuli provided a relatively wide range of perceived sensations, ranging from pleasant to unpleasant. Considerable intra-subject differences motivate future large-scale studies on the perception of whole-body vibrations in artistic music practice.

## 1. INTRODUCTION

This paper presents a follow-up study building on previous work presented in [1] in which a group of composers were asked to create music for the multisensory music installation *Sound Forest*. *Sound Forest* serves as a long-term installation at the *Swedish Museum of Performing Arts*<sup>1</sup> (Scenkonstmuséet) in Stockholm. It is a large-scale Digital Musical Instrument (DMI) that can host a range of different musical material, depending on context or current exhibition [2,3], see Figure 1. Since its opening in 2017, the installation has been visited by a total of 75 750 people<sup>2</sup>.

*Sound Forest* consists of five interactive light-emitting strings attached from the ceiling to the floor in a dedicated room covered by mirrors. The mirrors create infinite reflections reminding of an enchanted forest. An extended floor is built on top of the room's hardwood floor. For each string, there is a circular platform cut out of the extended floor. The platforms rest on vibration dampers, which enables them to vibrate freely if set into motion by two tactile



Figure 1. The interactive light-emitting strings in *Sound Forest*.

transducers (vibration speakers). The strings are decoupled from the platforms and are not affected by the haptic vibrations. Visitors can interact with the installation by plucking the strings (see Figure 2), resulting in sonic feedback played from top/ceiling speakers located above each string, light feedback emitted from strings, and haptic feedback perceived through the respective platform. A schematic representation of the system is displayed in Figure 3.

In our previous work, we identified a need for more structured workshops with composers in order to support and prepare them for the creation of tactile sounds for the *Sound Forest* installation [1]. The study described in this paper thus involved an extended workshop focusing on getting familiar with the haptic instrument before making music for it. The workshop allowed the composers to explore the sonic possibilities of the system by reflecting on their own perception of whole-body vibrations. Findings suggested that composers' awareness of the haptic possibilities of the platforms could be improved through training. Our study is novel in the sense that little prior work has focused on aiding composition processes for multisensory installations through an increased awareness of haptic perception. Results motivate future large-scale studies on the perception of whole-body vibrations in artistic practice. Findings also highlight the need for a sample library of whole-body vibration effects.

## 2. BACKGROUND

### 2.1 Haptic Perception

Haptic feedback refers to feedback perceived through the sense of touch. The haptic system uses sensory information derived from mechanoreceptors and thermoreceptors embedded in the skin (cutaneous inputs) together with mechanoreceptors embedded in muscles, tendons, and joints (kinesthetic, also sometimes referred to as proprioceptive, inputs) [4]. The cutaneous (tactile) inputs contribute to the human perception of various sensations such as pressure, vibration, skin deformation, and temperature, whereas the kinesthetic (proprioceptive) inputs contribute to the human perception of limb position and limb movement in space [4]. In the context of whole-body vibration,

<sup>1</sup> <https://scenkonstmuseet.se/>

<sup>2</sup> Estimated numbers provided by the Museum of Performing Arts.

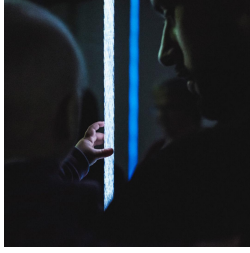


Figure 2. Visitor interacting with a string in Sound Forest.

visceral sensations registered by receptors in the abdomen are also important [5].

The manufacturer of the tactile speaker used in the current study defines five sensory pathways to perceiving sounds: 1) hearing via air transmission (through our ears), 2) feeling via deep tissue movement (stimulating nerve endings of the kinesthetic sense), 3) feeling via skeletal joint movement, 4) feeling via tactile stimulation (the sense of touch, stimulating nerve endings under the outer layer of the skin) and 5) feeling via bone conduction (stimulating the bone mass itself; the cochlea takes mechanical movements of acoustic energy and translates them into nerve impulses) [6]. Considerable research has focused on tactile stimulation in the context of music research (see [7–10]) and HCI applications [11]. However, less work has addressed how other pathways to perceiving sounds contribute to music experiences.

## 2.2 Vibrotactile Perception

Different vibrotactile frequency response ranges for the skin have been reported. For example, 0.4 to 500Hz is suggested in [12] while 20–1000Hz is reported in [13]. A frequency of 250Hz is suggested for optimal sensing vibration frequency for touch [13, 14]. In the current work, the primary body parts in contact with the vibrating platform are the feet. The foot is one of the most sensitive parts of the body when it comes to vibrotactile stimulation [15] and the sensory physiology of the foot sole is similar to that of the skin of the hand [16].

## 2.3 Perception of Whole-Body Vibrations

Whole-body vibration occurs “when a human is supported by a surface that is shaking and the vibration affects body parts remote from the site of exposure” [17]. Considerable research on whole-body vibration has focused on

ergonomics and health in industrial applications. Exposure limits and thresholds are published in [18]. For vertical vibration, motion is most easily perceived at around 5Hz [19]. For horizontal vibration, the corresponding value is found below 2Hz [20]. Laboratory studies of discomfort have established a relationship between the magnitude, duration, frequency content, and waveform of the signal, but the interaction between these properties is not trivial and is confounded by inter- and intra-subject differences [21].

Similar to the concept of a Head Related Transfer Function (HRTF), the body has a transfer function for vibrations (Body Related Transfer Function, BRTF) [22], which depends on body properties. In terms of transmission of vibration through the body, being exposed to a gradually increased frequency of a sinusoidal signal will result in resonance of different body parts [23]. Many body parts will resonate at about 5Hz (e.g., the head and abdomen), while others will resonate at higher frequencies (the eyeball resonates at about 20Hz, for example) [23].

## 2.4 Musical Haptics

Musical experiences involve both airborne acoustic waves and vibratory cues conveyed through air and solid media [24]. Papetti and Saitis [24] define musical haptics as an interdisciplinary field focused on investigating touch and proprioception in music scenarios from the perspective of haptic engineering, HCI, applied psychology, musical acoustics, aesthetics, and music performance. The fields of music and haptics are tightly connected in numerous ways. Auditory-tactile experience of music, especially the multimodal perception of attending a concert, has been stressed [25, 26]. Vibrotactile feedback can be added to restore intimacy in instrumental interaction with a DMI or to enable persons with hearing impairment to experience music [8]. Haptics also has a number of significant effects on users’ perception of usability in DMI interactions [27]. Moreover, the musical experiences of people with hearing impairments have been found to be enhanced by haptic feedback [28].

Previous research on the musical experience of whole-body vibrations includes work on perceptual dimensions of stage-floor vibrations [29, 30] and vibrations in concert halls [31]. Whole-body vibrations have been found to significantly affect loudness perception [32]. The synchronous presentation of vertical whole-body vibrations during concert DVD reproduction can improve the perceived quality of the concert experience [33]. In addition, it has been shown that subjects prefer when auditory versus vibration signals have the same frequency [34].

## 2.5 Haptic Composition

Several previous studies have focused on the composition of music for haptic displays. A system enabling the creation of vibrotactile music through a system based on transducers worn against the body was presented in [13]. The authors identified a set of building blocks for a tactile language for composition: frequency, intensity, duration,

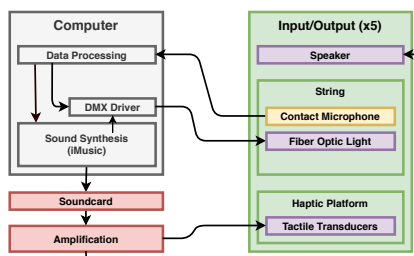


Figure 3. Schematic representation of technical setup.

waveform (or spectral content), and space (location). Another example is the haptic chair *EmotiChair* [35, 36], a sensory substitution system that translates auditory information into vibrotactile stimuli. Other relevant work includes research on vibroacoustic therapy (VAT), in which low-frequency sound in the audible range (below 100) is used to produce mechanical vibrations together with music listening [37]. An example of such a vibroacoustic device is the *Music Vibration Table (MVT)* [38]. Considerable research has also focused on tactile displays allowing deaf persons to experience music. For example, authors in [28] concluded that musical representations for hearing-impaired should focus on staying as close to the original as possible while conveying the physics of the representation via an alternate channel of perception.

In [39], composition techniques for the vibrotactile garment to be used in a composed immersive multimedia installation were explored. An iPad app was used to allowing users to draw trajectories of vibration on a representation of the body, and a tool for generating and playing back patterns. A portable wearable device that plays back vibrotactile compositions was presented in [40]. Another example is the work presented in [41], in which two underlying dimensions of tactile melodies were identified: tempo and intrusiveness.

Much research on tactile displays has focused on tactile icon design and on defining simple distinguishable tactile effects (see [42–44]). However, it is also possible to create more complex ambient sensations through the feet. For example, it has been shown that the same type of tactile transducer as the one used in the current study can be used to provide the impression of walking on different ground materials, such as gravel, carpet, or stone [45].

### 3. METHOD

#### 3.1 Haptic Platforms

There is a total of five haptic platforms in the Sound Forest room. One platform is larger than the other ones in order to easily fit a wheel-chair. Each platform is equipped with two vibration speakers of model TST239 Silver Tactile Transducer from Clark Synthesis<sup>3</sup>. We used a t.amp S-150 mk II amplifier to feed the signal to the tactile transducers. The TST239 speaker has a frequency response of 15Hz to 17kHz. It is an electromechanical device designed to drive large surfaces with auditory information from 1 to 800 Hz, which is higher than what subwoofers usually deliver [6]. The TST239 may supplement speakers and subwoofers in two ways: 1) it delivers physical vibrations that you both feel and hear through bone conduction and 2) it acts like a very large speaker in the sense that the resonant structure to which it is attached generates audible sound [6]. The haptic platform may thus also function as an audio diffusion surface.

#### 3.2 Participants

The study was coordinated within a course given at the Royal College of Music in Stockholm during Spring 2019.

Five students from the Master’s Program in Music Production participated (3 F, 2 M, average age=27.2 years). Students agreed that results from the study could be used for research purposes and consented to their data being collected. We have previously explored collaborations with students in our research, as this has proven to have major benefits both for education and increased diversity of the research outcomes [46].

#### 3.3 Workshop

A subset of the students (2 F, 1 M) participated in a workshop in which a version of the haptic platform was demonstrated<sup>4</sup>. The workshop lasted for approximately one hour. After an introduction, eight different sound stimuli were played through the platform. The participants were allowed to stand on the platform both alone and together in order to experience the haptic feedback. After each sound, they filled out a questionnaire about their perceived experience. They were asked the following questions: 1) *Please describe the perceived sensation of respective sound*, 2) *Where in the body can you feel the vibrations?* and 3) *How would you describe this sensation?* The participants also discussed every stimulus in the group. These discussions were recorded. After the workshop, audio recordings were transcribed by the authors to identify common patterns among participants’ perceived sensations. Body loci mentioned by the participants were also annotated. Interesting quotes from the discussion are presented in Section 4.

##### 3.3.1 Stimuli

Sound stimuli were synthesized in Max/MSP<sup>5</sup>. The stimuli selection was based on the findings presented in our previous work; the idea was to break down the composition process to the composers in an easily accessible way, thereby providing them with a basic understanding of the instrument’s technical possibilities and limitations regarding pitch, dynamics and timbre characteristics. Stimuli 1 - 3 were continuous sine wave tones (30, 70 versus 100Hz). Stimulus 4 was lowpass-filtered continuous pink noise with a cutoff frequency set to 80Hz. Stimulus 5 was lowpass-filtered pink noise with a repeated filter sweep that went from 15 to 80Hz on 200 ms, then from 80 to 15Hz in 200 ms. Similarly, stimulus 6 was a repeated sine-sweep going from 15 to 80Hz to 15Hz in 800 ms. Stimulus 7 was a slower repeated sine-sweep going from 15 to 80Hz to 16Hz in 2000 ms. The final stimulus, number 8, presented randomized rhythms of two filtered sine wave tones at 25 versus 85Hz, creating a stereo effect. All sounds are available online<sup>6</sup>.

#### 3.4 Composition Task

The students were given an open composition task. They decided themselves which aspects to focus on for their

<sup>4</sup> This version of the platform is located at the authors’ research lab and is very similar to the technical solution set up at the museum.

<sup>5</sup> <https://cycling74.com/>

<sup>6</sup> <https://kth.box.com/v/smc2020haptics>

<sup>3</sup> <https://clarksynthesis.com/>

project, such as visitors' experiences, technical or artistic decisions, haptic feedback, or multichannel audio. The project resulted in five multisensory interactive compositions. The students composed and produced the music and the audio for the vibration speakers using a music production tool free of choice. Separate audio files were exported and implemented into a JavaScript framework developed for Sound Forest, using iMusic<sup>7</sup>. iMusic controlled the playback, looping, randomization, and synchronization of all audio files. The iMusic tool also mixed the audio output to the speakers located above the strings and the vibration speakers located in the haptic platforms. The sounds were triggered based on the actuation of the strings, which was measured using contact microphones, see Figure 3. The students spent one day working in the installation at the museum, in order to soundcheck and optimize the compositions for the setting. All compositions were showcased for the public on the following day.

#### 3.4.1 Evaluation

The project finished with a written questionnaire in which students described their experiences related to composing tactile sound for Sound Forest. Four students (2 M, 2F) participated. Two of these students participated in the initial workshop. The following questions were included in the questionnaire: 1) *Which vibrations sensations did you aim to create?* 2) *How did you get the idea?* 3) *How did you create them (sampling, waveform, frequency, envelopes etc.)?* 4) *Describe how easy or difficult it was to perform the task and how close the result was to your initial music idea.* 5) *Describe what you learned from the workshop.* 6) *Is there anything else that you would have needed to perform the task even better?* As part of the examination, all of the five students also described their compositions in essays (approximately 1000 words long). We analyzed these reports to extract reflections about composing tactile sound.

## 4. RESULTS

### 4.1 Workshop

The students described perceived haptic sensations for the following body loci: lower part of the body, calves, thighs, legs, belly button, womb, belly, back, chest, hips, spine, knees, neck, hands, feet, toes, heels, footpad, head, forehead, teeth, lips and tip of the nose. Below follows a discussion on perceived sensations for respective sound stimulus, based on transcriptions and questionnaire results.

#### 4.1.1 Sine Wave 30Hz

All participants described haptic sensations in different parts of the body: S1 participant felt the vibrations in the neck and the calves, S2 in the thighs, and S3 in the lower part of the body as well as in the lips and teeth. S1 described the sensation as a tickling feeling that was somewhat unpleasant. S3, on the other hand, seemed to enjoy the sensation and described it as a drone (Swedish: "*basbördun*").

#### 4.1.2 Sine Wave 70Hz

Perceived sensations differed also for this stimulus, but areas in which the vibrations could be perceived somewhat overlapped. Two of the participants (S1, S3) described sensations in the lower parts of the body, two (S1, S2) in the lower parts of the abdomen and two in the head or mouth (S2, S3). S1 also described vibrations going through the whole body, particularly for the chest and the head; S2 in the hips and teeth; and S3 in the womb. Two participants (S2, S3) described the sensations as unpleasant. Interestingly, S3 mentioned that the sensation caused nausea, stating that she "*just wanted to get off the platform*". S1 described a feeling reminiscent of "*small ants*".

#### 4.1.3 Sine Wave 100Hz

For this stimulus, all participants described tickling sensations in the feet. Two participants (S1, S3) stated that this sensation as "*very intense*". However, S3 accounted that she did not think that the tickling sensations were unpleasant. S2 also described vibrations in the abdomen and chest, whereas S3 perceived vibrations in the legs and along the spine. S1 mentioned perceiving less vibrations in the rest of the body compared to the 70Hz stimulus.

#### 4.1.4 Low-pass Filtered Pink Noise

The participant's descriptions of where the vibrations could be perceived varied: S1 perceived them in the lower legs, feet and lower back; S2 in the chest, throat, and jaw; and S3 in the feet, chest, and throat. Two participants (S2, S3) described this stimulus as unpleasant, resulting in nausea or motion-sickness, whereas one participant (S1) labeled it as pleasant/comfortable. S3 accounted: "*it was a bit like I could not breathe*". Although the composers did not agree in terms of how pleasant the stimulus was, all participants associated the sensations to movement. For example, S1 compared the stimulus to the sensation of movement that can be felt in an airplane. S2 described a "*pulsating*" and "*heavy sensation*" in the chest, that moved upwards towards the throat and head. S3 specifically described the sensation as "*being in movement/moving forward*", as being on a boat, or sitting in a carriage that was pulled over gravel. She commented: "*it felt as though I was on the lower deck of a ferry*".

#### 4.1.5 Pulsating Low-pass Filtered Pink Noise

The participants agreed that this stimulus was primarily perceived in the lower parts of the body. For example, S3 mentioned perceiving the sensation from the belly button and below that point, whereas S2 described that she could perceive the sensation in the entire body, but primarily in the lower back and hips. The descriptions of the perceived sensations differed: S1 and S2 mentioned a pulsating sensation while S3 described that "*everything was vibrating at the same time*". S2 described that the vibrations were pleasant but also a bit annoying, but that they did not remind of a movement. S1 described the sensation as "*a bit weird*".

<sup>7</sup> <https://github.com/hanslindetorp/imusic>

#### 4.1.6 S6 - Sine Wave Sweep 15-80Hz

For this stimulus, S1 described sensations in the legs and at the tip of the nose. Also S3 mentioned the tip of the nose and the belly. S2 described sensations under the feet, in the belly and in the chest. Interestingly, all participants described somewhat similar sensations. S1 mentioned a sweeping sensation of “*falling*” and a tickling sensation in the belly. S2 described a somewhat unpleasant sensation going through the body followed by a release: “*I could feel a tickling sensation under my feet building up to a heavy vibration in the belly and chest at every pulse. Almost like a free-fall sensation. Like when you are jumping and are in the air.*” S3 described the sensation at the tip of the nose, similar to having a cold, but also a sensation of experiencing an “*an amusement park attraction*”.

#### 4.1.7 S7 - Slow Sine Wave Sweep 15-80Hz

S1 described sensations in the legs, in the nose and lower part of the forehead. S2 described a sensation in the entire body, including the upper part of the body towards the head. Similar to the last stimulus, S1 mentioned feeling like being in an attraction at an amusement park, acceleration, a sensation of falling, a sweeping sensation, and having a hard time keeping the balance. S2 also said that the experience was similar to the last stimulus, with the difference that it now felt further up in the head. The sensation was described as pulsating feeling going through the entire body. Finally, S3 accounted that “*it was like it was going faster when it got higher in frequency*”. She also described associating the movement to motion sickness.

#### 4.1.8 S8 - Randomized Rhythms at 25 versus 85Hz, Stereo

Participants described similar bodily locations; S1 and S3 mentioned sensations from the feet to the knees and S2 described that the vibrations could not be felt beyond the thighs. S1 described this stimulus as “*a drum concert*” and that it was a rather pleasant sensation. S2 described feeling confused and disoriented and a tickling vibration under the feet.

## 4.2 Composition Task

### 4.2.1 Observations

Observations made during the soundcheck at the museum suggested that testing the amplification of the haptic compositions was of great importance. If amplification is too low, the haptic feedback cannot be perceived; if amplification is too high, a distorted sound in conflict with the sound presented from the top speakers mounted in the ceiling is produced. All composers had to increase the amplitude level for the channels going to the vibration speakers more than what they initially expected. Moreover, the vibration speakers create audible sounds that can result in unwanted dissonances inflicting on the rest of the produced sounds. Some of the students handled this by choosing a pitch for the vibration speakers that harmonized with the key of the composition. Another method was to add a 12dB/octave

low-pass biquad-filter with a cutoff frequency set to 150Hz to the channels going to the vibration speakers.

### 4.2.2 Evaluation

The composers described different visions for the tactile compositions and how the haptic feedback would fit the other musical material. For example, S1 stated that the vibrations were thought to complement the rhythm of the sound presented in the top speaker; the vibrations should either “*fill up gaps*” or reproduce the same rhythm. In terms of inspiration for the tactile compositions, one participant (S2) mentioned being inspired by the workshop session. S3 declared that she strove for simplicity; most of her sounds distributed through the vibration speakers were single notes in the same key as the composition. She based her work on frequencies rather than rhythms and dynamics. S4 wanted the sensation in the body to be clearly perceived and described that she tried to customize the vibrations to fit the key of her audible samples from the ceiling speakers. S5 wanted to achieve a “*purely physical sensation*” enhancing the musical experience, emphasizing musical gestures such as crescendos, thus creating a feeling of being “*in the middle of the music*”.

Interestingly, none of the composers described working with different amplitude envelopes to shape the haptic sensations. Instead, they focused mainly on frequency ranges. For the sound synthesis, S1 created sounds by filtering sine tones. S2 also used a sine oscillator with different frequencies as this was “*the easiest way to control the vibrations*”. S4 recorded a base tone using different synthesizers in the same key as the composition. She then filtered these sounds to remove all frequencies that were not easily perceived in the body. Similarly to S1 and S2, S5 started from a sinewave synth sound, which was then equalized to a lower frequency range.

When it comes to the difficulty of the task and how the result came out in relation to the intended vision, S1 described that it was somewhat difficult to imagine how sounds would be perceived at the museum but that it was really worthwhile to participate in the workshop. S2 described starting off with a rather grand vision, which was later downscaled to a smaller idea. S4, who had not participated in the workshop, mentioned that she did not know how different sounds would be perceived and that she, therefore, consulted the other students in the group to get an idea of which frequencies that could be felt. S5 mentioned that the vibration speakers were more diverse than what he initially expected; not only lower frequencies produced good results. S2 described that he was surprised that various frequencies were perceived so differently, which was something that he actively used when creating his own sound files. He also mentioned that the workshop made him aware of the fact that you could create pulsating sensations.

For the final question about what could have been done differently, S1 mentioned that she wished that she would have visited the prototype platform a second time after the workshop, in order to try out her sounds. S2 mentioned that he would have wanted to work more on the composi-

tions in the actual installation at the museum.

#### 4.2.3 Project Reports

Interestingly, S1 noted that the vibrating platforms were greatly appreciated by a group of children with disabilities and that several of them burst into laughter when interacting with the strings. S3 also described a group of students in wheelchairs that visited the installation. Most of them were accompanied by personal assistants who demonstrated how sounds could be produced. S3 noted that these students spent longer time in the installation room compared to the average visitor. These visitors often stayed for a longer time at a particular string (a tendency we have also observed in previous work, see [1]).

Three students (S1, S3, S4) affirmed that the string/platform pairs that provided the strongest haptic feedback were the most popular ones. S1 observed that the most popular string/platform for her composition was the one providing a low-frequency filter sweep, not the one providing vocal music. Interestingly, S4 noted that the platform providing a clear sound of a bass drum was the most popular string/platform pair for her piece.

### 5. DISCUSSION

We observed that students successfully transferred knowledge obtained from the workshop to the tactile composition task. Even composers who did not attend the workshop managed to successfully create perceivable tactile sounds since they discussed the workshop with fellow students who had attended. In general, the project was much more successful than the previous iteration conducted the preceding year, as described in [1].

The way the music installation is presented to the students, i.e. how the preparatory workshop was organized, appears to influence the project outcomes; in the previous year, the mere fact that one of the organizing researchers mentioned that some frequencies and sensations might be perceived as “*unpleasant*” resulted in few composers daring to fully explore the potential of the tactile sound. This year, the students were encouraged to explore the vibratory properties of the platforms. More focus was also put on demonstrating a range of different vibratory possibilities of Sound Forest. This appears to have had a positive effect on the project outcomes.

Analysis of the sound files produced for the vibration speakers revealed that the sounds presented during the workshop might have influenced composition outcomes. For example, many of the sounds demonstrated during the workshop were sinewave sounds with amplitude envelopes held constant, similar to a lot of the samples produced by the students. The students appear to have focused mainly on exploring different frequency ranges in order to provide different haptic sensations, not on amplitude envelopes. For future sessions in which the vibration platform is demonstrated to composers, it will perhaps be good to focus more on a range of different sonic properties that can affect vibration sensations, such as choice of waveforms, envelopes, as well as frequency ranges. This will enable students to get a broader understanding of the cre-

ative potential brought by the vibration platform in terms of the produced sounds and corresponding haptic sensations.

Composing tactile sound was a new experience for all participating students and several of them commented on the need for more time with the equipment to explore and take advantage of the creative possibilities provided by the vibration platforms. The composition task could arguably be compared to composing for any acoustic instrument; it is, of course, important to have a solid understanding of the instruments’ acoustic possibilities. The students participating in this study normally produce music using Digital Audio Workstations, often using virtual instruments, which let them iteratively try out sounds, rhythms, and melodies. In the current study the process of composing and testing vibrations was disconnected. As such, the vibration platforms were not used to their full potential. One solution that would have benefited the composers in this project would have been to let them work undisturbed in the music installation for a much longer time.

When examining the audio files created by the students, it is obvious that the audible versus haptic channels were composed as relatively independent voices. It is worth noticing that we focused only on the vibrations and did not play any music through either the vibration speakers nor the normal speakers during the workshop session. Also we never discussed how vibrations and sound relate to each other and how they can be designed to present a united multimodal experience. This might have affected the way composers decoupled the experience of music from the haptic sensations. Composing for a multisensory experience might be considered as a particular discipline that requires a certain level of training.

Our results highlight the need for more large-scale studies on how whole-body vibrations are perceived in music contexts since significantly different bodily locations and perceived sensations were described for the same sound. Described sensations ranged from pleasant to very unpleasant; one student could perceive the sound as something inducing motion sickness while another might describe the sound as “*pleasant*”. It would be interesting to explore possible correlations between for example height and weight and perceived sensations. To conclude, it appears to be possible to produce different sensations (from positive to negative) using rather simple techniques; the samples used in the workshop were all based on quite simple sound synthesis methods. It would be interesting to develop a large haptic library for whole-body vibrations and to classify or systemize how different sounds are perceived.

Finally, observations made by several students suggested that children with disabilities stayed longer at platforms that presented distinct haptic feedback. It would be interesting to further explore the potential of using Sound Forest for musical explorations with haptic feedback for this particular user group, i.e., to compose haptic feedback specifically for these users. Furthermore, students observed that certain sounds were more popular than others. Suggestions for future studies involve composing a range of different sounds and simultaneously present them at dif-

ferent platforms in Sound Forest while observing tendencies in spontaneous behavior among visitors. In particular, it would be interesting to investigate if certain sounds are more popular than others and if and why visitors decide to stay at specific string/platform pairs.

## 6. CONCLUSIONS

Results from this exploratory work suggest that the Sound Forest installation has the potential to produce a range of different haptic experiences ranging from unpleasant to pleasant. We also observed considerable individual differences between participants in terms of associations, bodily locations in which the tactile sounds were perceived, and perceived pleasantness. As such, there is a need for more large-scale studies focusing on how whole-body vibrations are perceived. Finally, we can conclude that the composers' awareness of the possibilities of the haptic platforms can be improved through training. In order to fully explore the potentials of composing haptic music for Sound Forest, the composers need to have access to the installation, or a similar setup in a studio, throughout the composition process. This would allow composers to iteratively tune and optimize their haptic compositions.

## Acknowledgments

We would like to thank the composers Elsa, Frida, Gustav, Sebastian and Elina and the Museum of Performing Arts.

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