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Psychoacoustics of Sound Reproduction in Art Exhibits

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ABSTRACT

A study was conducted to understand how psychoacoustics can play a role in music "listening", particular in a small arts gallery. As the appreciation of a recorded audio of an exhibit can interfere with its adjacent exhibits, it is often very difficult to isolate individual exhibit's audio display without extensive sound abatement or control measures especially in the low frequencies range. In our study, high-frequency audio is extracted and played through small speakers while its low-frequency component is channelled to a vibration shaker mounted beneath a standing false flooring located in front of the exhibit. By making use of haptics in vibrotactile and psychoacoustics, a person standing on the false flooring is still able to "hear" and perceive the broad frequency spectrum without losing much listening pleasure. The location of the shaker on the false flooring is optimised through vibration measurements for maximum vibrational amplitude response.

1. INTRODUCTION

Acoustics in an arts gallery helps to create an ambience for a holistic experience in appreciating the exhibits on display. However, low frequency spectrum from a recorded audio source of one exhibit can interfere other adjacent exhibits and lose the holistic experience of the gallery itself. Particularly in smaller arts galleries, if an exhibit featuring soft and quiet recorded audio is located next to another exhibit with a recorded full bass spectrum, the strong bass spectrum will mask over the softer and quieter audio exhibit experience. Visitors to the gallery will not be able to get a complete experience out of each of the exhibit in the arts gallery.

For the exhibits, music recordings that contribute to the overall sound experience have to be aware of their recorded audio spectrum. For the bass frequencies to be heard, the audio may need to be played with increased amplitude. In order to isolate the audio exhibits effectively, some of the solutions explored include having curtains and wall partitions to enclose the low frequency spectrum exhibits. Another proposed solution studies the issuance of shoulder-mounted speakers for visitors or headphones where individuals are able to hear the exhibit's accompanying audio.

A study is conducted to understand how vibration can be used to reproduce only the low frequency spectrum of an audio track through a vibration shaker mounted beneath a false floor panel where a visitor stands in front of the exhibit. To reduce any masking interference from neighbouring exhibits, vibration is used to replace the low frequency spectrum of the sound recordings. Hence, if the high-range frequency contents are played through small speakers and its low-frequency content separately through vibrations only, the full audio spectrum can almost be replicated without interfering neighboring exhibits in an arts gallery. By making use of haptics in vibrotactile and psychoacoustics, a person standing on the false flooring is able to still "hear" and perceive a complete frequency spectrum without losing much listening pleasure.

2. PROTOTYPE

2.1 Physical Set-up

The prototype makes use of both the auditory and tactile perception to perceive a recorded music. We called it Ear&Tap (Exhibit Audio Reproduction and Tactile-Auditory Perception) Panel and it is a

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floor panel that a person can stand upon. Ear&Tap Panel (ETP) makes use of the ear to perceive audio and vibrotactile from the panel to perceive the fullness of the sound record's frequency spectrum.

The floor panel of the ETP prototype is made from a specially formulated cementitious compound. This compound reinforces the rigidity of the panel to stand uniform load resistance (1), which helps to transmit vibrations throughout the panel. Four steel pedestals were used and the panel is cornered lock to provide the boundary conditions for the vibration excitation. Table 1 below shows the specifications of the floor panel.

Table 1 – Floor panel specifications.

Panel System Type	Corner Lock
Weight	41 kg/m^2
Concentrated Static Load	454 kg
Ultimate Static Load	1374 kg
Uniform Static Load	2039 kg/m^2
Impact Load	68 kg
Pedestal Floor Height	150 mm
Pedestal Axial Load Tested	2296 kg

In order to ensure no tripping hazard to the person standing on the floor panel, a vibration shaker is installed at the underside of the floor panel. It is noticed that there are bumps and concave holes which does not make for a good flat surface to install the shaker. As the shaker requires a flat surface for vibrations to be fully transferred to the top surface where humans stand, an 8-mm flat aluminum plate is installed in between the floor panel and the shaker. Without knowing the best position for the shaker to be installed, a few mounting holes were drilled such that the shaker's position can be easily changed for the positional calibration process.

While installing the aluminum plate, another thing that was taken into consideration is the possible presence of vibration harmonics. When the shaker is vibrating on the aluminum plate, if the plate has too large an area vibrating freely without fixed boundary conditions, harmonics may be introduced. Hence, after careful consideration, the aluminum plate is fitted to only the areas where the shaker would be installed during calibration. Figure 1 shows the shaker and aluminum plate installed at the underside of the floor panel.

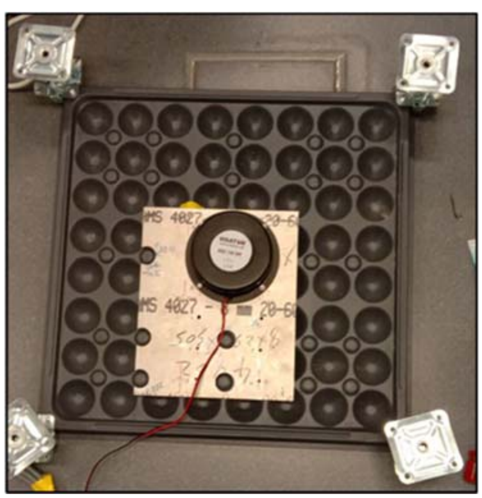

Figure 1 – Shaker and aluminum plate installed at the underside of a floor panel.

When the floor panel is upright, the shaker will be hanging underneath the aluminum plate in a fixed position. The shaker's vibration is concentrated to the aluminum plate, which is held by bolts secured to the floor panel. This creates the fixed boundary conditions. This vibration will then transmit through the floor panel to the top surface where a person stands.

The next step is to divide the frequencies of the audio track to channel the high- and mid-frequencies to two small speakers and the low frequencies to the shaker as vibration in order to test the overall audio experience. The final prototype setup for the ETP will additionally consist a laptop to play the edited audio tracks for the preliminary tests, and an adjustable gain amplifier to amplify the vibrations. Figure 2 shows the final prototype setup and Figure 3 shows the setup in its schematic form.

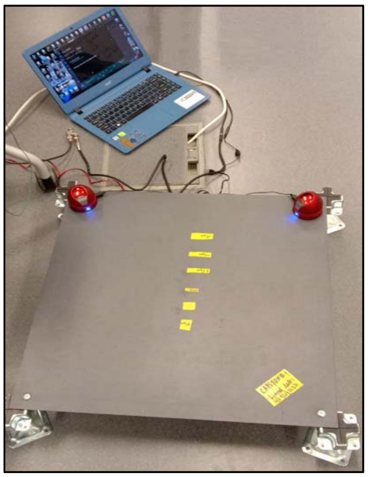

Figure 2 – Final prototype setup with audio speakers.

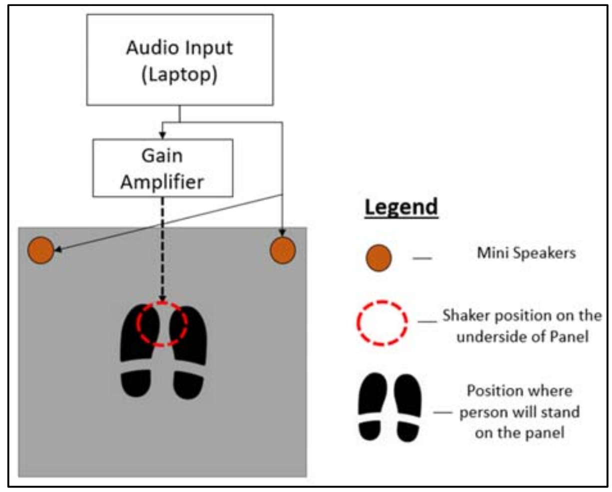

Figure 3 – Schematic diagram of improved prototype for audio reproduction.

2.2 Calibration

The best position for the shaker is where it produces the highest vibration amplitude on the floor panel felt by a person standing on it. In order to calibrate the prototype and test for the best shaker position, a tonal frequency generator is used together with an adjustable amplifier, an accelerometer and an oscilloscope. Figure 4 shows the setup of the calibration process.

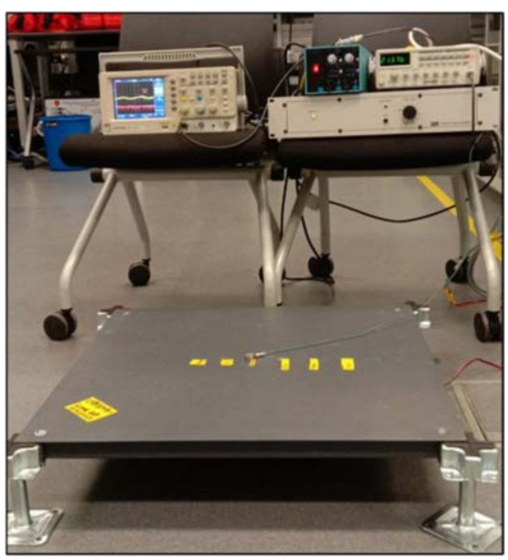

Figure 4 – Complete experimental setup.

To ensure the accuracy of the accelerometer and the reliability of the prototype, a simple calibration exercise is also conducted where measurements are taken at different positions of the aluminum plate. While there is no distortion in frequency transmission from the shaker to the aluminum plate, results show a drop in the magnitude gain of approximately 30dB from the shaker to the floor panel, likely due to energy absorption of the floor panel. The best shaker position chosen should eventually be one where any frequency distortion and amplitude loss are the least.

The calibration process measures 2 points. Measured points are designed to figure the amount of vibration lost due to the transfer of energy through the floor panel and also to check that the ball and heel of the feet can sense appreciable vibrations generated. Following, the experimental trials will test three different scenarios of the location of the shaker. For the case in scenario 1, as the two measuring points are the same, hence only one set of readings was measured. For the other scenarios, there will be two measuring points to determine the amplitude and frequency of the vibration transmitted by the shaker. As shown in Figure 5, the schematic diagram of the scenarios and measuring points are outlined, showing from the top view of the prototype.

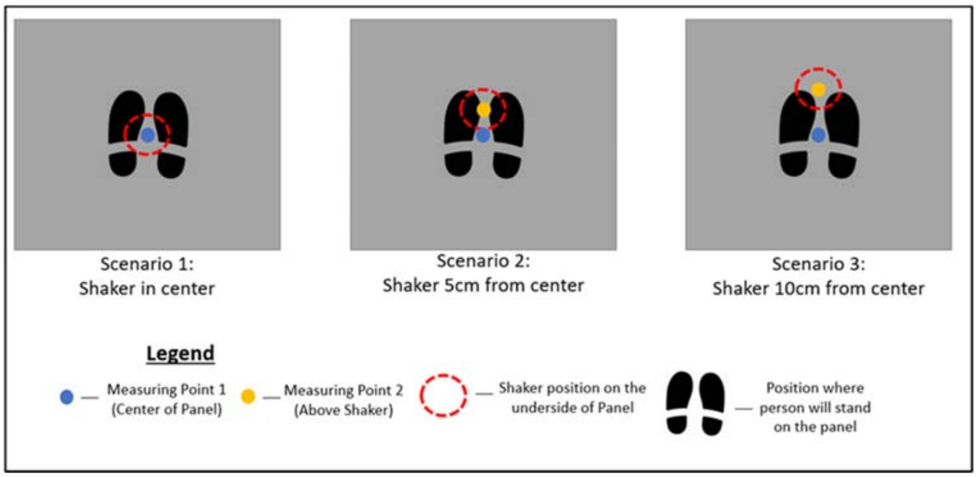

Figure 5 – Schematic diagram of scenarios and measuring points.

According to Gu and Griffin (2), human feet can sense frequencies between 20Hz to 250Hz, with the heel being more sensitive to 20 and 31.5 Hz and the ball of the feet being sensitive to 63 Hz to 250 Hz. Hence, the test will be conducted with single pure tones in the 1-1 octave, from 31.5 Hz to 250 Hz. In total, four different frequencies (31.5 Hz, 63 Hz, 125 Hz and 250 Hz) are tested in each scenario and this is shown in Figures 6 to 9. The master gain value on the amplifier is fixed throughout all tests.

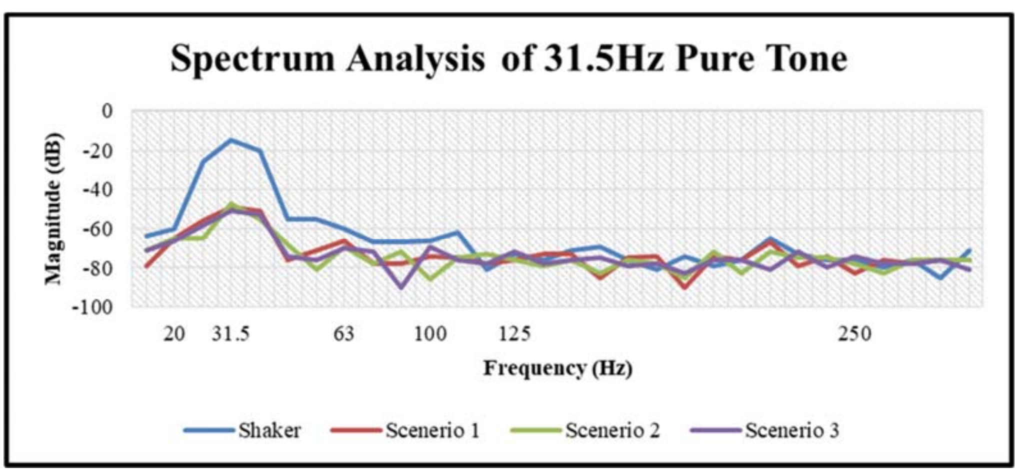

Figure 6 – Spectral analysis of 31.5Hz pure tone in the three scenarios.

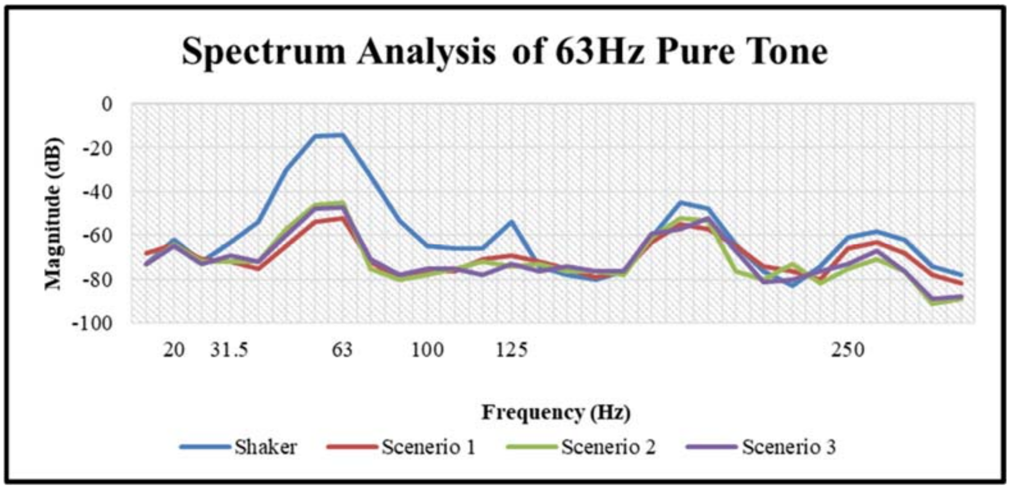

Figure 7 – Spectral analysis of 63Hz pure tone in the three scenarios.

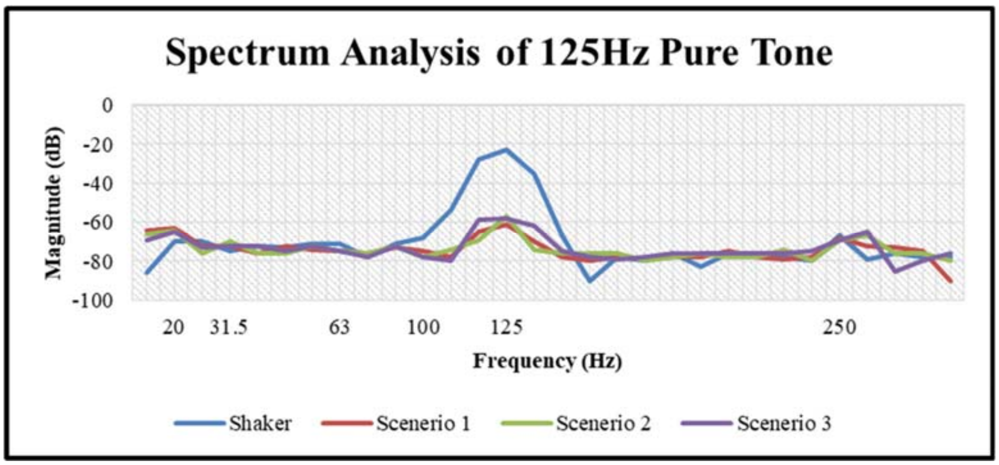

Figure 8 – Spectral analysis of 125Hz pure tone in the three scenarios.

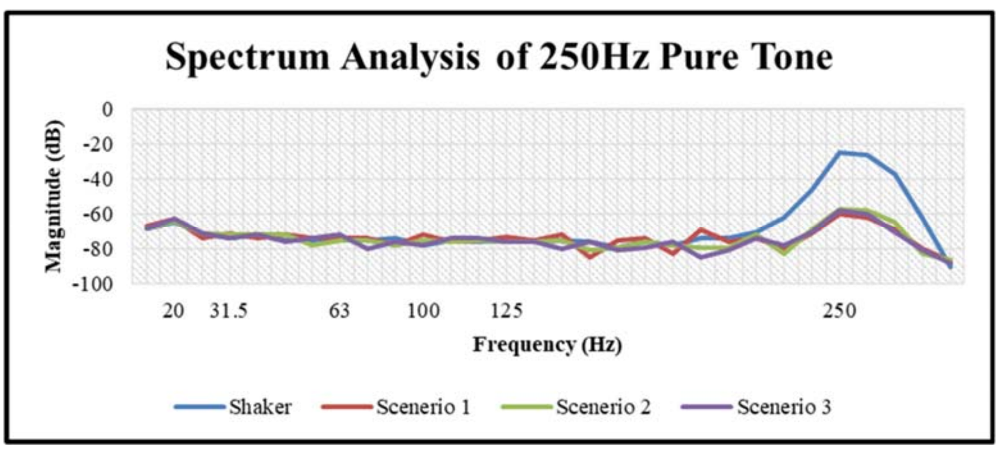

Figure 9 – Spectral analysis of 250Hz pure tone in the three scenarios.

It can be observed that there is no significant frequency distortion from the shaker to the floor panel. This can be seen from the graphs where all three scenarios have a peak in magnitude gain at the source frequency. The 30dB loss from shaker to the three scenarios is also noticed in all cases. Comparing the region where the peak in amplitude occurs, Scenario 2 reads the highest amplitude for magnitude gain compared to the other two scenarios across all four frequencies. Scenario 1 records some loss in magnitude with respect to Scenario 2 as the vibration excitation point and recording point are the same on the surface. Scenario 3 reads lower magnitude compared to Scenario 2 as well. From the figures, Scenario 1 records a slightly better amplitude when 31.5Hz is used. Scenario 3 records a slightly better amplitude when frequencies of 63Hz, 125Hz and 250Hz are used. Even though the loss is minimal between the three scenarios, it is still better to use the scenario with the least amplitude loss. The results suggest that the best position to have the shaker installed is as in Scenario 2.

In terms of vibrotactile, all four frequency tones can be felt on the panel when a person is standing on the panel. However, it was also observed that at 31.5Hz and 250Hz tones, they seem to be more resoundingly felt, causing some discomfort when a person is exposed to it for a prolonged period of time. However, a person will not be exposed to these specific frequencies extensively only since most audio tracks consist of a wide frequency spectrum. Studies have shown that different body parts are sensitive to different frequencies of vibration, wherein if vibrations are not well controlled, they can cause discomfort or adverse after-effects (3).

3. EXPERIMENT AND REPLICATION

3.1 Audio Reproduction

Following the calibration of the prototype, a simple test is conducted to achieve audio and tactile pairing. Audio from a laptop is chanelled into a set of mini speakers and the shaker separately. Expectedly, the mini speakers are lacking in the low frequency spectrum while the shaker lacks in the high frequency spectrum. The audio and vibration is recorded and the frequency spectrum is analysed using an audio editing software called Audacity. The frequency spectrums of the audio played through the speaker only, vibrations transmitted through the shaker only, and both speaker and shaker are shown in Figure 10, 11 and 12, respectively.

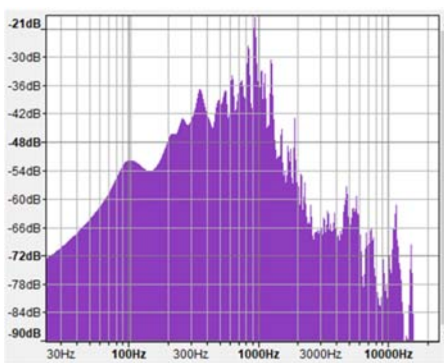

Figure 10 – Frequency spectrum of speaker only.

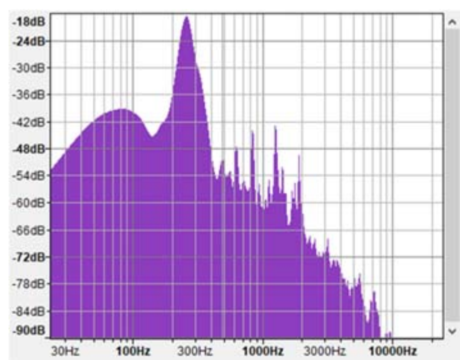

Figure 11 – Frequency spectrum of shaker only.

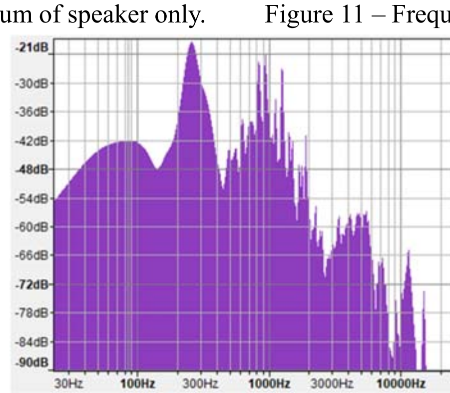

Figure 12 – Frequency spectrum of the prototype (speaker and shaker).

When an audio track is played to the prototype, a couple of observations can be made. Firstly, before stepping on the panel, the high frequency sound can be clearly perceived from the mini speakers. The low frequency vibration from the floor panel is not so clearly hear auditorily and can only be better perceived only when the person steps on the floor panel as shown in Figure 13 and 14. Since the mini speakers reproduce the high-frequency range well and the shaker at low-frequency range, it is noticed that mid-range frequencies can also be experienced by the person standing on the floor panel. Hence, through the prototype, a person is still able to perceive the fullness of the audio track's frequency spectrum.

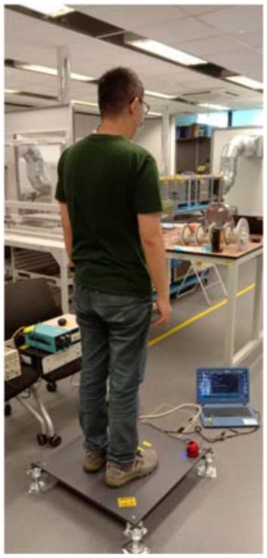

Figure 13 – Back view of a person using ETP.

Figure 14 – Side view of a person using ETP.

3.2 Exhibit Replication

A side-by-side exhibit replication is done to test the music reproduction and perception using the prototype. Unedited music sample tracks are played through the prototype. At the same time, at approximately one meter away from the prototype, another music sample is played at higher volume through separate a pair of large speakers. This sample is played at higher volume such that the low frequency tones can be perceived auditorily. Standing in the middle of the two audio cross-paths, expectedly the higher volume music sample is masking out some of the high range tones from the prototype's speakers. As the prototype is playing the low-range frequencies through the shaker, low frequency tones were not auditorily heard. As such, it does appear as if the prototype is not playing any audio. However, when a person steps up onto the prototype, the vibration immediately brings out the tactile sensing in the low-frequency tones. With the help of this vibration, a person is able to perceive the high frequency audio from the small speakers as well. This results in the perception of the full frequency spectrum independent from the interference of the music sample that is playing at higher volume. While standing on the prototype, it is also noted that the person can be focused on the music sample track coming from the prototype. It did not result in distractions coming from the neighboring audio that is playing at higher volume.

The observations can be better understood as effects of localisation and haptics. Localisation is when a person is able to indicate the location of the sound source (4). When the person is standing in the middle of the two audio cross-paths, the audio playing at higher volume will masked out the audio from the prototype which is playing at about 60% of the higher volume. Hence, the person may not be able to localise the audio from the prototype. When the person steps onto the vibrating floor panel, haptics trigger his sense of touch and draw his attention to the source where vibration and accompanying sound are generated. Haptics perception is known as human's natural ability to recognise objects through the sense of touch (5). Humans have developed a keen sense to touch when feeling objects in order to assure ourselves of their reality (6). Haptics, hence, increases interaction and engagement. When both hearing and touch senses are alerted to the same source, localisation in psychoacoustics will ensure that the person follows and pair both the sound and accompanying vibration together. This is known as absolute localisation, which is a person's ability to judge the absolute position of the sound source (7). Therefore, the audio playing at higher volume at one meter away will not interfere with the audio perception of the person on the prototype at all.

4. BENEFITS

4.1 Easy to Implement

The ETP can be easily installed to any exhibits that require audio reproduction. The setup simply involves a floor panel with a shaker and the high-frequency audio source. The panel is easy to fix and remove depending on the needs of the exhibition space. Hence, an exhibition space can have more than one such panel installed. It is also possible to implement if the exhibition space already uses a raised floor with panel grids. When an exhibit requires music, the normal floor panel can be removed and replace with the ETP. When the exhibition is over, the ETP can be removed and the normal floor panel installed back on the grid accordingly. Since it is easy to be removed, maintenance needed on the ETP can be easily done when required. Wires for the shaker and amplifier can be stored under the floor panel making the area neat and safe for people to move around.

4.2 Interference to Neighboring Exhibits

As tested during the exhibit replication, the prototype ETP will result in minimal to no interference with the neighboring exhibits. Sound and vibration generated are generally localised to the panel. In an exhibition space that has raised floor with grids, the grids and pedestals will normally have rubber pads installed for vibration absorption, just like the original construction of the panel. These will help to further absorb and isolate any excess vibrations from being transmitted to neighboring panels.

5. CONCLUSION

The ETP makes use of more than one sensory input to perceive music. When more than one senses is used, audio perception is improved. While the floor panel prototype works well in transmitting vibration and sound, there is still room for improvement to allow for more seamless transmission of audio and tactile through the different exhibits in the exhibition space. Psychoacoustics and vibrotactile of music reproduction in exhibits will definitely reduce exhibit-to-exhibit interference. This will improve the general holistic experience of exhibitions and galleries.

Combining human senses sense of hearing with the sense of touch can improve the overall audio perception as demonstrated in this case study. Vibration is used to generate the low-frequency range to improve the psychoacoustics of sound perception. By understanding how the human brain perceive different sensory information, vibrotactile can help to inform a deeper auditory appreciation of music. This can in turn help to overcome physical limitations or sound interferences where the music is delivered.

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