Dissertation

Reiwa 6 Year (2024)

# Design of Multi-Stimuli for Interactive Environment Prompting Desired Human Behavior

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Graduate School of Bionics, Computer and Media Sciences

Major in Media Sciences

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博士論文 令和 6 年度 (2024)

# 望ましい人間行動を促すインタラクティブ環境を創る刺激のデザイン

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# Dissertation Abstract

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| Title | Design of Multi-Stimuli for Interactive Environment Prompting Desired Human Behavior |
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| Keyword | Interaction design, human behavioral response, interactive environment |

**[Abstract]**

This research proposes a design concept for ambient computing, in which digital functions are realized as part of the environment to subtly influence human behavior. The main idea is to design a digital prompt that individuals will react to instinctively without consciously thinking about it. As nowadays most of today's digital functions are realized as smartphone apps, and one of the problems, that is, the concentration of digital applications on smartphones impairs people's awareness. My objective is to design interaction to seamlessly integrate the interaction between human and ambient digital functions in daily life. I intend to design such a prompt that would be ubiquitous without being noticeable; the proposed system would be used to investigate a human behavioral response through digital techniques. Furthermore, I aim to create a new type of interaction between digital function and people that does not require people's intentional interaction, and implement examples, and evaluate the effectiveness of the approach. The design concept is not to "operate" the system, but to realize it as part of the environment, and to design interactions that not only hide the physical presence of the system but also integrate it naturally into the context of a particular situation, thereby making the function "transparent" from the viewer. I have also implemented a system that utilizes sound and underfloor vibration as presenting examples, thereby validating the above concept. The results demonstrated that individuals adjusted their behavior to align with the environment without intentional effort, suggesting that the stimuli effectively influence awareness. This finding is crucial for refining the system design and expanding its function to broader contexts. The research culminates in the design interactions of ambient digital functions that match seamlessly into the context. The core ideas of the study are clarified through concrete implementations and experiments, providing a solid foundation for future interaction of people and digital functions in diverse settings.

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# Chapter 1

# Introduction

In our daily lives, we frequently observe people misbehaving in the public manner or unaware of public uses in their surroundings [1]. One of the reasons, that is, the concentration of digital applications on smartphones that impairs people' s awareness (Figure 1.1). Based on this background, the unexpected accident could happen from these major behavioral problems in public space if the issue is not being solved [2]. Such as texting while walking, talking on cell phones, or using a mobile device with headphones to listen to music while walking. These routine activities may cause people to be unaware of situations around them that could result in injury – or even worse – death [3, 4].

Figure1.1 Use of smartphone while walking.

Moreover, nowadays many convenient things are realized as smartphone apps, mobile users spend 86% of their time on these apps [5]. Hence, in my motivation, I proposed innovative design concept for digital function that differs from smartphone applications. I would like to free people from having to give commands or operate applications. Additionally, I would like to explore new ways for people to interact with digital functions in the future.

I propose innovative design concept for digital function that differs from smartphone apps. This approach creates a sense of dynamic environmental changes, prompting immediate reactions. I considered designing a stimulus to present that change. My approach works on one’s instinctive reaction rather than on one’s conscience. I considered designing a sensation using a nudging for that strategy. I attempt to make a stimulus effective in the context of each situation. The stimulus should not be a warning signal but an incident seamlessly integrated into living environments. “seamlessly integrated” means not only installing the system physically into the surroundings. The stimulus has to be designed to make the interaction natural with the situation’s context.

In this dissertation, I applied my approach to different examples of the scenario into our environments such as one when a person may not notice the opposite door in an elevator, and one where people are not aware the safe distance in the seat during the COVID-19 pandemic situation. Based on this, I came up an idea of creating the sensation to arouse people for these situations where people feel as if something is occurring in a certain moment. That is, I provided “environmental occuring” with that a person feel something occurring and would react instinctively. The idea is to design a sophisticated stimulus suits the context, and utilize it to prompting people’s awareness of their situational context. I then made the decision to “design occuring” by utilizing and process the multi-stimulation such as vibration and sound in each specific situation to realize such a sensation. The entire system components—which are referred to as an “interactive environment” included an interactive floor surface was implemented to produce a series of vibrations that mimics natural phenomena in a specific surrounding context. Besides, the 3D directional speakers are designed in a specific environment context. I also examined behavioral responses utilizing the floor surface and 3D directional sound systems to observe if it can cause the desired subsequent action.

As I present a design concept for integrating digital functionality into living environment, there is no need for intentional engagement through operations or commands. There are design approaches that inspired my design concept, that is, Nudge Theory, Ambient Computing, Interaction Design, and Haptic Interface. Thaler et al. [6] introduced the concept of nudge, which is a concept of designed environments to influence a human to take an action desired in a specific (e.g., nudges use in digital and physical environments [7, 8, 9, 10, 11, 12, 13, 14, 15]). Besides, ambient computing (e.g., the automation of tasks at home with an ambient physical display [16, 17]), interaction design (e.g., creating the design solution of functions in the context [18, 19]). And Haptic Interface (e.g., the digital emerges beyond the surface into the physical environment [20, 21]) which also affects my proposed design approach, uses a digital function where systems can interact directly with people everywhere. That is, the impact of instinctive behavior on human responses through environmental changes.

This study proposes a design concept for ambient computing, in which digital functions are realized as part of the environment, and examines the effectiveness of the concept through implementation examples. While most of today's digital functions are used by conscious manipulation by people, I anticipate that digital functions will constitute part of people's living environment in the future, and my objective is to propose how the functions should be devised at that time. The design concept is not to "operate" the system, but to realize it as part of the environment, and to design interactions that not only hide the physical presence of the system, but also integrate it naturally into the context of a particular situation, thereby making the function "transparent" from the viewer. I have also implemented a system that utilizes sound and underfloor vibration as presenting examples, thereby validating the above concept. This design proposal and demonstration differs from the conventional approach of realizing such a system as a smartphone application, and will make a significant contribution to this field by showing how digital functions should be in the future.

I designed stimuli with different scenarios based on my core idea of the design placing stimuli in living environment. For example, I utilized and processed the vibrations underfoot to realize such for a sensation, an interactive floor was implemented to produce a series of vibrations that mimics natural phenomena in a specific surrounding context [22]. Similarly, the virtual representation of sound utilizing the directional 3D audio effect which mimicked the mosquito buzzing that causes the desired person to feel anxiety or fear in a specific situation [23]. I expected that people would unintentionally adjust themself through their instinctive reaction in the specific context. Based on my prior researches, I confirmed my approach's validity and aimed to expand the approach with the same core idea.

In my research process, I designed digital support for the cases in which it needs to prompt a person's action. I also Implemented a system that does not work on people’ s conscience and attention but considers something that a person reflects without paying a thought. Finally, I evaluated approaches to sound and vibration in environmental contexts.

Contributions of this proposal include:

1. Development of the expanded design from my core idea of integrating an ambient digital function into a part of environments.
2. Proposition of a system design approach that outlines the capability of an interactive environment in various situations.
3. Providing a framework for the development of the research area and concept, which my approach does more instinctive response to prompt the desired behavior.

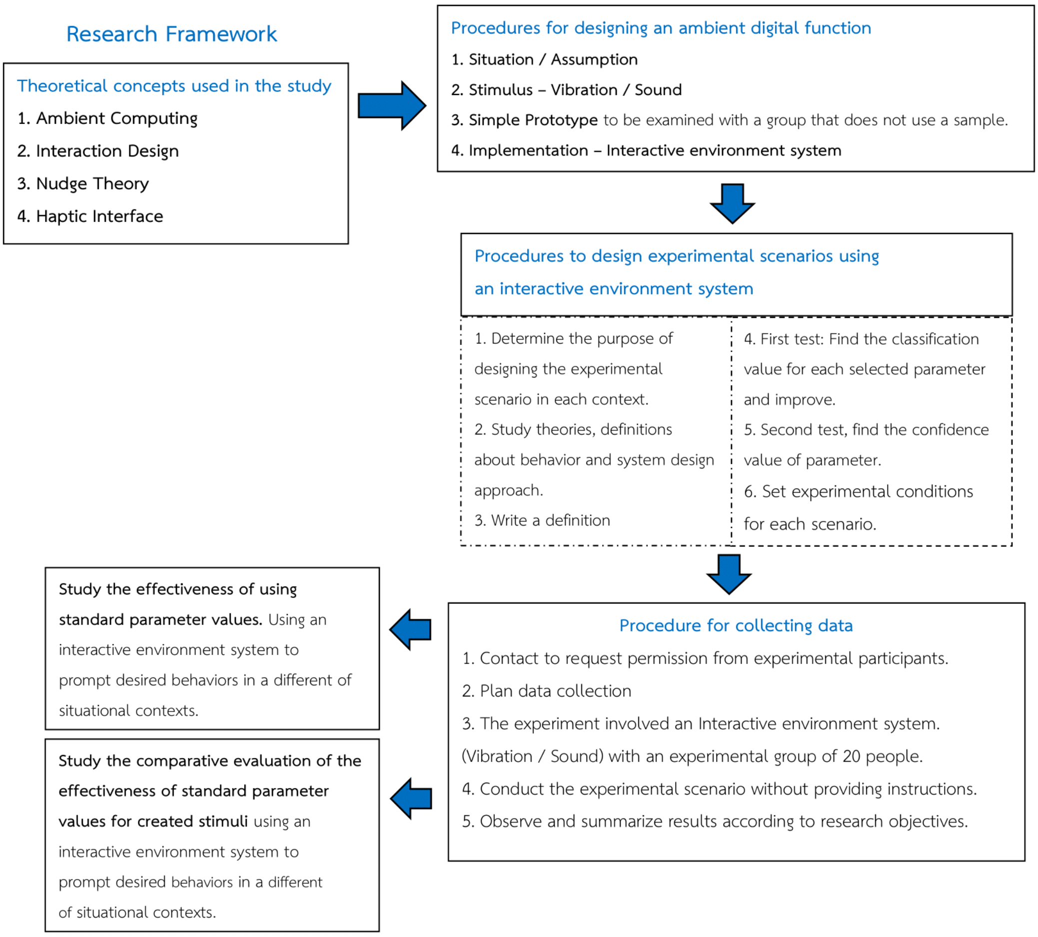


Figure1.2 Research Framework

# Chapter 2

# Literature

## 2.1 Concepts

### 2.1.1 Ambient Computing and Interaction Design

The concept of ambient computing has a significant impact on my research as I construct the system. It is a concept that has roots in Mark Weiser' s ubiquitous computing [24], but has now reconsidered its importance when discussing the future vision of computer usage [25], [26]. Similarly, the Internet of Things (IoT) is maturing from "ambient computing" [17], that is, the backdrop of sensors, devices, intelligence, and agents that can put the IoT to work. It is the idea of having sensors imbedded throughout a number of different devices, then being able to use data from those sensors to trigger actions. For example – the usage of IoT devices is rapidly growing. Many users may want to add them to their homes to automate certain tasks, help themselves with information, or monitor their environment continuously. Quick IoT development is taking place on privacy, protocols, and other areas. However, the user interface area is being left out of the efforts. Mobile applications and websites are merely focused on technical requirements. The prior studies outlines the possibility of integrating digital functionalities that are both physically and usability integrated into everyday environments and that interact with human activities without requiring a command.

In relation to research on interaction design, [18, 19]. A wide range of disciplines, including psychology, human-computer interaction, information architecture, and user research, are incorporated into interaction design to produce designs that are specifically catered to the requirements and preferences of users. The concept on interaction design involves figuring out the context in which the function will be used and establishing toward the goals and behaviors of the user, and creating design solutions that meet the needs and desires of the user. My proposal aims to design stimuli by borrowing the concept of ambient computing and interaction design to create a new type of interaction between digital function and a person that a function does not require intentional interaction of people within a given context. Therefore, my approach would be broadly used without being noticeable to itself; the proposed system would be utilized to use digital techniques to investigate into human behavioral responses in the context.

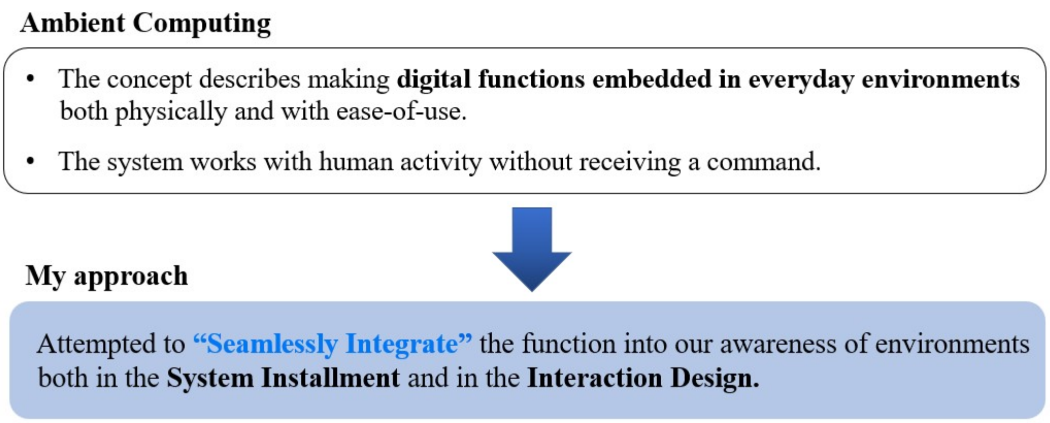


Figure2.1 My idea of approach for integrating a function into environments.

### 2.1.2 Behavioral Sciences and Nudge Theory

In everyday life, we interact with a constantly changing environment that presents us with multiple objects and action opportunities [1]. Against this background, theories on the action control are designed for successful operation or commanding the human action. For example, the binding theory is addressed that the features of multiple stimuli and executed responses can be integrated together in one event file. Binding of stimuli and responses has been identified as a critical mechanism in behavioral action regulation. Perceived stimulus or external properties (such as touch, sound, color, and position) and executed responses are recorded simultaneously in one short-term memory tasks [27, 28]. Similarly, nudges [6] is a concept based on human behavior insights that aims to alter environments to increase the chance of specific actions. When applied to the digital context, digital nudging is described as the use of user-interface (UI) design features to guide choices or alter the physical effort in terms of searching and finding item on social media by manipulating UI design components that it affects user responses in online context [7, 8, 9]. Besides, researchers and designers attempted to integrate multiple stimuli (e.g., light and sound) utilizing digital functions into the human living environment to influence the behavioral control and to use interactive technology to design playful experiences (e.g. public areas and transportations [10, 11, 12, 13, 14]). Likewise, Adolphs [29] stated that humans experience anxiety and fear in response to stimuli that occur in their environment, and also when they merely think about them where the stimuli are not occur. This aspect of human anxiety or fear induction mostly contributes to human response that they are highly dependent on conscious experience and environmental context. However, there has been a few empirical studies that underlies digital function and behavioral economics (e.g., nudge concept) integrating in human living environments that does not operate or require people's intentional interaction.

Hence, in this proposal, I highlighted the aforementioned challenge by examining the human response utilizing an interactive environment. That is, integrated stimuli by utilizing digital means such as, vibration and sound approaches. Installing each in a specific situation which designs strategy to create feelings to a person (e.g., anxiety/fear and fun/joyful) in the environmental context. These stimuli are transferred to prompt a person's desired reaction responses in situational changes that does not require people intentional interaction in the specific situation.

The position of this proposal is based on the benchmark of the nudge in the HCI area [30]; They distinguish nudges into four categories based on two variables: mode of thinking engaged (e.g., automatic vs. reflective) and the transparency of a nudge (e.g., if the user can perceive the intentions and means behind the nudge).

This classifies nudges into this proposal that intends between ones to influence behavior (automatic-transparent, e.g., the designed environmental changes) and ones that intend to prompt reflective (reflective-transparent, e.g., the designed stimulus to prompt the desired behavioral response). I intend nudges possess this characteristic as form of paternalistic learning. Nudges work by providing contextual features (i.e., a change of the environmental context) that take advantage of the human instinct to prompt people' s instinctive responses (e.g., a reaction) in a specific situation.

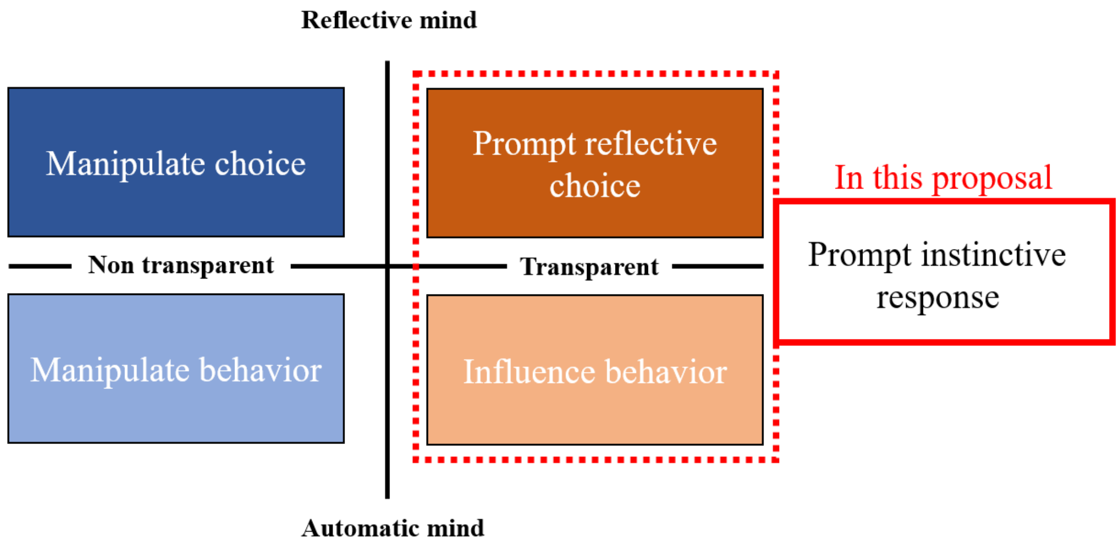

Figure2.2 The position of my proposal in nudge benchmarks obtained in the HCI field.

### 2.1.3 Haptic Interface for Feet

There are many studies on variable aspects of haptic interfaces that requires constant hand interactions or additional devices, such as shape displays (e.g., shape displays [31, 32, 33]) or (e.g., shape-changing mobile phones [34, 35]). This barrier restricts the research community to prototype and explore applications beyond human hand. My study addresses the aforementioned challenge by developing the haptic interface for the perception experienced (e.g., feet) and aims to explore possible applications through the designed stimulus in a specific situation.

The conventional haptic interface for whole-body has been implemented in the study on the large-scale shape-changing interfaces. Ryo et al. introduces LiftTiles [36], modular inflatable actuators for prototyping room-scale shape-changing interfaces. That is, a user can sit down and step on to simulate the shape of an object to facilitate designers in various indoor situations. Similarly, Teng et al. [37] proposed the concept of dynamically providing supporting shapes that are scaled to the entire human body through shape-changing floor tiles for facilitating virtual environments.

Besides, the conventional haptic interface for the foot sole has been evaluated in the study on vibrotactile display. Visell et al. [38, 39] explored possible uses of such floor interfaces in daily environments. Magana et al. [40] presented an on-shoe tactile display to examine the human interpretation of the information through their feet. Similarly, Keigo et al. [41] presented haptic interfaces that is extended to the feet to enhance foot-based activities, such as guidance while walking or stepping on virtual textures. However, Magana et al. addressed the haptic feedback with a conventional tactile interface is insufficient for accurate recognition of shapes. Because the haptic interface cannot deform the structure if it is excitated by dynamic force, which has the same frequency as the natural frequency of the structure, the shape has no unit. In this proposal, my approach is based on the shape-changing interface theory [36, 37, 42, 43, 44]. It allows specific deformations as physical changes of the actuated surface array range from the basic height that presents more detailed physical haptic feedback than haptic feedback with a conventional method regarding shapes. Therefore, I utilized the ambient digital stimuli to directly interact with users using the advantage of a haptic interface to deliver the tactile sensation to human perception for feet. Furthermore, as my approach intended to free people from commanding or operating applications that the system will react to a person' s action in a specific situation. That is, a function does not need intentional manipulation from a human' s side on a system or device. My proposal differs from operating or receiving commands from devices to use applications or interact with the system (e.g., an integration of a system into shoes, cloth, sticks, and AR glass [45, 48]), which is out of my scope.

Meanwhile, haptic interface, given either on the skin' s surface or directly to the brain via vibration stimulation in the somatosensory cortex [45], could be used to prompt people while they are distracted. In creating a vibration system to distract people from their actions. I can first distinguish several sensory input/output channels between the environmental context and the user. In line with its predominance in the benchmark [46], the common interaction modalities in public environments were used such as visual stimulation. However, using visual feedback in particular circumstances while people are distracted is insufficient to capture people' s attention because it requires sustained visual attention to absorb the information [47]. Such as in the elevator and the social distancing situations while people are distracted and unaware of changes in the environment. Thus, utilizing haptic interface via vibration stimulation which can directly convey information to human's feet tends to be the first idea of mine. I then designed a floor vibration system for prompting jostling oblivious people.

Hence, in this proposal, my approach proposed utilizing an interactive surface array that can transform the subtle-like movement to induce people in a specific situation. I highlight the use of a method to provide a stimulus in which an interactive floor is not simply conveying messages, but molding digital technique-mediated nudging to impact the human desired behavior.

## 2.2 Researches

### 2.2.1 Tangible User Interface

As I build the system, Tangible User Interfaces (TUIs) have impacted my design approach. TUIs are an interface type that connects the digital and physical worlds (e.g., the digital emerges beyond the surface into the physical environment [48, 36, 31, 21, 20]). TUIs have the ability to improve how people engage with and use digital information by leveraging users' knowledge and abilities of interacting with the actual, non-digital world. However, more studies of TUI research are needed to fully comprehend the consequences of tangible user interfaces, to create innovative technologies that further connect the digital and physical worlds, and to provide empirical knowledge to guide TUI design.

My approach to design stimuli is influenced by empirical studies. Below are some references to research on physical interactions utilizing actuation approach. Poupyrev et al. [49] propose Lumen, a low resolution 13 $\times$ 13 pixel bit-map display with individual pixel up/down movement, as an example of a shape-shifting display. This makes it possible to have tangible 3D controls that can actually be pressed down, as well as a moving physical shape or texture that enhances a 2D visual display. SproutI/O [50] uses shape-memory alloys combined with textiles to provide a touch-sensitive, kinetic display made of soft textile.

Studied in the field of product design as well, where movement, also known as "behavioral expression" offers a way to boost a product's expressiveness [51]. Because human sight has a natural tendency toward animism, movement may give abstract forms the appearance of life [52]. For instance, the LED on the Mac laptop blinks periodically and softly to simulate breathing. Additionally, products have the ability to move physically, adding a fourth dimension to design. Young et al. [53] distinguish between organic, random, and mechanistic movement as well as path, volume, direction, and velocity as components of an object movement language. Even variations in speed, acceleration, route type and volume, rhythm, and unpredictability can be used by product movement to convey emotions [54].

Another great example of how to use actuation subtly to almost imperceptibly ease a work is given by the Linguabytes project [55]. Multi-handicapped toddlers with motor disability benefit from this learning technique. When a physical item is placed on a platform, it guides their hand (if the RFID tag is recognized, electromagnets pull the piece into place) and features a slider that automatically restricts range based on the position of the piece. Some TUIs use actuation, such as vibrotactile feedback on data that is picked up and sent to a portable device [56].

Regarding the digital emerges beyond the surface into the physical environment, users interact directly. Interaction with TUIs is not limited to the visual and aural senses, but also relies on the sense of touch. In this proposal, I utilized the TUIs design aspect to make the interface natural in the context. The proposed interactive environment system is able to evoke the sensations of touch and hearing to influence human behavioral responses. I created a system that mimics natural events utilizing designed stimuli. Besides, I designed occurring to create a series of stimuli that simulated environmental occurring in a specific context utilizing vibration and sound systems.

### 2.2.2 Audible-Sound Traditional/Directional Approaches

There are studies on the ambient intervention sound to affect the behavioral response. Thaler et al. [6] used the example of people in various music stages being tempted by music and being instructed on their choices in the danger of the sirens and their irresistible songs. However, in my proposal, I emphasize using a nudge signal to directly impact the human's instinct where they can promptly response about situational changes rather than deciding on choices. Studies on sound based on the aversiveness levels for sounds, John et al. [57] they designed ambient sound that are an integral component of a real-time behavioral intervention to reduce secondhand smoke exposure in homes. This ambient sound can be engineered to shape behavior independent of, or synergistically (e.g., brief coaching and education [58, 59]). Besides, Thoma et al. [60] they examined music effects across endocrine, autonomic, cognitive, and emotional domains of the human stress response. Jikke et al. [61] they addressed the influence of sound on human performance of the indoor sound environment on people. However, limited studies on sound intervention have been evaluated based on digital nudge aspects for desired behavioral responses. In this proposal, my proposed method uses the virtual representation of a mimicking and rhythmic sound stimulus when people feel the beat or source changes and imagine the situation where they take the desired response. This can prompt people to work on a nudge and influence them to take the specific action unintentionally in the designed situation.

The directional sound stimulation is one of the most common aspects of stimulus and real-world interactions. Sound waves, unlike light rays, have a reduced directivity and are picked up by listeners who were not specifically targeted by the speaker. Conventional loudspeakers are essentially omnidirectional, which is typically undesirable in public spaces. In ubiquitous computing, a solution that can offer varied sound information to the target user is desired (in other words, non-wearable computing). Ochiai et al. [62] present an ultrasound-based approach for spatial audio rendering. The increased audience selectivity implies that our sound-point loudspeaker can transmit sound to the target person's ears. Similarlly, Muramatsu et al. [63] for example, present a real-time indoor dynamic acoustic field creation system for a spot audio directed at a specific person. The directional loudspeakers are sub-unit arrays (small audible-sound loudspeakers). All of the sub-units are driven by a certain signal, resulting in the output of plane sound waves. A narrow sound beam is formed by the plane waves of audible sound [64]. Beam steering is also feasible [65]. Although these loudspeakers create sound beams at a restricted angle, all people standing inside that angle get audio information. A super-directional ultrasonic loudspeaker [66] based on the self-demodulation effect of air, uses ultrasonic plane waves as an end-fire array of audible-sound sources to form a narrower sound beam. In this case, listeners are subjected to high-intensity ultrasounds. The creation of sound spots in the air is another type of sound manipulation. By adjusting time delays, or phase delays, between the loudspeakers, an array of loudspeakers forms focus points of audible sound waves (e.g., phased-array control) [67]. Another approach employs several ultrasound-based super-directional loudspeakers to produce the audible sound at ultrasonic beam crossing places [68].

However, in contrast, in this proposal, I hightlighted the way how to provide the designed stimulus to impact the desired behavioral response. I intend to design such a stimulus not like giving a simple notification or conveying audio information to the target person, but by molding digital techniques-mediated nudging so that it can impact people psychologically to stop the unmannered activities in public spaces.

### 2.2.3 Human Perceptions and Effects of the External Stimulation

The tactile sensory of the foot has been extensively studied. Johnson et al. [69] addressed two types of mechanoreceptors can be found: type I and II. Type I cells have small well-defined receptive areas and are sensitive to low frequencies (5-40Hz) (200-25ms). Type II cells have large hard-to-bound receptive areas and are sensitive to high frequencies (100-300Hz) (10-3.33ms). There are four types of mechanoreceptors can be found: slow adapting type I (SAI), slow adapting type II (SAII), fast adapting type I (FAI), and fast adapting type II (FAII). Ramiro et al. [70] reported that FAI cells constitute the majority by far and, as already mentioned, they are sensitive to vibrations. It seems then that stimulation of FAI mechanoreceptors is more suitable for information transmission to the foot. They addressed the guidelines for the spatial discrimination and the delivered force for the foot sole. Concerning spatial discrimination, the median receptive field size for FAI cells is 0.38 cm with the spacing between 0.058 cm to 3.336 cm. Concerning force, FAI units can be activated with forces between 0.071 to 28.75 gf, with a median of 1.2 gf.

These insights can be implemented through an interactive surface in the floor setting stage described in this proposal, either as a central or a complementary feature. There has been a study on an isolated haptic phenomenon on the vibration that represents the smallest unit of a constructed haptic signal. Enriquez et al. [71] addressed that the haptic phonemes can be combined serially or in parallel to form haptic words, or haptic icons, which can hold more elaborate meanings for the users. This lead to the fundamental theory of producing the rhythmic grouping [72], using the proposed vibration method which is based on a multi-time scale decomposition of the human nerve response to which meaning can be assigned via the vibration phenomenon. Similarly, the studies on the rhythm of sound theory. Neil et al. [73] stated that a rhythmic sequence can be influenced by rhythmic factors, i.e., timing and dynamics that are the influence of the fundamental temporal closeness that everything else being equal, i.e., intensity, pace, articulation of the events in the sequence the rhythmic process does not last endlessly. This is due to the fact that brain activity connected with events preceding longer gaps has more time to accumulate.

Besides, Neil et al. [74] developed a sensory-motor theory of rhythm, such as a form of sensory-guided action incorporating all of the sensory and motor components that involves, such as essential aspects of the nervous system and the muscular system that it regulates. They interact with the perception of rhythmic time, and beat induction would reflect temporal information for sensory-guided action. Using the Short-Term Memory (STM) to recognize a temporal series of events.

Similarly, the auditory perception, the sound output in this proposal can be influenced by using a sensory-motor theory of rhythm to the intended human response as a nudge in the given scenario. Cyril et al. addressed that the frequency range of human hearing is generally considered as 20 – 20,000 Hz [75]. The upper range varies greatly among individuals and decreases with age and noise exposure. The amplitude of human's sensation ranges from the threshold of hearing ( 0 dB) to thresholds of discomfort and pain (above 140 dB).

Besides, there are studies on the virtual environment using the sound stimulus based on the cognitive theory of emotions for the study of how emotions are affected by game sound. Toprac et al. [76] stated that the sound properties are reduced to three independent variables: volume, timing, and source. These are three of the most basic properties of sound that are considered when designing the soundscape of a virtual environment. Volume is the relative loudness at which a sound is heard from a loudspeaker. Timing is the relative synchronization of the sound with its source. The source is the origin of a sound. However, we proposed using the sound stimulus based on our design strategy [77]. To cause the feeling of anxiety and fear to work as a nudge to prompt people about the situational changes in a real environment where the human living environment can be facilitated.

In this proposal, based on my investigation, the model of digital means can keep track of the interval time of salient events and volumes. I attempted to produce such a stimulus in a specific situation using the proposed virtual representation and rhythm of the vibration and sound stimulation. This can be applied to my approach in producing designed stimuli parameters. I expected human's responses to the changes of the intervention of designed stimuli to impact their feelings such an anxiety or fear. I evaluated the effectiveness of my approach by impacting a digital stimulus to people's instincts and observing the effects of human responses in a specific situation.

# Chapter 3

# Concept

## 3.1 Background and General Idea

In this study, I aimed to design the sensation to impact people' s reaction who does not behave properly in their surrounding or unaware of the public uses. I proposed utilizing a digital stimulus that would be seamlessly integrated into an environmental context. The most relevant literature reviews that influenced my approach in this proposal were those that discussed how ambient computing affects the design strategy for integrating ambient digital functionalities into environments. Additionally, the concept of nudges has a significant impact on how I indirectly prompt desired behavior. I would like to realize it as not a simple beeping or a warning signal, but a representation that affect human' s instinctive reaction. A simple signal represents a message, but needs to be noticed by people, that is, such an approach tries to appeal to one' s conscience, but unfortunately easier to be ignored.

My idea is to create a design that seamlessly integrates a digital function into the living environment. To achieve that objective for the design strategy, there are 3 conditions in the design process as follows: 1. a physically hidden system in the background, 2. allows interaction to occur naturally within the context of the circumstance, and 3. prevent the user from comprehending the message and instead prompt thoughtful response. The strategy to make the interaction ambient includes it as well. Hence, in order to give feedback on the interaction, I want to use a subtle stimulus as using it for nudging by appealing to a person' s reflection.

In this Section, I examine a person' s reflection of a stimulus as the preliminary experiment by using simple digital stimuli such as vibration, sound, and visual. Then I observe the human response to the stimuli as a foundation for designing the digital stimulation mentioned in Section 3.2.

## 3.2 Preliminary Research

In this section, I carried experiments to examine a person' s reaction to simple stimuli to be a supplement to support my approach. The purpose of this experiment is to show that a person will react to simple stimulus unconsciously. To ensure the validity of this research idea, the multimodal perceptions were selected such as sound, pressure, and visual modality to be fundamentals in application scenarios which I designed in Section 3.3. Besides, I examined on how participant's reaction to simple stimuli as a basis for the system design and the designed stimulus following the subsection below.

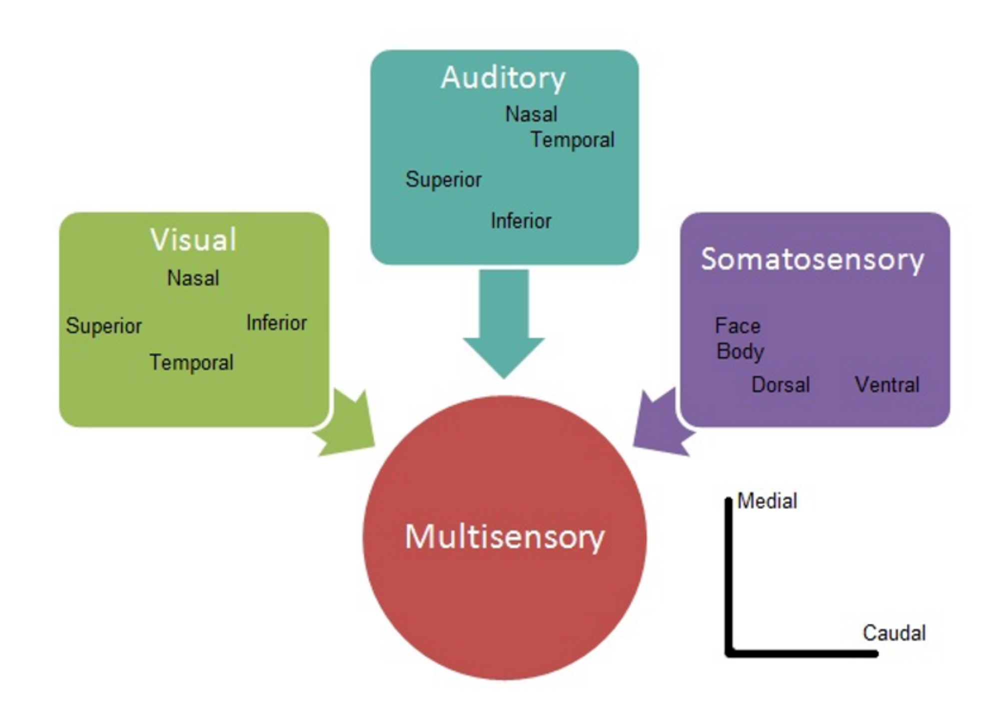


Figure3.1 Location of visual, auditory and somatosensory perception in the superior colliculus of the brain [78].

### 3.2.1 Evaluation of Pressure Modality

To design the sense of the haptic stimulus, I examined how the human responses to simple vibration stimulus. According to the fundamental to design the stimulus in the sense of touch, or tactile perception, which it allows organisms to feel the situational changes around a person. The environment acts as an external stimulus, and tactile perception is the act of passively exploring the world to simply sense it. To make sense of the stimuli, an organism will undergo active exploration, or haptic perception, by moving their hands, feet or other areas with environment-skin contact [79].

#### 3.2.1.1 Procedure

In experimental procedure, participants were examined individually in the appropriate room to exclude all sources of sensations except the proposed haptic stimulus. Prior to the trial, a participant was requested to stand in the center of the room without any kind of instruction (Figure 3.2, left) while I prepared another person to stand next to the participant. Later on, person manually provides a simple haptic stimulation by poking participant with elbow (Figure 3.2, right). The experimenter afterwards observes their responses and interviews participants.


Figure3.2 Participants in the experimental field

#### 3.2.1.2 Experimental Condition

In this section I defined the experimental condition mentioned in Table 3.1. The participants were asked to cover their eyes and ears. The experimenter provided tactile feedback by poking an examinee with an elbow. I prepared a poking pattern in 3 variables. The duration of the stimulation is two seconds for one time, this is based on my findings, which most participants responded to the increased prompt of the behavioral trial. Each stimulus pattern will be presented twice and stop stimulating when participants react.

Table3.1 Experimental condition

| Subject | Condition |
|---|---|
| Wearable | The participants were asked to cover their eyes and ears. |
| Environment | Laboratory room |
| Stimulus control | Tactile feedback by poking an examinee with elbow. |
| Poking pattern | (1) One time, (2) Two times, and (3) Three times |
| Duration of stimulation | The duration of the stimulation performing for two seconds for one time. |
| Time | Each stimulus pattern will be presented twice and stop stimulating when participants react. |
| Sex | The experiment involved 5 participants (1 female and 4 males; average age: 20 years). |
| Data collection | I collected 3 (poking pattern) x 1 (time) = 3 trial data per participant. |

#### 3.2.1.3 Result

In this investigation, I manually poked participant with an elbow to provide a basic haptic stimulation. Regarding the participant interviews, almost all of them reported feeling as though something was touching their body. I observed that when the subject was manually poked, he/she would unconsciously move slightly in response. The participants felt that they had been nudged or pushed to move. Some people are quite concerned that the contact will result in anything harmful. Furthermore, I discovered that as the frequency of touching increased, individuals became more conscious, to the point where some were startled by pokes. Regarding the experimental results, I can assure the validity of this research's idea and confirm that a person will react to simple stimuli unconsciously such as vibration stimuli without any instruction. So that the vibration stimuli can be utilized for my proposed system to impact human behavioral responses.

### 3.2.2 Evaluation of Sound Modality

To observe how a person' s reaction to simple sound stimulus, I examined the stimulus modality for hearing, that is, sound that he reacts in that situational changes. As sound is created through changes in the pressure of the air, an object vibrates, it compresses the surrounding molecules of air as it moves towards a given point and expands to move away from the point [80]. In this experiment, I set up the sound stimulus so that I could observe how a subject responded to a simple sound.

#### 3.2.2.1 Procedure

In the experimental procedure, participants were examined individually in the appropriate room to exclude all sources of sensations except the proposed sound stimulus. Before to the trial, a participant was requested to stand in the center of the room without any kind of instruction (Figure 3.3, left). I placed loudspeakers in front of the participants, keeping them out of view. Later on, I manually play an unpleasant sound from a speaker (screaming sound) (Figure 3.3, right). The experimenter afterwards observes their responses and interview participants.


Figure3.3 Participants in the experimental field

#### 3.2.2.2 Experimental Condition

In this section I defined the experimental condition mentioned in Table 3.2. Before starting the experiment participants were asked to cover their eyes. I prepared the screaming sound source, which based on the examination to determine which unpleasant sound prompts a person' s reaction. I used 3 volume parameters such as (1) low volume [20dB], (2) medium volume [40dB], and (3) high volume [80dB]. Note that

I chose the loudness level based on the person’ s response. Besides, based on my findings, most participants responded to the increased prompt of the behavioral trail. The duration of the stimulation is two seconds for one time, this is based on my findings, which most participants responded to the given duration of the behavioral trial. Each stimulus pattern will be presented twice and stop stimulating when participants react.

Table3.2 Experimental condition

| Subject | Condition |
|---|---|
| Wearable | The participant asked to cover their eyes |
| Environment | Laboratory room |
| Stimulus control | Playing unpleasant sound from a speaker |
| Sound source | Screaming sound |
| Sound pattern (the loudness) | (1) Low volume [20dB], (2) Medium volume [40dB], and (3) High volume [80dB] |
| Duration of stimulation | The duration of the stimulation performing for two seconds for one time. |
| Time | Each stimulus pattern will be presented twice and stop stimulating when reaction. |
| Sex | The experiment involved 5 participants (1 females and 4 males; average age: 20 years). |
| Data collection | I collected 3 (sound pattern) x 1 (time) = 3 trial data per participant. |

#### 3.2.2.3 Result

In this study, I manually played an unpleasant sound—a screaming sound—to the participants in this investigation as a basic form of sound stimulation. Regarding the interview with the participants, almost all of them reported feeling and hearing something, like screams coming from the specific spot around. When participants were deliberately exposed to unpleasant sounds, I discovered that they would unconsciously respond to basic auditory stimulus. When they suddenly realized what was going on, a few people jumped and moved away. Others believed that the sound would cause something hazardous to occur. Additional investigation showed that when the sound's frequency grew, participants' awareness of the auditory stimuli in their surroundings increased as well; some even became scared of the louder sound. The experimental results demonstrate that people react unintentionally to simple stimuli, such as sound, without instruction. So that sound stimuli can be used in my proposed system to impact human behavioral reactions.

### 3.2.3 Evaluation of Light Modality

The stimulus modality for vision is light; the human eye is able to access only a limited section of the electromagnetic spectrum, between 380 and 760 nanometres [81]. Specific inhibitory responses that take place in the visual cortex help create a visual focus on a specific point rather than the entire surrounding situation [82].

#### 3.2.3.1 Procedure

In the experimental procedure, participants were tested individually in a completely darkened room (no daylight) to exclude all sources of sensations except the proposed visual stimulus. Before to the trial, a participant was requested to stand in the center of the room without any kind of instruction (Figure 3.4, left). Afterwards, the examiner uses a smartphone to manually control a flashlight pattern (using a brightness level that is not harmful to the eyes around 600 nits) that is pointed at the participant (Figure 3.4, right). The experimenter afterwards observes their responses and interview participants.

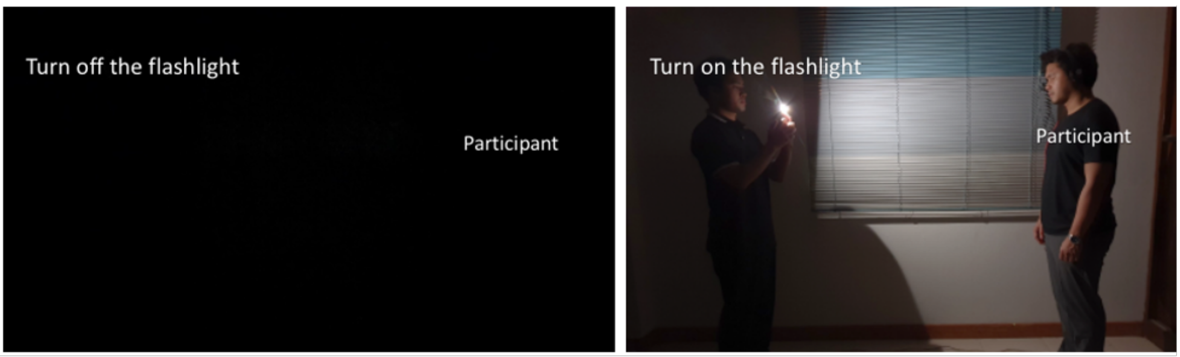


Figure3.4 Participants in the experimental field

#### 3.2.3.2 Experimental Condition

In this section I defined the experimental condition mentioned in Table 3.3. Before starting the examination, I instructed participants to cover their ears. The experimenter prepared a smartphone to manually control a flash light to deliver the visual stimulus to participants. The experimenter prepared light patterns (on and off) such as (1) Low interval speed (2000ms), (2) Medium interval speed (1000ms), and (3) High interval speed (500ms). Based on my findings, most participants responded to the increased prompt of the behavioral trial. The duration of the stimulation is two seconds for one time, this is based on my findings, most participants responded to the given duration of the behavioral trial. Each stimulus pattern will be presented twice and stop stimulating when participants react.

Table3.3 Experimental condition

| Subject | Condition |
|---|---|
| Wearable | The participant asked to cover their ears. |
| Environment | Laboratory room |
| Stimulus control | Use a smartphone to manually control a flash light. |
| Light pattern (on and off) | (1) Low interval speed (2000ms)<br>(2) Medium interval speed (1000ms)<br>(3) High interval speed (500ms) |
| Duration of stimulation | The duration of the stimulation performing for two seconds for one time. |
| Time | Each stimulus pattern will be presented twice and stop stimulating when reaction. |
| Sex | The experiment involved 5 participants (1 females and 4 males; average age: 20 years). |
| Data collection | I collected 3 (light pattern) x 1 (time) = 3 trial data per participant. |

#### 3.2.3.3 Result

In this proposal, I performed a simple light stimulation by manually control a flash light to participant. Regarding the participant' s interview, all of them were able to see something is happening at the spot of the light. I observed that when participants were manually presented to light, their unconscious reactions to basic visual stimuli occurred, as they turned away from the light source because they thought it was too bright. Because the light may be a warning message, some people feel that it makes them want to leave the area. Furthermore, I discovered that participants became more conscious when the light interval speed rose, to the point that some were taken aback by increased brightness. The results of the experiment show that individuals instinctively react to simple stimuli, such as light, without any prior instructions. This suggests that light stimuli can be utilized in my proposed system to influence human behavioral responses.

### 3.2.4 Discussion

In this section, I investigated a person' s reaction to simple stimuli to be a supplement to support my approach. Regarding experimental results, I can assure the validness of this research' s idea and confirm that a person will react to simple stimulus unconsciously such, visual, sound, and light stimuli without any instruction.

The present results clearly indicate a representation of a simple stimulus at a perceptual level. Yet this does not mean that a stimulus could never be represented at a conceptual level in general. Indeed, the present finding suggests that the representation of a stimulus at a conceptual level is not a general phenomenon that can be observed in every situation, but is dependent on specific task conditions. Certainly, the finding that the retrieval process is dependent on the repetition of the specific percept of the stimulus is in line with the assumption of a direct link between perception and action, independent of semantic processing.

I assumed that my proposed approach has the potential of conveying sensation to users and it could be further developed and applied the feature such, the floor surface and directional speaker prototype in a specific situation whether in central or partial parts. Besides, the findings confirmed my hypotheses participants had ability to perceive multiple stimulation modality. Most participants can distinguish changes in each single stimulus, they were affected by the level of designed stimulus's parameter to make them reacted to simple stimuli unconsciously.

## 3.3 Design Strategy

In my design concept, I proposed to design the sensation to prompt people's awareness of their surroundings and they would react instinctively. I attempted to design the interaction to create the intervention strategies. To make it happen, I place the system itself in the environment that is not only design the system in the context, but seamless integration the system into the context. So that the system will be natural in the view of context of function. Based on my idea, I provide the "environmental occurring", which people would feel something occurring that impacted the desired behavioral responses.

For designing the stimulation, I contextualized responses to people's everyday actions and designed response regarding to specific situations, which the response will be natural in the context. As for my design approach for creating a stimulus, I can distinguish the multi-stimuli of sensory input/output between people and environments. The most common interaction modalities were used to "design occurring" by digital means such as vibration, auditory, and visual approaches. These stimuli tend to be the first idea coming to my design concept. In my design process, I considered exploring the human cognitive response to multiple stimuli. And evaluated how effective my approach using an interactive environment was in prompting people in specific situations. Additionally, I demonstrated the potential and value of contributing to the same core idea into other cases.

I aimed to design one of such approach to meet a specific context and examine the validity of the concept. I do not pursuit to create a high effective warning in this research though. That is out of my scope here. In this proposal, I make use of an interaction design to develop intervention strategies that can stimulate human behavior in specific contexts. These design ideas could serve as a useful framework for discussing about my design intervention strategies at the current stage of my proposal. The strategies I design for each context include the following:

(1) Anxiety or fear strategy: in order to affect people's reactions to situations, I thought about utilizing the sensation of anxiety or fear in my design strategy. People faced to unexpected environmental changes, which causes them to respond differently in a specific environment context. The ideas show how to employ interactive environment to create anxiety/fear experiences that seamlessly integrates into the environmental context.

(2) Psychological barrier strategy: despite a rather individualistic view on daily

activity, my explorations also include concepts linked to psychological barriers. In an effort to impact people's behavior responses in the environment, I created a virtual representation of a specific sensation that would alter human behavioral responses.

(3) Fun and attractiveness strategy: the most commonly explored strategy is the use of fun or entertaining elements or gamified elements. My idea focused on designing a stimulus and seamless integration the approach into living environments to create playful experiences based on daily activities.

Based on my design strategies, I envisioned using designed stimuli to create intervention strategies in specific situations. In this proposal, the feasibility of the concepts of anxiety/fear and psychological barrier strategies were partially examined in relation to the core idea that I presented. I also present the possibilities of the expanded core idea by applying other strategies in specific situations such as fun and attractiveness strategy. It is also meant to inspire researchers and designers, and to pave the way for new designs and applications. And optimizing the role of an ambient digital function to impact human behavioral responses in boarder scope.

In this dissertation, I use two different stimulus types for different scenarios to be the example of my design approaches. Such as 1. using the sound stimulus explained in Chapter 4 and 2. using the vibration stimulus explained in Chapter 5.

# Chapter 4

# Using Sound Stimulus

In this section, I give an example scenario using my proposed approach. Besides, the functional system architecture, which includes the digital methods utilizing the series of sound approaches that is used in this proposal. The system components— which are referred to as "3D directional speaker" —that I implemented a system. I proposed a system to be incorporated into the design of living environments so that a system may induce a variety of different sensations to people in the environmental context (e.g., hearing). In a particular situation, I anticipated that the proposed approach can be seamlessly integrated and may affect people' s desired subsequent action.

## 4.1 Scenario

Imagine a group of people is sitting together (Figure 4.1, a) [23], unaware of the safe distance needed to adhere to COVID-19 prevention guidelines. They might be instructed by others to observe the safe distance, or notice something happening and feel anxiety or fear. In this case, I can assume that people will observe the safe distance or get up to avoid psychological discomfort. The aforementioned perception of something happening may be through a sensory modality, as hearing. Based on this natural situation, I selected to use a designed sound stimulus to produce the natural phenomena of mosquito buzzing.

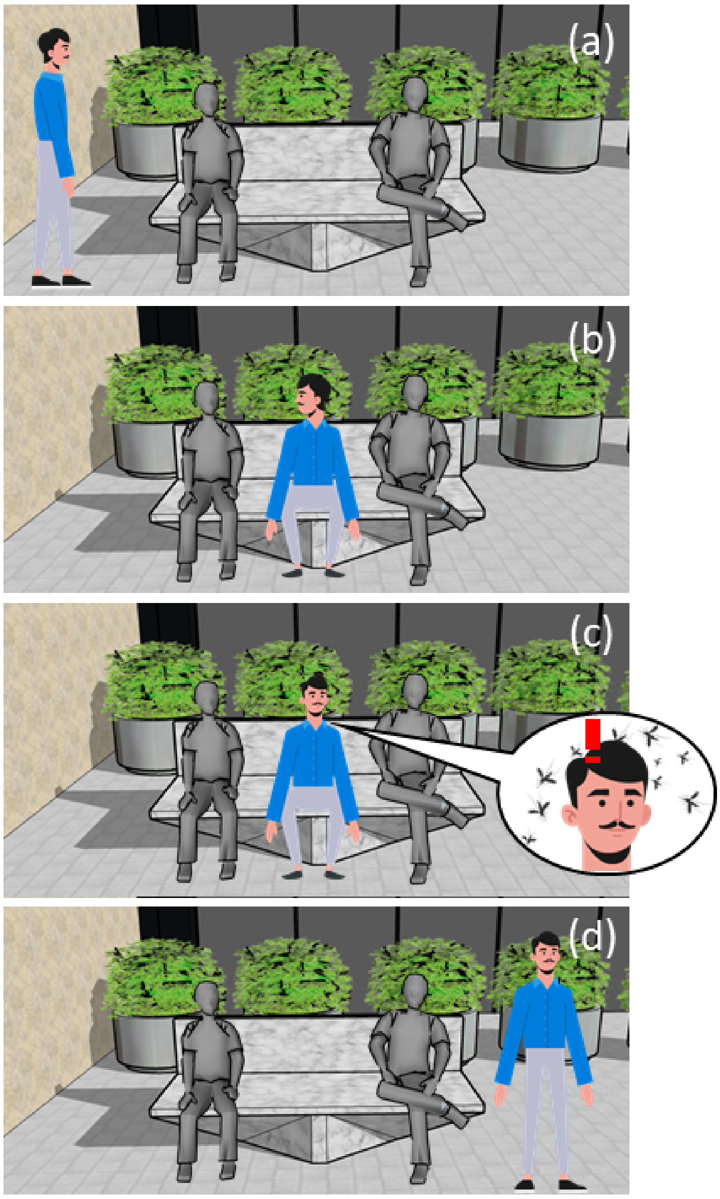


Figure4.1 Prompting a person of the safe distance while sitting

## 4.2 Stimulus Idea

In this scenario, the multi-directional speakers would surround the center seat, such that people would not notice the presence of the devices as well as in the ongoing shift toward Human-Environment Interaction (HEI) [83]. Where devices are becoming more naturally immersed into the environment, such that they are often ubiquitous yet unnoticed. The audio system would create a harmful psychological effect by delivering a mimic sound (e.g., mosquito buzzing) to the targeted person in the center seat. The designed sound stimulus transfers the prompt sound effect to arouse the target person, causing him to envision something adverse happening in his environmental context (Figure 4.1, b). The increased volume and rhythm of the mimic sound would be delivered to the targeted person, such that it becomes stronger at the surrounded target point where the specific person still sitting and disappears when the target person gets up. This design assumes that the person will feel anxiety or fear when they perceive a strong sound stimulus and when the sound source changes (Figure 4.1, c). In this case, a person hearing the mosquito buzzing mimic sounds would envision mosquitoes physically buzzing around them. As a response, I expect that the person would get up and move to the safe position at which point the stimulation vanishes (Figure 4.1, d). In this scenario, a designed sound stimulus was used to affect the desired behavioral response. When the sound source, rhythm, and volume changed, it can act as a nudge and would alter a person' s behavior, such that they unintentionally adjust oneself in social distancing.

## 4.3 System Implementation

I utilized four super directive speakers, each one consists of thirty-eight ultrasonic speaker array (Figure 4.2).

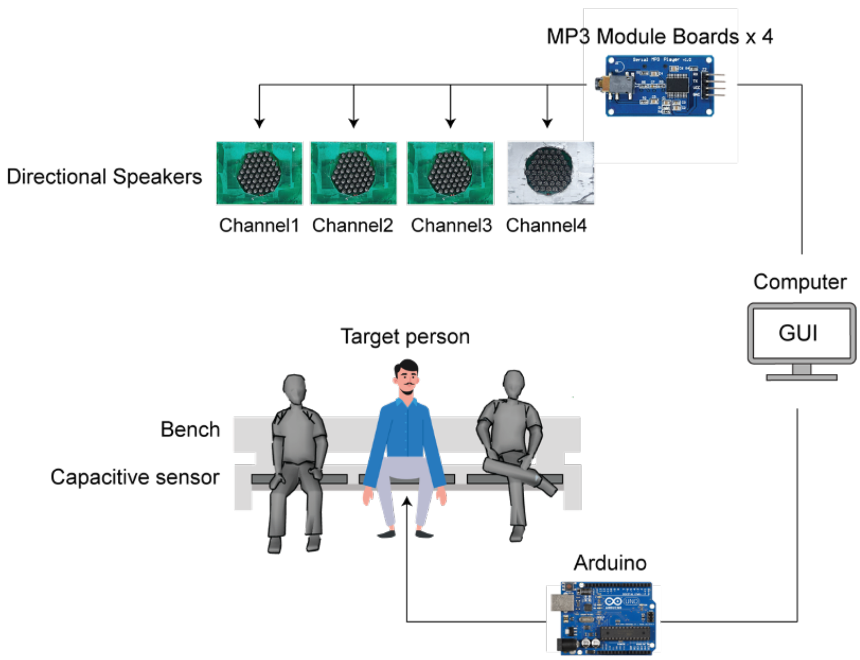


Figure4.2 The overview of 3D directional sound system

The audio interaction is produced by the directive speaker which is activated by the capacitive sensor beneath the seat surface (Figure 4.2). The purpose of this system is to create a sound stimulus and to generate an acoustic field to reach a specific area of the environmental context.

In the social distance in the seat scenario (Figure 4.1) [23], the directive speaker is powered, which means I used an additional amplifier that limits the maximum volume of the speaker, its power draw(max) at 50W. The speaker rated at 90[dB]/m, it could output up to 120 [dB] measured from one meter away. I used the maximum output of an amplifier is restricted by the power supply, which is 24V, as well as how well it can dissipate heat. I examined the preliminary experiment for selecting the designed position of the parametric speaker integrating into the scene. I set the position of the parametric speaker in front and back in the height of constant variables at (1) Low (the ground position), (2) Medium (ear position while sitting), and (3) High (above ear position) (Figure 4.5, b). The speaker's height position is based on each ground state that I increased the height equally. Besides, I set the difference distancing of the speaker's position at 1 to 5 meters away from the target position respectively. Noted that the super directive speaker's capacity can emit the sound wave ranging up to 5 meters approximately.

In my findings, every time I distance I will lose the sound pressure, so from 1-meter I would only get 120[dB], from 2-meter I would only get 114[dB], from 4-meter I would only get 108[dB] up to 5m respectively. Besides, this finding shows that without strict control of the ultrasonic principal signals, I can achieve the length limited effect. I assumed that I still can set up designing the directive speaker at any height and distance from defined positions to affect the human response. Hence, I then used these results to consider the design of the super directive speaker in the environmental context.

The audio interaction is produced by the loudspeaker to emit the sound to the desired area in the environmental context which is activated by the capacitive sensor (Figure 4.4). I can control and play the sound stimulus using both types of speakers via the MP3 audio files simultaneously or sequentially through MP3 Module Boards. And 4 Breakout Boards 74HC4067 where we input the sound source data in the Micro SD Card. These boards are controlled via 1 Arduino Mega 256 (Figure 4.3).

In this proposal, I intend to design such stimuli not like a simple notification or delivering the sound to the target person [57, 58, 59], but by molding the design effective technology-mediated nudges to produce such a stimulus by digital means in the environmental context physically. So that they affect people' s instinctive reaction.

I set the super directive speakers emitted to the desired target's seat using the design of environmental variables mentioned in Table 1. All speakers are circularly arranged with the spacing of 1-meter cm (Figure 4.5, above). This measurement is based on the center position from the target seat. Regarding, our preliminary experiment, I can set up speakers at any position which can affect the human response and the super directive speaker's capacity can emit a wave range up to 5 meters. Besides, I designed a directive speaker set suitably based on my design in this real environmental context. The first to the fourth speaker of the defined sound source are emitted respectively. Thus, the virtual representation of the sound feedback is created. I used the capacitive sensor installed onto the bench to activate when the examinee sits on it.

Table4.1 Environmental design for sound conditions

| Subject | Condition |
|---|---|
| Sampling frequency | 44100 Hz |
| Number of speakers | 4 |
| The angle θ for the directional characteristic | (No.1) 0° , (No.2) 135° ,<br>(No.3) 180° , and (No.4) 225° |
| The weather | Sunny |
| Temperature | 25 degrees |
| Sound duration | 5 seconds |
| Speaker sequence pattern | No.1 to no.4 (loops) |

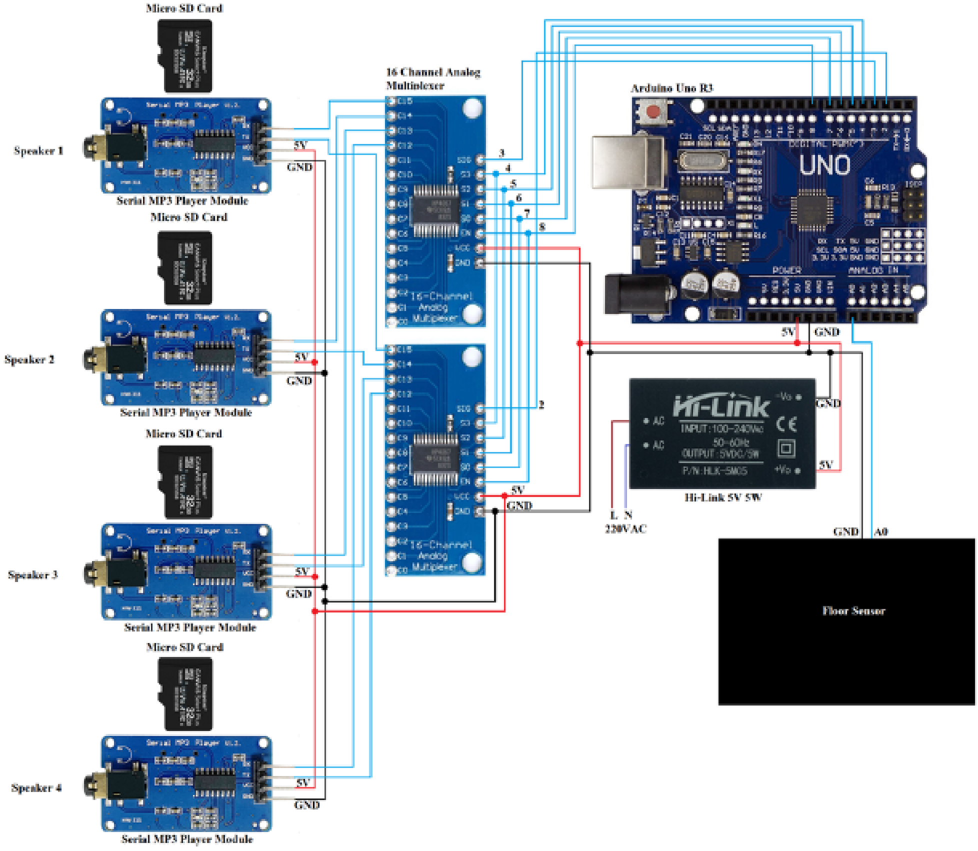


Figure4.3 The circuit design of the 3D directional sound system


Figure4.4 Hardware design in specific scenarios; the capacitive sensor

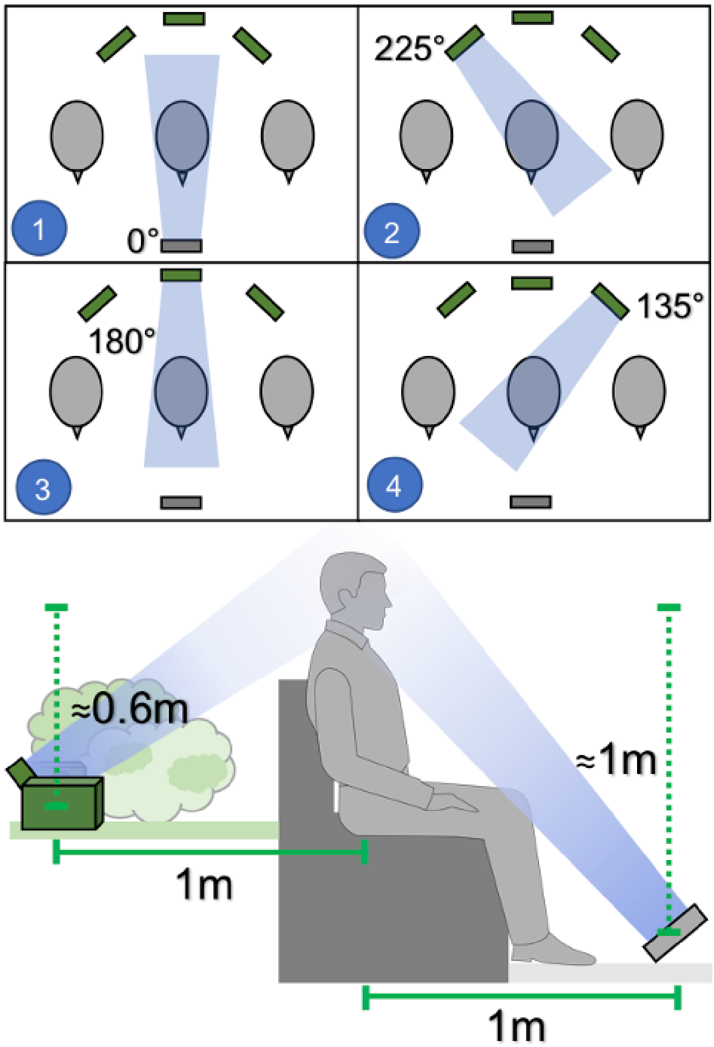


Figure4.5 (Above) The directional 3D audio effect and (Below) the distance adjustment of devices.

### 4.3.1 User Interface

#### 4.3.1.1 System Overview of Sound System

The software implementation of Interactive Environments comprised of two main systems: 1) the Visual Studio software running on a Windows OS computer, 2) the Arduino code running via the 1 Arduino Mega 2560 microcontrollers, and Each of the systems will be described in the following sections. Figure 4.6 shows the working order in controller system.

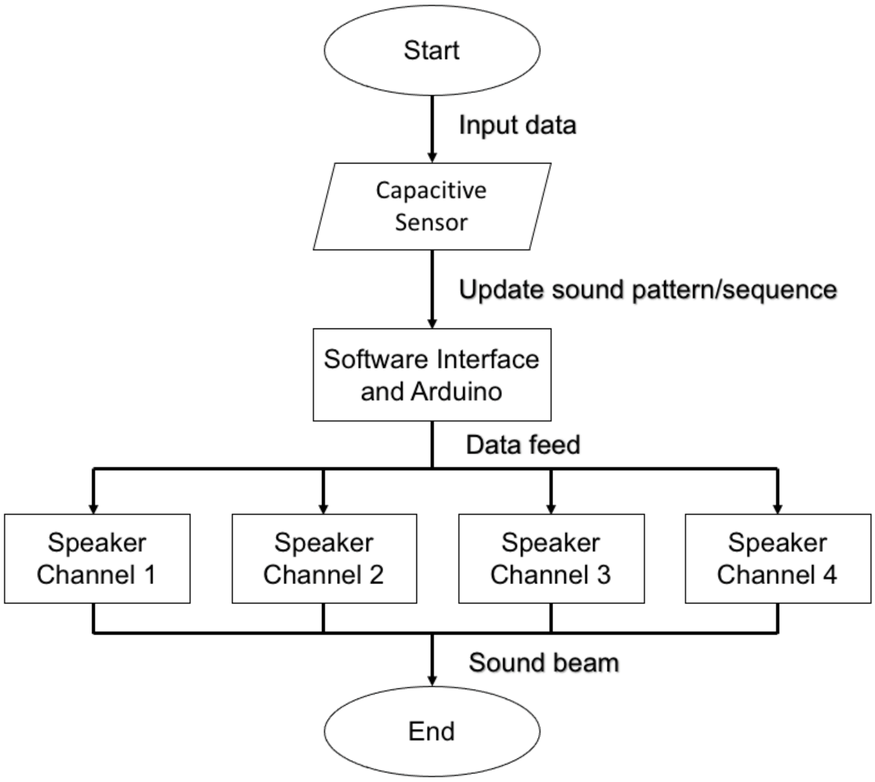


Figure4.6 Working order in controller system of sound

#### 4.3.1.2 System Controllers

The control software for sound system is entirely procedural. I prepare a GUI for the system (Figure 4.7), whereas the system is expected to work interactively with the situation and not controlled by a manipulating person. For the software interface control, the data were input into a GUI generator (to create sound patterns and sequences) by selecting selected speakers to be activated and setting their desired interval speed.

Using the GUI generator, I run the sound rhythm pattern. The proposed sound parameters are defined using the user interface's preset buttons. Audacity for Windows [84] was used to convert the selected sounds into pulsed sound rhythm patterns by modifying the frequency, speed, and the number of cycles each sound was repeated. Audio files containing audio signals were modified and stored as LPCM-encoded Waveform files at 44,100 samples per second and 16 bits per sample after being modified. It is controlled by the capacitive sensor beneath the seat (Figure 4.4). A user interface controls a coordinated stimulus that matches a sequence of sound patterns to provide the stimulation.

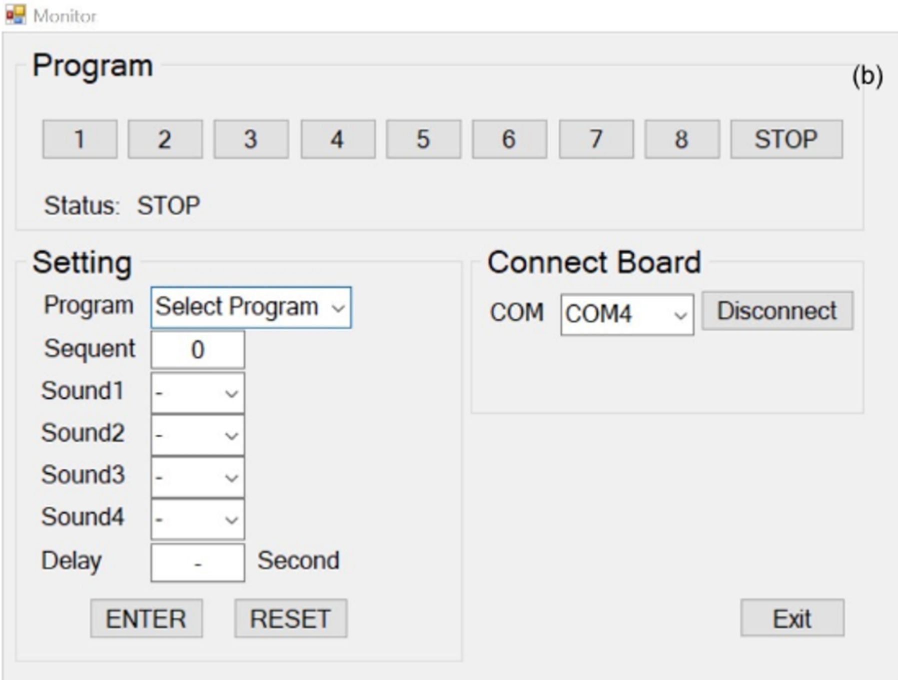


Figure4.7 Software interface that generates stimuli data; a sound control interface.

#### 4.3.1.3 Microcontroller

An Arduino code resides in the 1 microcontroller, it send back the height and current values of each motor back to the Arduino software. Besides, the Arduino software is responsible for sending the audio to the defined speaker. Communication between the Arduino and the microcontrollers is done via GUI interface.

Notably, a floor surface and sound systems, without master coordination from the Visual Studio software, a microcontroller only knows the position/current values of 4 directional speakers. The GUI interface software was written on the Visual Studio code, which coordinated the target heights of sound patterns. Then the GUI sent the target positions to the Arduino software, which then simply passed it onto the microcontrollers. Software interfaces require accuracy and speed. They were developed with minimal involvement from the operations to minimize delays.

### 4.3.2 The Designed Pattern of Stimuli

In this section, I described the design of digital means as stimuli. For example, sound patterns and rhythm grouping.

#### 4.3.2.1 Designed Sound Pattern and Rhythm Grouping

Additionally, I proposed the design of the virtual representation of the mimic sound using the 3D directional sound systems (Figure 5.10) to produce such a stimulus to affect the feeling of anxiety or fear in the specific the sitting scenario (Figure 4.1). Then the sound panel is explored for free sample sounds on the internet that could be utilized and/or adjusted to meet the sound selection criteria. At first, four sounds were initially identified for making an anxiety or fear feeling according to our designed intervention strategy in the outdoor environment context (1.Mosquitoes buzz, 2.Dogs barking, 3.Children scream, 4.Explosion sound and 5.UFO). The purpose of the survey was to evaluate the level of anxiety associated with each auditory intervention, as well as participant's reported behavioral responses to those sound sources. The survey questions produced the following variables: 10 participants were instructed to choose one of four sound sources in the survey. Respondents indicated how each sound made them feel anxiety the most in order of sound sources from 1 to 5, with 1 indicating very unconcerned to 5 indicating very concerned. The audio warnings for nudging the behavioral intervention in an environmental setting were chosen using the results of empirical sound experiments. The Mosquito Buzzing was shown to be the source of the most anxiety. It was chosen as a result of the findings. I selected the sound source (Mosquitoes buzz sound effects) that it can affect the human anxiety or annoying feeling to cause their response in the specific public bench scenario (Figure 4.1).

I examined a primary experiment for determining the criteria for the appropriate sound volume levels for nudging in the social distance scenario. Using a sound pressure level meter (SPL) to use for acoustic measurements and the directive speaker to emit sound sources in the actual experimental scenario. The primary results revealed that the participants had lower responses to slow vibration speed ranges under 40 [dB]. Furthermore, my data also suggested that most participants tended to perceive a wave speed above 40 [dB]. Therefore, I designed a number of different rates using assumed volume ranges for human hearing at: (1) Low 40 [dB], (2) Medium 80 [dB], and (3) High 120 [dB]. This selected volume's levels variables based on the closest ranges of the vibration speeds through the threshold of hearing ranges [75]. Regarding my previous observation and experiment increasing the loudness of volume levels can change the sensation to the examinee. Hence, I designed the increased volumes for hearing sensation mentioned in Table 4.2.

Table4.2 Variable used in the designed sound volume

| Subject | Condition |
|---|---|
| Increased sound volume | (1) Low: 0-40 [dB]<br>(2) Medium: 40-80 [dB]<br>(3) High: 80-120 [dB] |

I defined amplitude to be sufficiently loud to be heard over televisions and music played at a "normal" volume. So that, I chose the sound with tones of 800 Hz were considered the greatest frequency tolerable and the duration greater than 200 ms but less than 5000 ms according to the criteria of audio intervention for the behavioral response [84]. I choose the rhythm ranges correspond to the effect on the sensory-motor as the prior study at a number of different rates [73]. I also examined a primary experiment for determining the criteria for the appropriate rhythmic sound pattern and interval speed for prompting in the outdoor bench scenario. The interval sound speed can create by combining the simplest repeatable alternating sequence of a sound's on and off states with predefined interval speed lengths (500ms, 250ms, and 125ms) using the smallest unit alternating itself at 125ms. The primary results revealed that the participants had lower responses to the interval speed under 500 ms. Furthermore, our data also suggested that most participants tended to perceive the interval sound speed lower than 500 ms. Therefore, I designed several different rates for affecting a sensory-motor from; (1) Low (500ms), (2) Medium (250ms), and (3) High (125ms) (Figure 4.8). Regarding a primary experiment using the interval-produced process by increasing interval sound speeds can change the sensation to the examinee. Thus, I designed the increased interval sound speeds to impact the human cognitive response mentioned in Table 4.3.

Table4.3 Variable used in the designed sound speed

| Subject | Condition |
|---|---|
| Increased sound speed | (1) Low: (500-250ms)<br>(2) Medium (250-125ms)<br>(3) High: (125-62.5ms) |

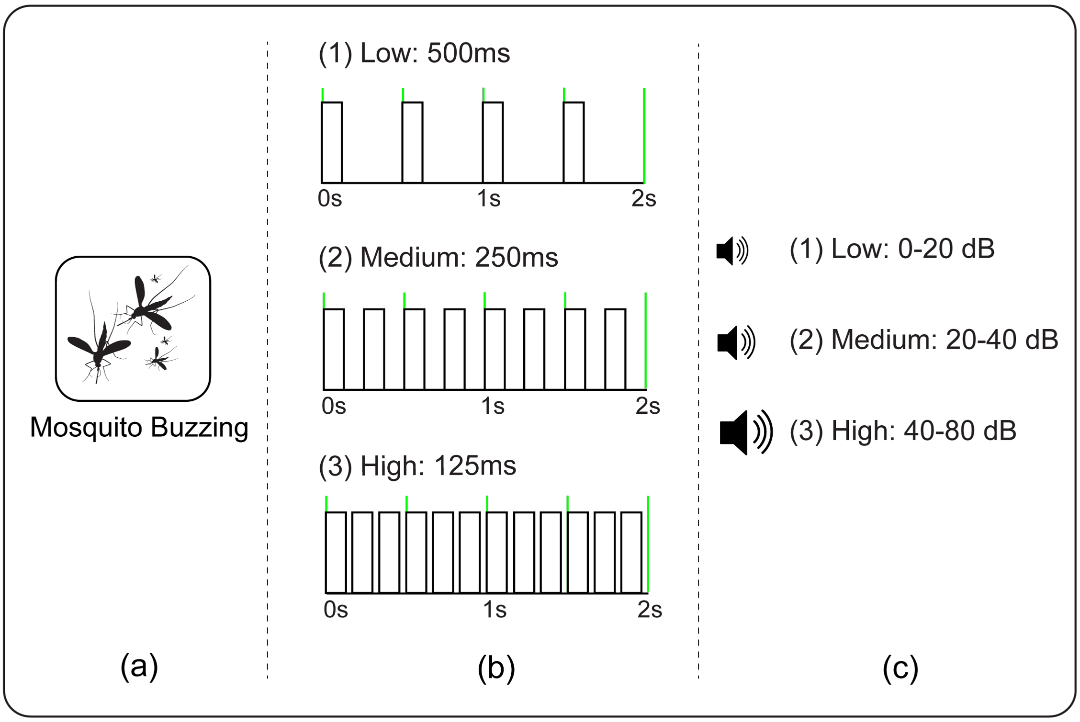


Figure4.8 Designed stimulus patterns; sound wave patterns.

# Chapter 5

# Using Vibration Stimulus

In this section, I give an example scenario using my proposed approach. And the functional system architecture, which includes the digital methods utilizing the series of digital vibration approach that is used in this proposal. The entire system components—which are referred to as "interactive floor"—that I implemented a system. I proposed a system to be incorporated into the design of our environments so that a system may induce a variety of different sensations to people in the environmental context (e.g., touch). In a particular situation, I anticipated that the proposed approach can be seamlessly integrated and may affect people' s desired subsequent action.

## 5.1 Scenario

I envision the signal change scenario (Figure 5.1), I situated the situation when while people are waiting for the traffic light changing in a crosswalk, they are using a smartphone without realizing that the signal is changing (Figure 5.1, left) [22]. Afterward, a person feel about the surrounding, in this case, I assume that a person start to go forward. To design such a sensation, I considered producing such vibration stimulus by applying vibration under the feet using the forward wave pattern (Figure 5.12).

Figure5.1 Prompting a person about signal change

Imagine the opposite door in an elevator scenario (Figure 5.2). For example, a person is taking an elevator while using a smartphone or is otherwise preoccupied without realizing that the opposite door was opened (Figure 5.2, a) [85]. I assume that a person should turn around to find the exit door when he felt someone had entered. According to our survey, companies such as Mitsubishi Electric Corporation [86] are aware of similar problems with elevator usage where people are not aware of the display' s brightness. This may cause people to be not aware that the door will be opened on their target floor. Besides, the report from MIT [87] stated that if people are not paying attention to the view, they may exit on the wrong floor.

Meanwhile, I observed that some elevators are operated with two side elevator doors which are at the front and back. The use of the door, whether to open or close, will be defined by the position or based on the structure of the building [88]. This misleads people if they enter an elevator and see the elevator doors which are two sided. At the same time, people are using smartphones after entering the elevator. These may cause them to keep standing with their backs to the exit door when they enter.

Based on this background, I observed that it is necessary to prompt people's awareness of the environmental changes in the elevator. I attempted to design an alternative approach to affect the awareness of a person in an elevator environment.

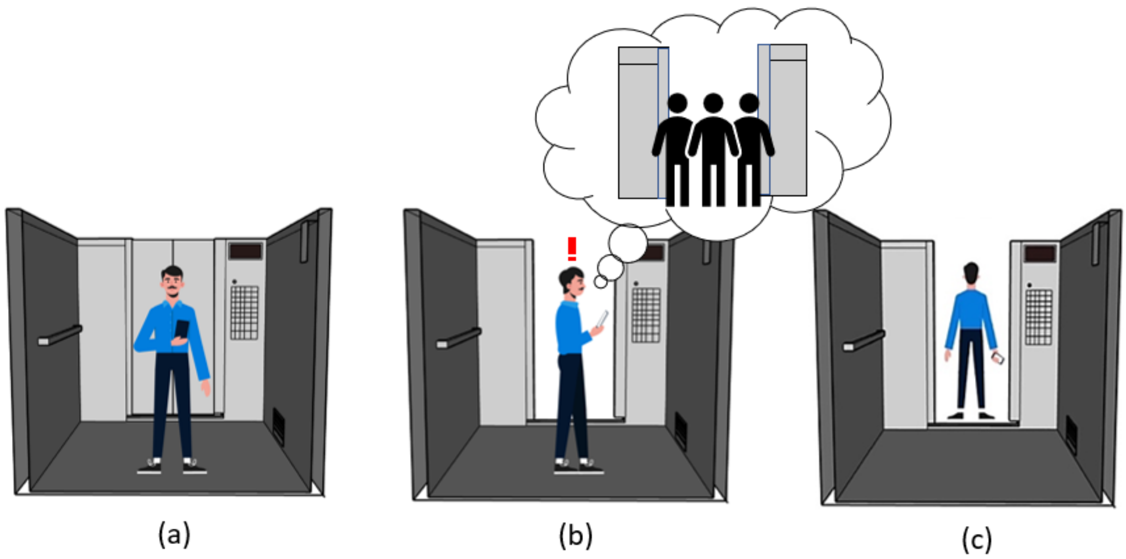


Figure5.2 Prompting people about the opposite door in an elevator

Another situation of maintaining the distance in a queue (Figure 5.3). Suppose a person is mostly using his smartphones or engaging in conversations while he is queuing (Figure 5.3, a) [85]. Later, due to distraction, he fails to realize the importance of maintaining a safe distance between himself and others during the COVID-19 pandemic and the need to take the necessary precautions to do so while standing in line. In this case, a person may be instructed by staff to maintain a safe distance or adjust himself following others afterward. I assume that a person will then take necessary measures to maintain the distance.

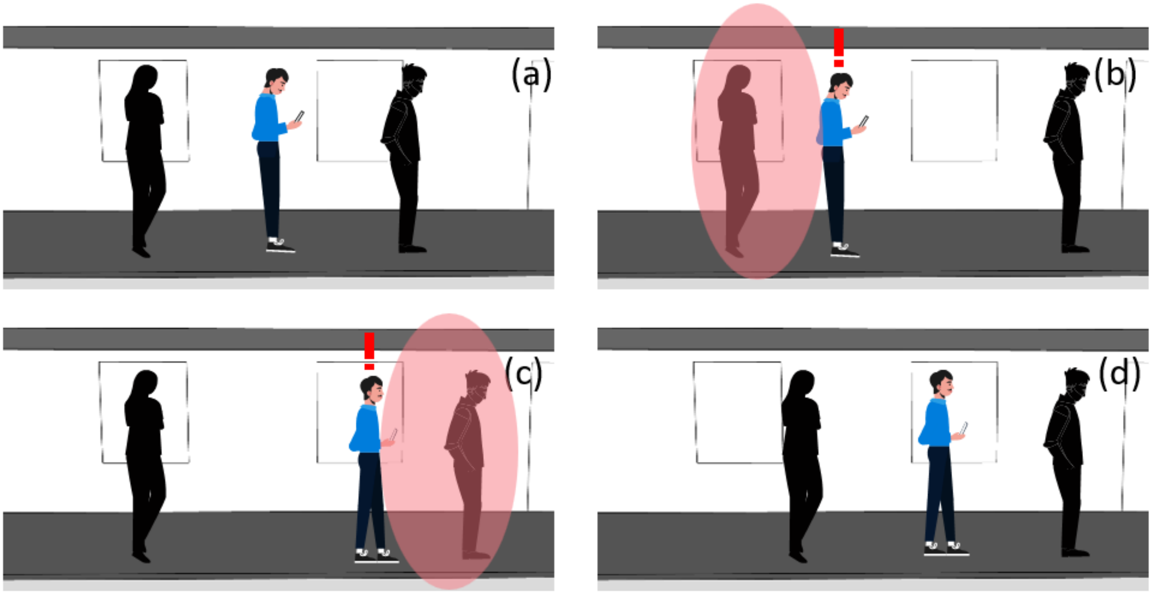


Figure5.3 Prompting people to maintain distance in queue

## 5.2 Stimulus Idea

In the signal change scenario (Figure 5.1), my idea is to design a sensation as if someone is walking from behind. I proposed utilizing an interactive floor to prompt a person to notice the changing signal based on nudging. A person will be prompted by the subtle-like movement on their feet (Figure 5.1, right). This will notify a person about the change in signals, he can take an action unintentionally. This differs from informing or instructing a person to do the action. For realizing such a stimulus, I utilized a floor system that can produce the desired vibration patterns as a series of impacts underfoot according to the signal changes. I expected the proposed system to prompt a person' s awareness of the environmental changes that impact his instinctive reaction.

For the opposite door in an elevator scenario (Figure 5.2), my idea is to make the person feel someone entered and left from behind. For creating such a sensation, I decided to provide a designed vibration under the foot. If a person feels the vibration comes from behind, he may react it instinctively feeling something happens behind. I designed the vibration so that it comes from behind to forward repeatedly. I also designed the change in increased speeds and intensity of the wave pattern (Figure 5.12), considering it would make a person feel someone walking up from behind (Figure 5.2, b). This sensation would prompt the person to look around by making him notice the situation had changed. Later on, I expect the person would turn toward the opposite door to leave (Figure 5.2, c). For realizing such a stimulus, I utilized a floor system that can produce the desired vibration patterns as a series of impacts underfoot. I created the interaction so that once a person enters the elevator, the floor' s sensor recognizes him and waits to activate until he arrives at his destination. When he eventually reached the desired floor, the opposite door was already opened. The vibration will be produced, if no one leaves the door for a brief period of time.

Besides, as for the maintaining distances in a queue scenario (Figure 5.3), my idea is to make a person feels unstable in his position by utilizing an under-foot vibration blending it into his surrounding. This may prompt a person' s instinctive reaction to observe his surrounding changes. I thought of using the isolated wave pattern (Figure 5.12) depending on the distance from the undesirable position to the desired position. Besides, a change in diminishing speed and force intensity with a wide range isolated vibration rhythm can be applied to realize the desired subsequent action. More specifically the vibration gets louder (faster) as the person gets closer to the person in behind (Figure 5.3, b) or front (Figure 5.3, c), and stops when the person stands at just the right spot (Figure 5.3, d). Such signals assume that a person may feel anxious of something would be unstable in his position and notice the changes in the speed as he moves to the proper position; that is, I expect a person to move to the position in which the vibration weakens and become aware of the surrounding as the speed changes. These reveal how the system and interaction would be "seamlessly integrated" into an awareness of the environment; in the elevator scenario, it would be natural to feel the floor vibrate when people come in and out. For the social distancing case, the vibration is not a phenomenon to be felt in a natural situation, but it uses a metaphor of a vibration that provides when something' s wrong in a video game aspect.

All in all, I ilustrated how the system and interaction would be "seamlessly integrated" into people's awareness of the environment for example; in the elevator scenario, it would be natural to feel the floor vibrate when people come in and out. For the social distancing case, the vibration is not a phenomenon felt in a natural situation, but it uses a metaphor of vibration to highlight when something is wrong, such as in a video game. Besides, the reason I adopted a vibration under foot in the specific situations, comparing its merits with another approach, such as using sound or light, is because the vibration can provide directive touch that will elicit a greater sensational effect on a person than other stimuli. Thus, in both use cases of my proposed method, the elevator and social distancing scenarios, I employ the benefit of vibration where people are distracted by devices or occupied in situations. Based on my ideas for designing stimulation using other methods, such as sound and visual, I have designed the system and interaction in each specific situation individually, focusing on the integrating stimuli in the context according to the same core idea.

## 5.3 System Implementation

In this section, I implemented prototypes utilizing the vibration approach. I proposed the system be incorporated into the design of an environmental context so that a system may induce a touch sensation in people.

### 5.3.1 Interactive Pavement

I implemented my first interactive pavement prototype [89] using tiles and 3D-printed actuators for driving them. The system could deploy instruments such as motorized rod arrays to move the tiles for fully conveying information by physical movement in the form of wave patterns. Practically, I used a realistic tile in the shape of a square for my prototype. The actuator system consisted of 16 rods, each of which was individually enclosed in a tile surface of 3 $\times$ 3 inches.

Servomotors and 3D-printed actuators were used to move the rods; the vertical length of the rods was 20 cm. I was constrained by the dimensions of the 3D-printed actuators to achieve minimum distance between each of them. The actuators were placed in a square grid with a spacing of 8 cm in each rod of the conversion process. I used four Arduino boards to power 16 rods. This approach was used for the system to achieve wave patterns to convey information to users.

In our prototype, the actuators were made from acrylonitrile butadiene styrene (ABS) by a 3D printer. Each joint of the actuator was connected with screws and the base of the interactive pavement was made of wood. This complete structure is shown in Figure 5.5.

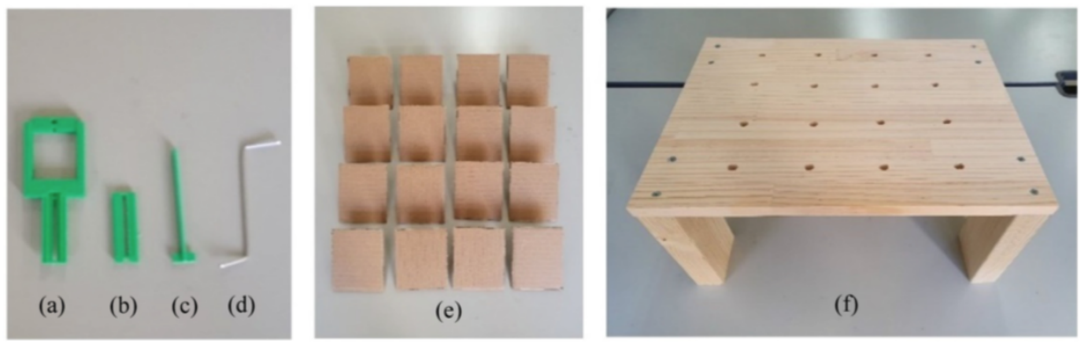


Figure5.4 Elements of an interactive pavement prototype

Figure 5.4 shows the following constituent elements: (a) 3D-printed motor holder, (b) 3D-printed slider holder, (c) 3D-printed linear slider, (d) steel linear rail shaft for joining the servomotor with the 3D-printed linear slider, (e) tile formed by paper, and (f) the base of the tile made of wood.

The actuator structure can be moved by connecting the 3D-printed motor holder (Figure 5.4, a) with the 3D-printed linear slider (Figure 5.4, c), as shown in Figure 5.5. The steel linear rail shaft (Figure 5.4, d) is used as a deformable joint slider to generate wave patterns by moving the tile surface. The tile can be controlled by the servomotor. These parameters related to the ease of deployment of the deformation structure as a linear actuator.

The servomotors were installed as actuators; their axis movement was controlled by the 3D-printed motor holder (Figure 5.4, a), 3D-printed linear slider (Figure 5.4, c), and steel linear rail shaft to create the linear motion of each rod (Figure 5.4, d). The rods move from 0 to 90 degrees to create wave patterns respectively following by Figure 5.6.

The linear actuator system has a hardware limitation that it cannot support the weight of a human body. To solve this issue in our first prototype, we attempted to create strong and independent materials as joints between the base (Figure 5.4, f) and tiles (Figure 5.4, e). Therefore, instead of using a servomotor to support the weight of a human body directly, it is possible to transfer the weight to the base to avoid damage.

Figure 5.5 shows the overview of the rod when the interactive pavement is moving. The rod produces the power to hold the position of the steel linear rail shaft. When a user takes a step toward the rods, each rod must push itself outward to create wave patterns on the tile surface to convey information to users. A servomotor moves each rod according to the wave patterns described in Sect. **??**.

The interactive pavement consists of 4 × 4 columns in one group, and an individual 4 × 1 column in a sub-group of rods. To align the interactive pavement, four Arduinos were used to monitor each sub-group of rods for physical movement. To achieve this, the pavement surface was constructed using tactile-surface materials that convey information by physical movement in a dynamic form.

Figure5.5 An tnteractive pavement (the 1st prototype)

The pavement moves in the required wave patterns by the movement of the servomotor rod array; the movement depends on the direction and rod' s position. I programmed the wave pattern of the pavement like a sine wave. If the rod is flat, the sine angle will be 0° (Figure 5.6, a) pattern encoded in the shaft of the motor, and is usually a value 0 with no load. In addition, if the rod is at a height, the sine angle will be 0° , 45° , 90° , 45° , or 0° like a sine wave movement (Figure 5.6, b); the rod array will have corresponding angles to create sinusoidal movement.

However, when there is a load on the generator, these values are saturated. Therefore, I must first have good estimates of the sine angle variables to form a good estimate of the body weight. I do this during the calibration stage, where I run a data collection routine for each servomotor rod to collect the sine angle values. To characterize the linear proportion of the actuator, I ran the calibration several times: first without weights and then by adding different weights to the rod.

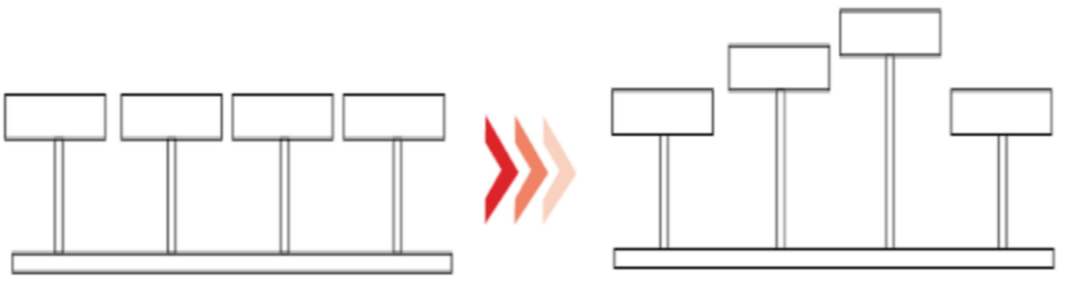

Figure5.6 Design space of an interactive pavement for presenting wave patterns

I used my first interactive pavement prototype to initiate the creation of interactive feet in the concept of digital means as my first attempt that integrates into the real-life environment of everyday life. From my pilot studies of creating the digital mean, the outcomes showed that our first prototype is still in the concept stage that is not yet fully functional, such as being unable to stand and walk because the prototype device is not yet able to support full-body weight well. I have been studying, testing, and investigating the basics of this prototype were to further develop the hardware and software control systems to enable them to operate in designed situations and interact with people effectively. I expected this first prototype to expand the interaction that does not require people's intentional interaction for the next stage of the study.

### 5.3.2 Interactive Floor

An interactive floor vibration which is the developed system for producing the touch sensation. The system is developed using actuators embedded beneath the surface. I prepared the floor surface included an active surface for three units and six dummy surface units (Figure 5.8) [22, 85]. I created an interactive surface's changeable resolution, which can be calibrated along horizontal and vertical lines. I aimed to create an interactive surface to function as the chair and floor of the stage settings (Figure 5.9) in the specified scenario. The surface size for a unit is 40 cm wide and 40 cm high. On each active surface unit included a 5 x 5 rods layout of the solenoid actuators with a spacing of 3 x 3 cm in each solenoid rod. I established the resolution of the actuator on the interactive surface by taking into consideration the size of the actual solenoid, which has a minimum interspace of 3 cm between them. Which mechanoreceptors in the foot sole is appropriate [70].

According to my observations and preliminary experiments, increasing the force intensity can present participants with a sensation. However, due to the restrictions of the solenoid, the force load cannot be increased. As a result, I adjusted the resolution of the actuator's base to calibrate the force intensity from the rod's height in the plane vertical of all rod stages (Figure 5.9). I measured the force value in each rod' s stage using a force sensor placed above the rod. I applied force load by actuating the rod in each level through the user's foot at (1) Low stage at 23 gf (0 cm), (2) Medium stage at 37 gf (0.5 cm), and (3) High stage at 51 gf (1 cm) (Figure 5.9). The force intensity following the closest range of mechanoreceptors in the foot' s sole [72].

I developed an interactive floor by employing the interaction for generating the designed wave pattern and speed parameters to the specific human position (Figure 5.12). I fabricated the capacitive sensor-like under the surface using the aluminum foil that installing on both sides of the hold rubber sheet. I connected each side of them to an Arduino Mega 2560. One side is wired to the 5V DC and another side is wired to the 5V ground. Then I covered the sensing part with the smooth rubber sheet on both sides of them. So that when the foot is placed onto the floor surface, it can detect the human position and the system will be activated.

The actuator rods are controlled by 1 Arduino. It can control 75 solenoids of 5 columns and 15 rows of solenoid rods and regulate the solenoid beneath, sending data from the computer. The computer transmits tactile data to an electronic module via the RS232 protocol, where a controller interprets command strings and sets each actuator of the display. To receive the AC input voltage from a wall power source, an AC-to-DC converter has been adapted as a power source. I developed durable and autonomous materials using a stainless steel base; it can well support the full body weight.

A conventional haptic interface for feet was evaluated in studies [38, 39, 40]. They explored the possible use of such a haptic interface through the vibrotactile approach for feet to convey information in daily environments. However, in this proposal, I highlighted the usage of the way how to provide the designed stimulus. I designed such a stimulus, not merely by conveying information or a simple notification to people, but by molding the design effective technology-mediated nudges to produce such designed stimulus by digital means in the environmental context physically. I proposed using under-foot vibration (Figure 5.7) that can produce the wave motion of actuator through the actuated floor system works as a nudge which can prompt the desired behavioral response. So that the nudge can affect people psychologically produced by an interactive floor.

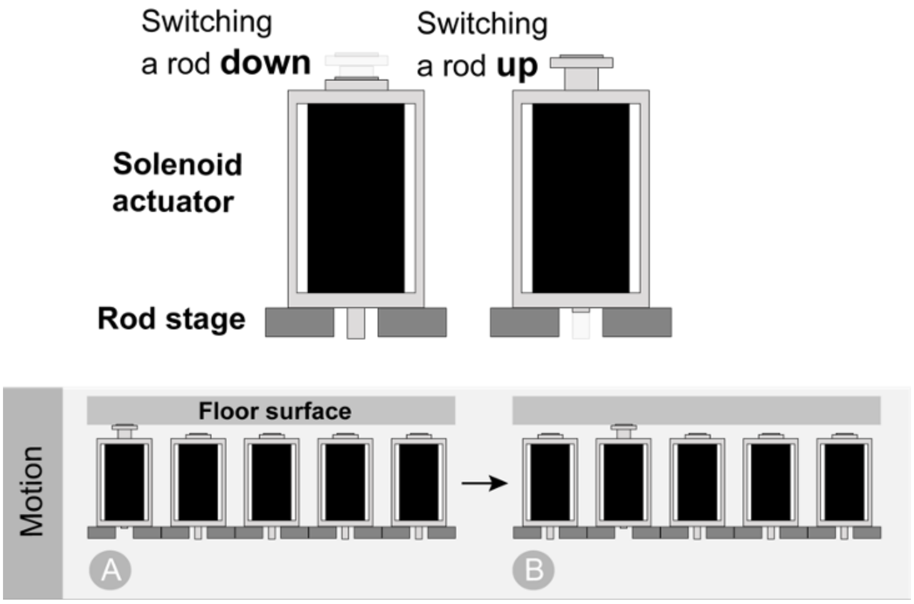


Figure5.7 Motion of the actuator


Figure5.8 Overview of an interactive floor

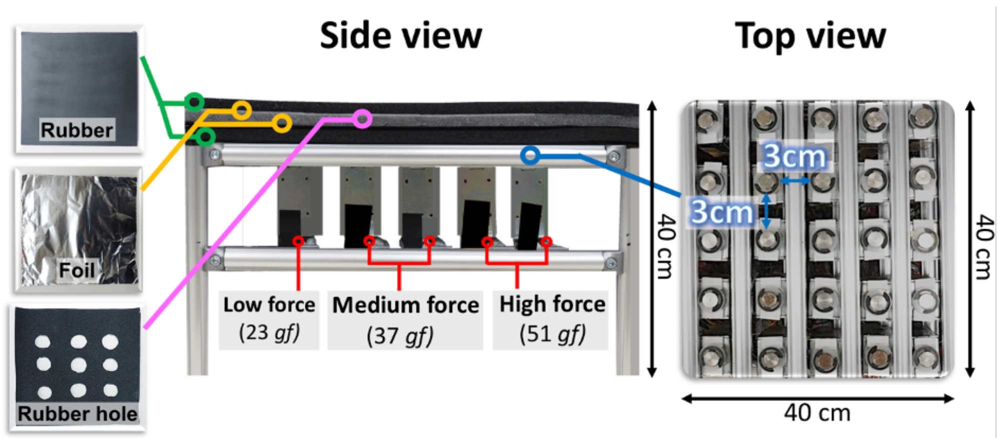


Figure5.9 Assembly components of a floor unit

### 5.3.3 User Interface

#### 5.3.3.1 System Overview of an Interactive Floor

The software implementation of an interactive environment comprised of two main systems: (1) the Visual Studio software running on a Windows OS computer, (2) the Arduino code running via the 1 Arduino Mega 2560 microcontrollers, and each of the systems will be described in the following sections.

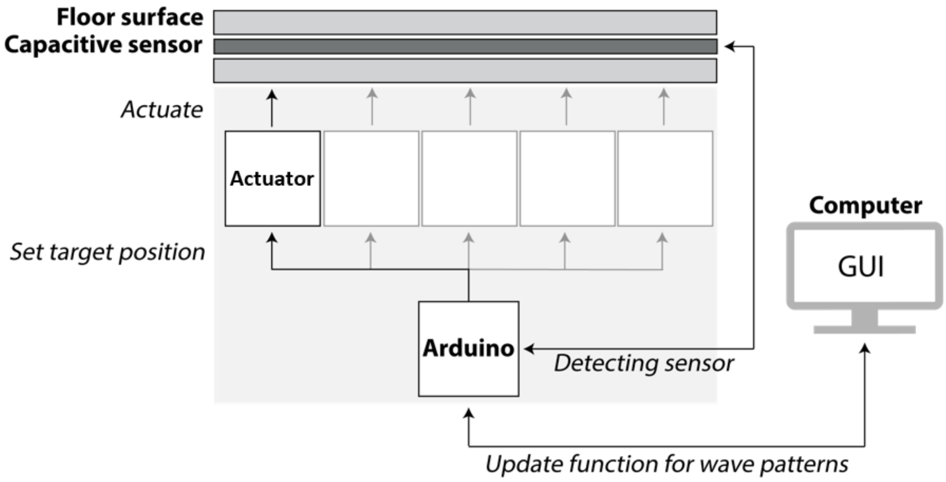


Figure5.10 Working order in controller system of an interactive floor

#### 5.3.3.2 System Controllers

The control software for an interactive floor is entirely procedural (Figure 5.10). I prepare a GUI for the system, whereas the system is expected to work interactively with the situation and not controlled by a manipulating person. For the software interface control, the data were input into a GUI generator (to create shapes, pictures, patterns, and sequences) by selecting the tactile actuators to be activated and setting their desired interval speed (Figure 5.11). The actuator rod' s period in each position sequence (up and down) can be defined by inputting the time data (milliseconds) into the delay time section on the GUI. Each rod was defined to create a movement corresponding to the designed wave pattern. The movement of the rod can be calibrated via a software interface and automatically controlled through the capacitive sensing system installed beneath the floor surface to generate tactile data

A stimulus coordinated with the matched sequence of vibration patterns that is controlled via GUI to provide the stimulation.


Figure5.11 Software interface that generates stimuli data; a vibration control interface.

#### 5.3.3.3 Microcontroller

The Arduino code resides in the 1 microcontroller. I used the Arduino software to run; a microcontroller is responsible for controlling its own 75 of solenoid rods and 4 directional speakers. The Arduino software is responsible for sending the target position on and off to a microcontroller, which then the microcontrollers move the motors accordingly. The microcontrollers send back the height and current values of each motor back to the Arduino software. Communication between the Arduino and the microcontrollers is done via GUI interface.

Notably, a floor surface, without master coordination from the Visual Studio software, a microcontroller only knows the position/current values of 75 actuator rods. Thus, it would be impossible without a master coordinator to create simulations that have the pins working together, since each Arduino only knows the information about a small subset of the pins. This is why initially, all of the GUI interface software was written on the Visual Studio code, which coordinated the target heights of all 75, sent the target positions to the Arduino software, which then simply passed it onto the microcontrollers.

Software interface that does require accuracy and speed. They were developed entirely in operations, which minimal involvement from the software, so as to get rid of as many of the delays as possible.

### 5.3.4 The Designed Pattern of Stimuli

In this section, I described the design of digital means as stimuli, for example, the vibration wave patterns (Figure 5.12).

#### 5.3.4.1 Designed Vibration Pattern and Rhythm Grouping

I considered designing the physical wave movements formed on the interactive floor surface (Figure 5.10). The vibration speed can be created by combining the simplest reversible alternating sequence of ON and OFF states of a solenoid actuator with predefined speed lengths, and the phenomenon in the isolated wave pattern for each state was considered [71].

I examined a primary experiment for determining the criteria for the appropriate wave pattern and speed for prompting a person' s reaction in a specific scenario (Figure 5.1, 5.2, 5.3). The speed variables were selected based on the appropriate range of vibration speeds that can be felt through the large cell' s receptor range (5-40 Hz; 200–25 ms) [85]. I designed a vibration rhythm to interact with STM based on human cognitive psychology [73, 74]. This provided a process for interval-produced rhythm wherein a beat was applied to reflect an actuation ON state and intervals (silence) to reflect an actuation OFF state to produce a rhythm set [72]; the interval speed is the interval between one ON stage and the next rod ON stage performed in a sequence. The interval speed can be increased or decreased based on the command set in each rod. Thus, the interval-produced rhythm simply provides vibrations with the desired frequency from the rod array. Based on STM, I defined silence (OFF) as the designed rhythm set after the beat (ON). Additionally, based on our previous observations and experiments, I know that increasing the interval speed and force intensity can change the sensation perception of the participant. Hence, I designed the rhythmic speed from the selected speed variables in three stages mentioned in Table 5.1.

Table5.1 Variable used in the designed wave speed

| Subject | Condition |
|---|---|
| Increased wave speed | (1) Low (10–20 Hz) (100–50 ms) |
| | (2) Medium (20–40 Hz) (50–25 ms) |
| | (3) High (40–80 Hz) (25–12.5 ms) |

The design of the wave pattern shown in (Figure 5.12) was expected to create the change in vibration speed on the floor surface. I intended to design a stimulus using the speed of a vibration that changes according to the distance from the target person to the desired position. I assumed designing gradually increased or decreased speeds based on our finding from the preliminary experiment by changing speeds of vibration can impact participants' s perception. Regarding the user' s study, some participants indicated that "Strengthening or Speeding" made them feel anxious and want to leave where the strong wave occurred, while others stated that "Diminishing Speed" made them want to keep moving to the position where the wave faded to feel safe. Hence, I designed a series of speed changes that can impact people psychologically as follow: (1) "Strengthens or Speeds Up" where a person stands in an inappropriate position. (2) "Diminishing Speed" when the person is on the right track. (3) "Vanishes" when a person is in the desired position.

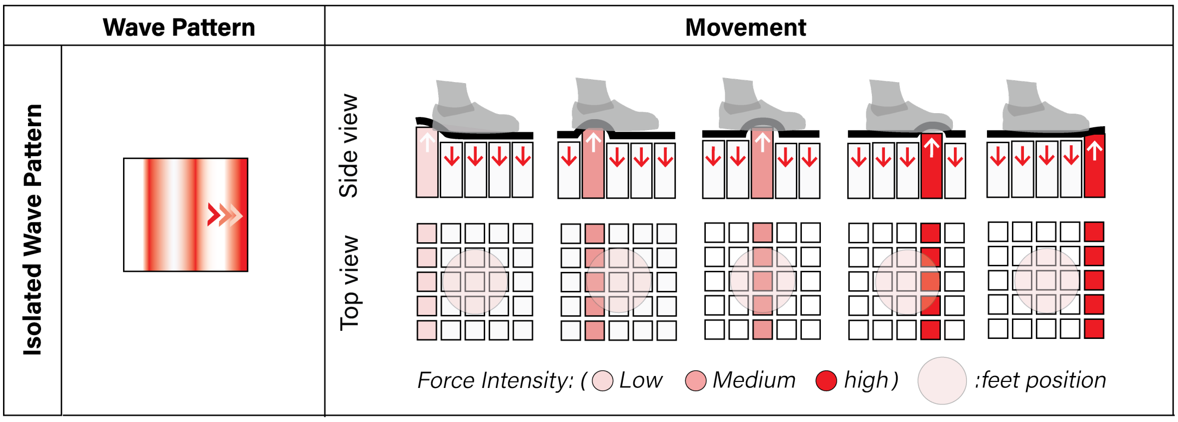


Figure5.12 Designed stimulus pattern; vibration wave patterns

# Chapter 6

# Experiments

## 6.1 Sound Stimulus

### 6.1.1 Accuracy Evaluation of the Audio System

I examined the functionality and effectiveness of the system to determine whether it could control the sound pattern (Figure 6.1, below). Moreover, it was necessary to examine whether the system had the potential to control the rhythmic sound pattern. If the system worked, it could then transmit the audible phenomenon to people' s ears to induce them via the prompt with more sophistication. So that they may affect a person' s reaction.


Figure6.1 (Above) An audio output. (Below) The monitoring page of the GUI software interface.

#### 6.1.1.1 Experimental Condition

In this section I defined the experimental condition mentioned in Table 6.1. I prepared a directional speaker with three rhythmic sound patterns. I used a GUI generator to create the sound patterns ten times to determine the accuracy rate.

Table6.1 Experimental condition

| Subject | Condition |
|---|---|
| Device | A directional speaker |
| Rhythmic sound patterns | (1) Low 500ms<br>(2) Medium 250ms<br>(3) High 125ms |
| Controller | I used a GUI generator to generate the sound patterns (Figure 6.1). |
| Time | Ten times to determine the accuracy rate. |

I use software measurement of the sound emitting. I defined the speed of the sound on the Auda City program and import the design sound sources through GUI preset button and measured it using the time processing of an Arduino function that returned the time (ms) that had passed since the program started, and whether the actuation time was within the defined threshold or not. I collected 1 (sound source) $\times$ 3 (interval speed) $\times$ 10 (times) = 30 trial data per a sound parameter.

I defined the threshold, when the sound responded as it emits within the defined speed variables at (500 ms), (250 ms), and (125 ms), respectively. The feasible number of accuracy rates could be expressed as (n $\times$ 100)/N, where n is the accuracy rate and N is the total number of experimental trials.

#### 6.1.1.2 Result

The experimental results of the average accuracy rate for the sound pattern in three different interval speed directions was 86.66% (SD: 5.77), the error rate being approximately 13.34% (Figure 6.2). I concluded that the interactive sound could be controlled using the GUI generator; via an Arduino, using sound wave patterns in three different interval speed. The results showed the potential of controlling the rhythmic sound pattern, including the interval speeds of the system, which meant that the phenomenon could be transmitted to people' s ears, so that they could be induced to respond via prompting.

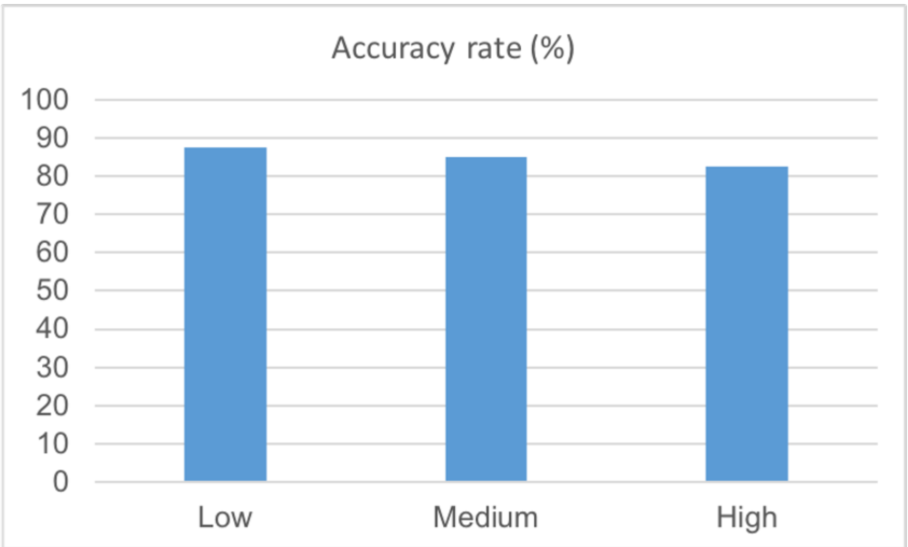


Figure6.2 Accuracy of sound patterns

### 6.1.2 Experimental Scenario: The Safe Distance in a Seat

The purpose of the experiment [23] is to examine human' s cognitive response using an interactive multimedia to nudge the examinee of the safe distance from each other while sitting. I simulated the situation when a person is going to sit on the public chair with people on the side which they do not pay attention to the social distance while they are sitting (Figure 6.5). In this experiment, I considered producing the stimulus for making the feeling of anxiety or fear to prompt people using the virtual representation of sound stimulus integrating in the surrounded environmental context of the bench. I proposed an interactive multimedia to prompt people of the social distance while they are sitting. The experimental procedure, before starting the experiment, I set people on both sides who sit on the bench to make a participant realizes the real situation. In the beginning, a participant is instructed to stand by in front of a bench. Later, a participant will be allowed to sit on a bench in the defined center position without any given instructions then the defined stimuli will be displayed.

#### 6.1.2.1 Experimental Condition

In this section I defined the experimental condition mentioned in Table 6.2. In this experiment, I set up two sound sources with three audio effects, varying rhythms, and volumes as experimental parameters. The duration of the stimulation was five seconds each time. Based on my findings indicate that most participants responded to the given duration of the behavioral trial.

Table6.2 Experimental condition

| Subject | Condition |
|---|---|
| Sound source | (1) The mimic sound (mosquito flying effects)<br>(2) The conventional warning sound<br>(siren sound effects) [57]. |
| Audio effect | (1) The 3D audio effect<br>(2) The traditional audio effect |
| Rhythm | (1) Low (500-250ms)<br>(2) Medium (250-125ms)<br>(3) High (125-62.5ms) |
| Volume | (1) Low 0-20 [dB]<br>(2) Medium 20-40 [dB]<br>(3) High 40-80 [dB] |
| Duration of stimulation | The duration of the stimulation performing for five seconds for one time. |
| Participant | 20 university students (1 female and 19 males; average age: 20.9 years, SD: 2.24) |
| Data collection | I collected 1 (mimic sound) $\times$ 1 (warning sound) $\times$ 3 (rhythm) $\times$ 3 (volume) $\times$ 1 (3D audio effect) $\times$ 1 (traditional audio effect) $\times$ 1 (time) = 9 trial data per examinee. |

I used the capacitive sensor installed under an interactive surface to generate all stimuli to produce such a stimulus of something is coming. When the examinee sits onto the surface, the increased volume of sound will be activated. The participant is allowed to take their desired action.

The data was gathered by direct observation during the experiment. I defined the threshold based on human reaction times (RTs) to audio (ART) [90]. When the participant responds to the surrounding situation as they get up from the chair after finishing the stimulation within two seconds is considered to be prompted by n, and the total number of participants is N. The feasible number of participants who are nudged can be expressed as n x 100) / N.

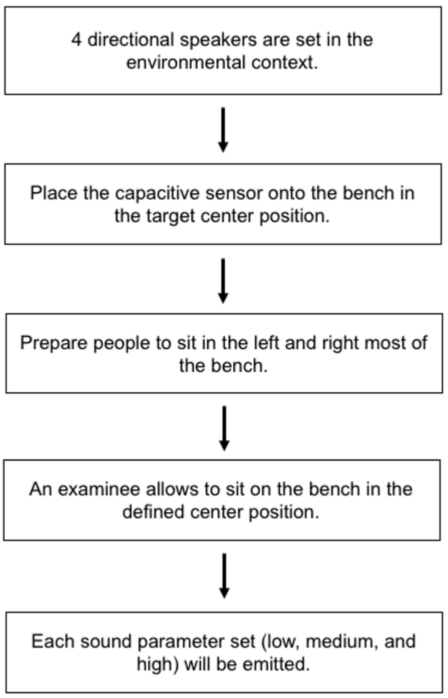


Figure6.3 Experimental procedure flow chart

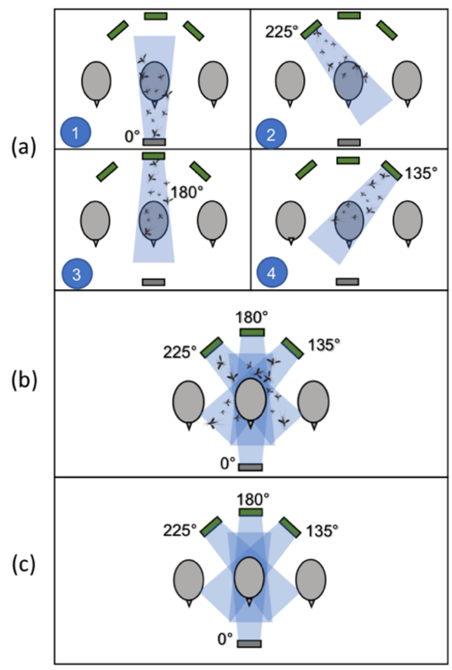


Figure6.4 Designed audio effects: (a) The directional 3D audio effect (mosquito buzzing sound), (b) The traditional audio effect (mosquito buzzing sound), and (c) The traditional audio effect (siren sound).

#### 6.1.2.2 Result

Figure 6.6 shows the experimental results of the participants who were prompted through the multi-channel directive speaker system by a nudge using the proposed virtual representation of 3D-sound (mosquito flying effects). The results indicated that a highest level of the designed sound parameters is superior to others, the overall average rate was 56.66%.

Regarding the participants who were prompted by the surround sound system (mosquito flying effects). The results indicated that a highest level of the designed sound parameters is superior to others, the overall average rate was 46.66%.

Additionally, the experimental results of the participants who were prompted using the conventional warning sound approach by the surround sound system (siren sound effects). The results indicated that a highest level of the designed sound parameters is superior to others, the overall average rate was 30% .

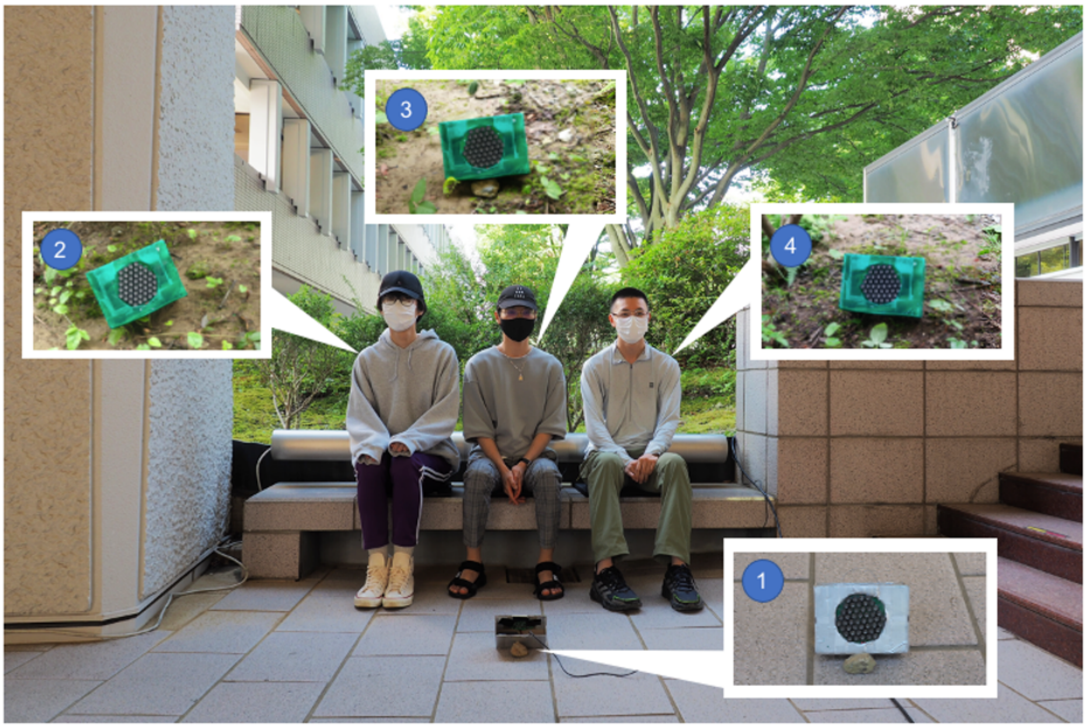


Figure6.5 Simulated environment of a sitting scenario

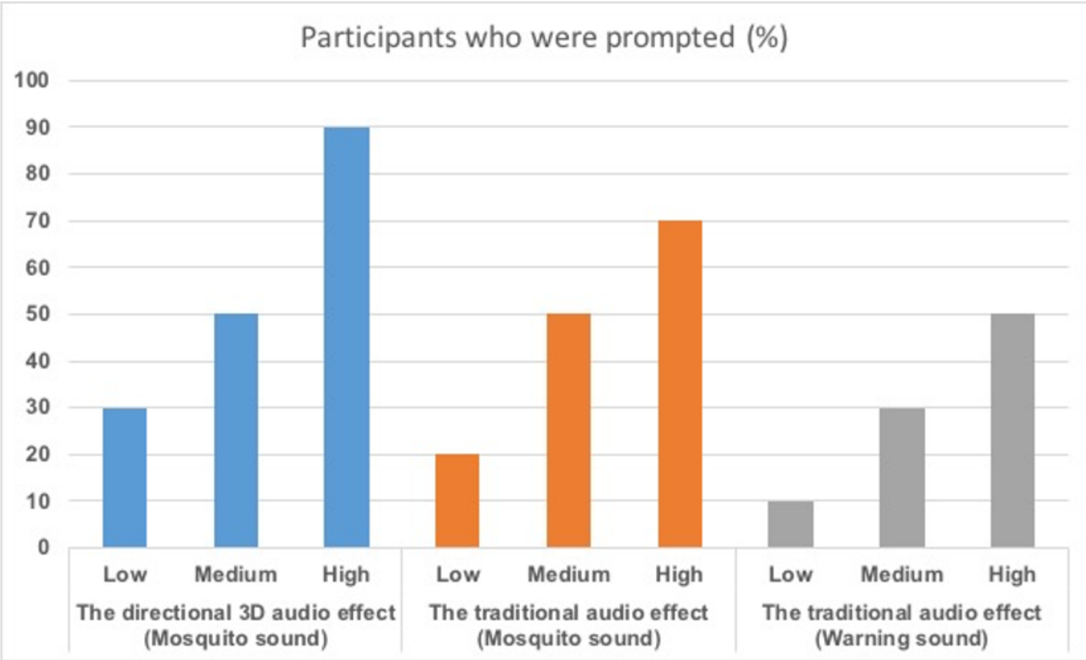


Figure6.6　Results of the social distance scenario

### 6.1.3　User studies

#### 6.1.3.1　Examination of the Directive Speaker’s Position to User’s Responses

I examined the super directive speaker’s position settings on how it can deliver the defined sound to the desired target’s seat in front and back positions.

#### 6.1.3.2　Experimental Condition

In this section I defined the experimental condition mentioned in Table 6.3. I positioned the speakers in the front and back. I placed the speakers at a distance of 1 to 5 meters from the target position, considering the capacity of the speaker to deliver sound waves up to 5 meters. For the sound stimulus, I displayed the defined sound for five seconds.

Table6.3　Experimental condition

| Subject | Condition |
|---|---|
| The speaker’ s position (front side) | (1) Ground position: 0 cm<br>(2) Ear position: 90 cm<br>(3) Above position: 180 cm |
| The speaker’ s position (back side) | (1) Ground position: 0 cm<br>(2) Ear position: 80 cm<br>(3) Above position: 160 cm of the position |
| The speaker’ s distancing | 1 to 5 meters away from the target position. |
| Sex | The experiment involved 10 participants (1 female and 9 males; average age: 21.2 years). |
| Duration of a stimulation | I display the defined sound stimulus for five seconds. |
| Control condition Data collection | I collected 6 (the speaker’ s height) $\times$ 5 (the speaker’ s position) $\times$ 1 (trials) = 30 trial data per participant. |

The experimental condition is based on the social distance in seat scenario (Figure 4.1). The participant is allowed to take their desired action. I defined the threshold based on human reaction times (RTs) to audio (ART) [91]. When the participant responds to the surrounding situation as they get up from the bench after finishing the stimulation within 2 seconds is considered to be prompted. The experimenter interviewed the participant.

#### 6.1.3.3 Result

From the experimental results of measuring different positions, both front and rear, using the 3D directional sound speaker to be installed in the designed area of a specific situation. I concluded that I can install speakers anywhere because the result shows in the response of the most target user having a response to the sound and affecting the desired response (a person’ s reaction).

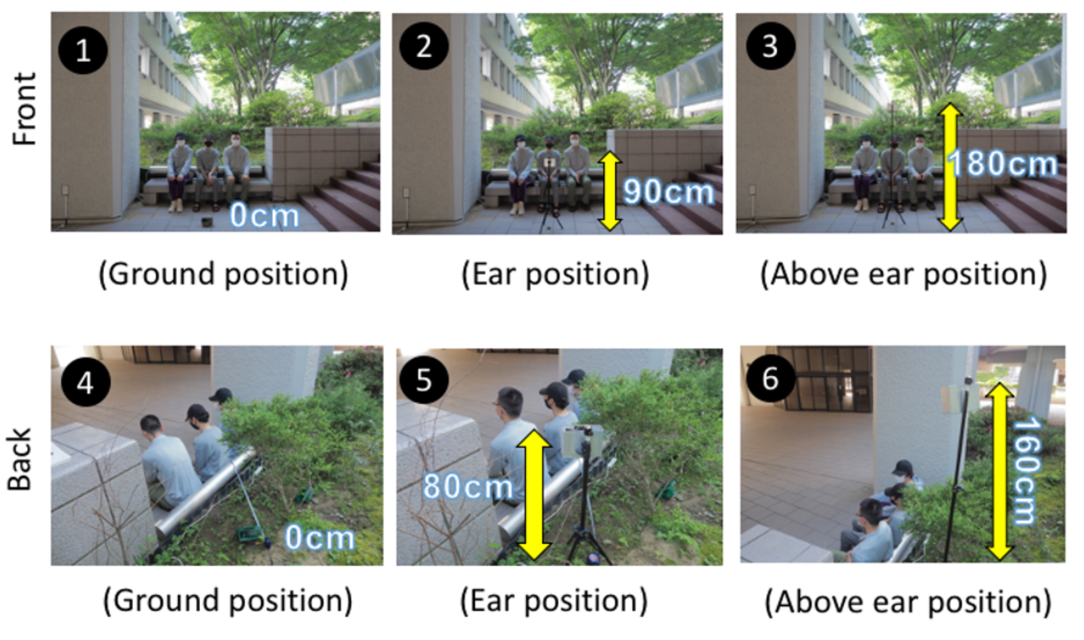


Figure6.7　Participants in the experimental field of 1-meter condition

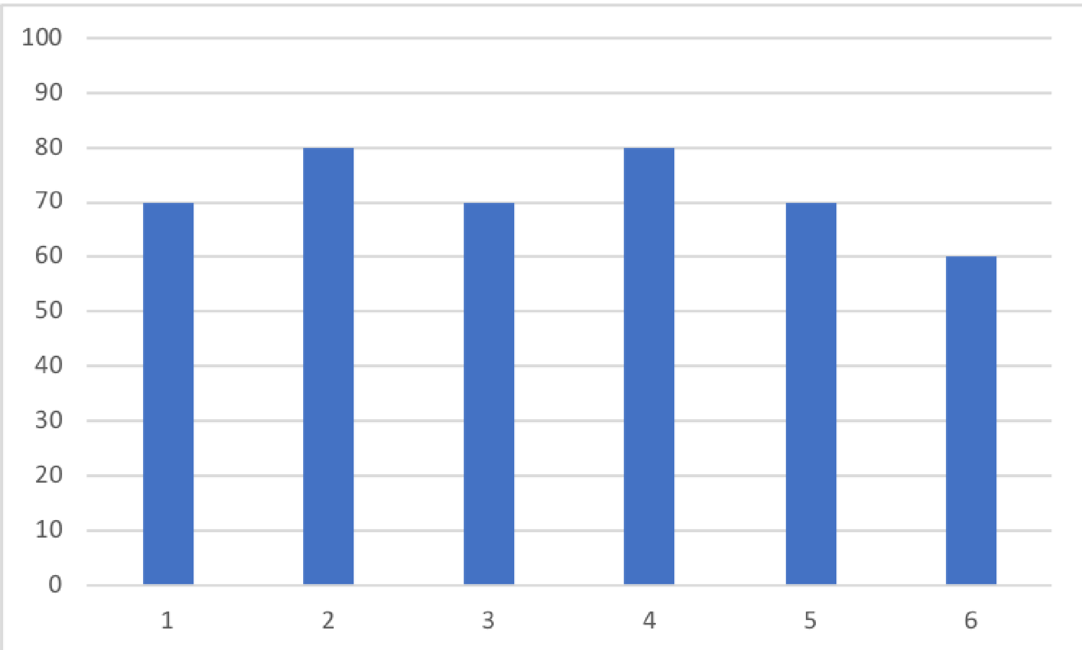


Figure6.8　Experimental result of the speaker’s position of 1-meter condition

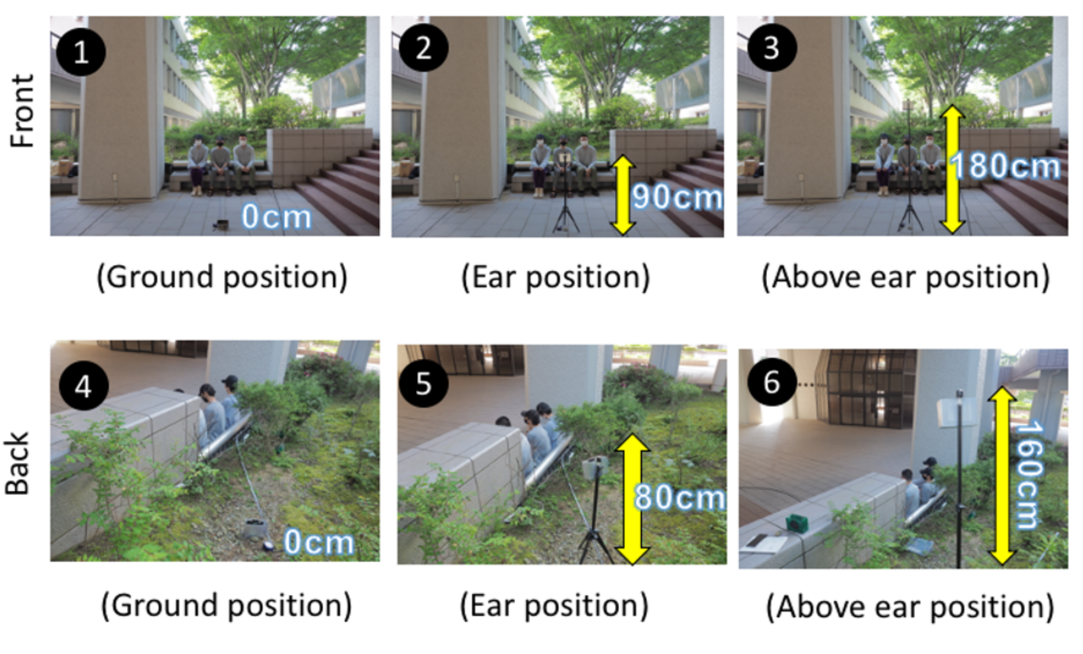


Figure6.9 Participants in the experimental field of 2-meter condition

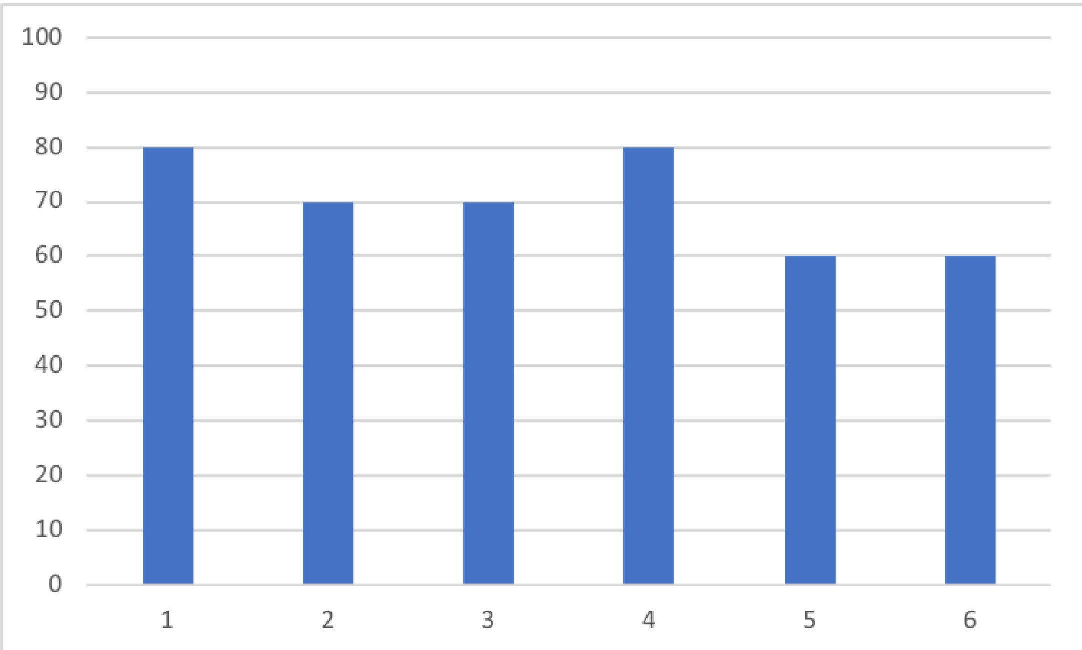


Figure6.10 Experimental result of the speaker’s position of 2-meter condition

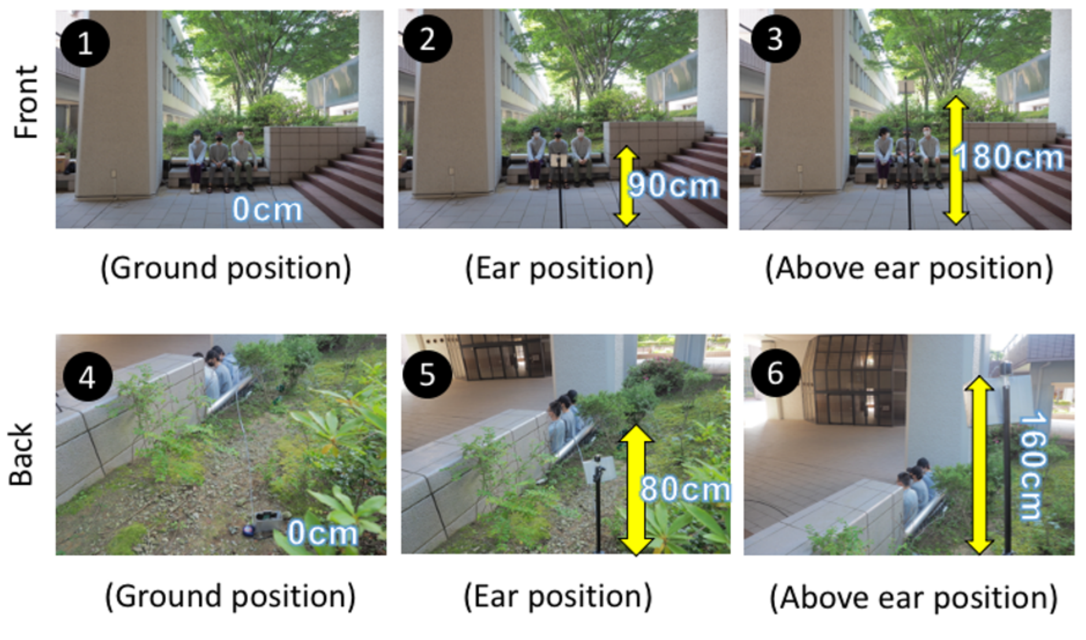


Figure6.11　Participants in the experimental field of 3-meters condition

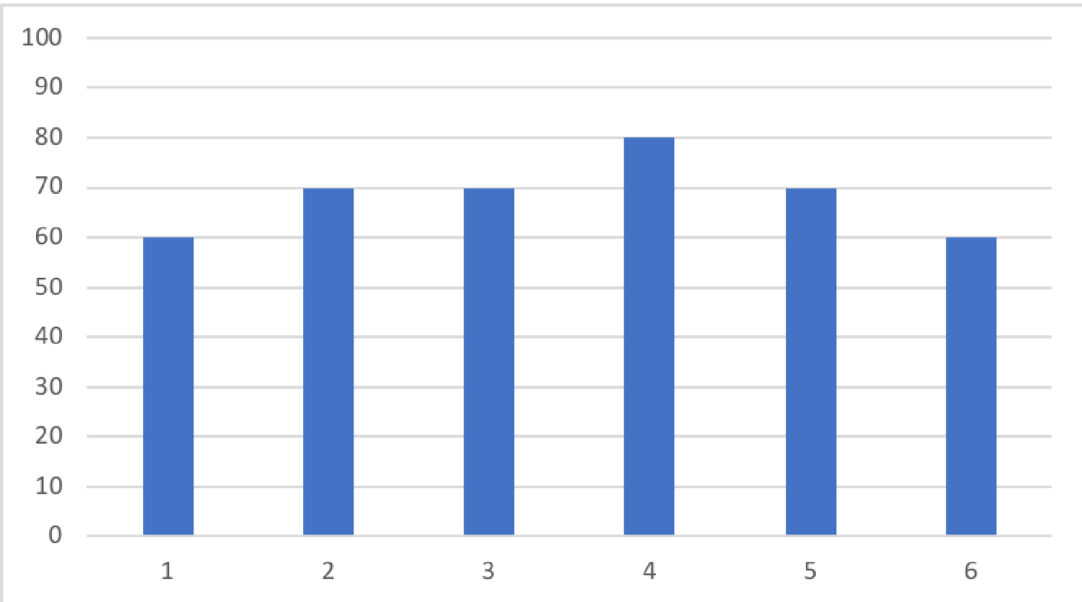


Figure6.12　Experimental result of the speaker’s position of 3-meters condition

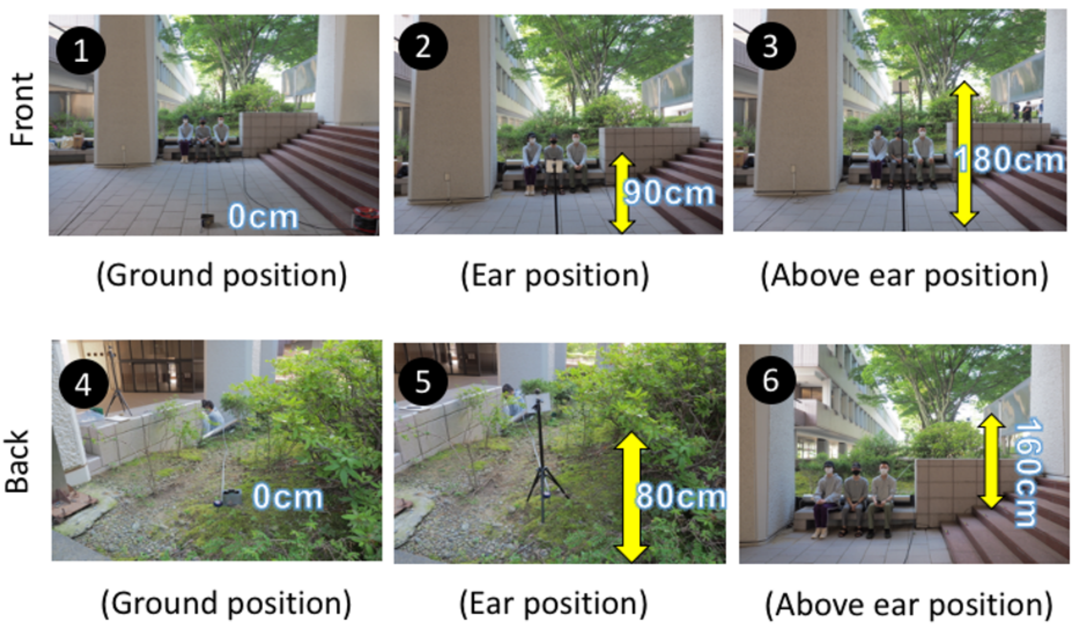


Figure6.13 Participants in the experimental field of 4-meters condition

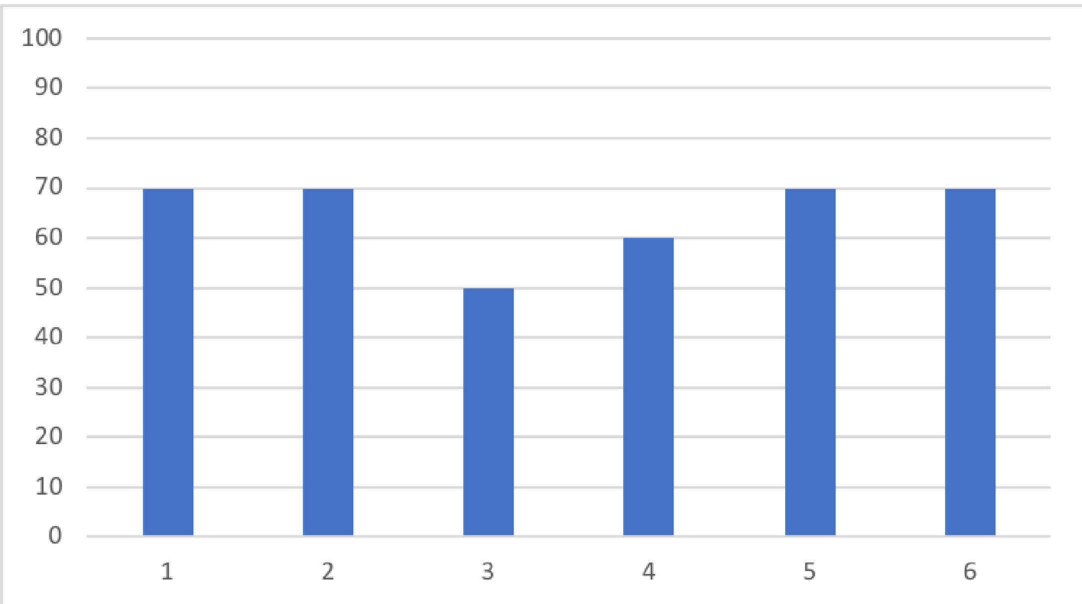


Figure6.14 Experimental result of the speaker’s position of 4-meters condition

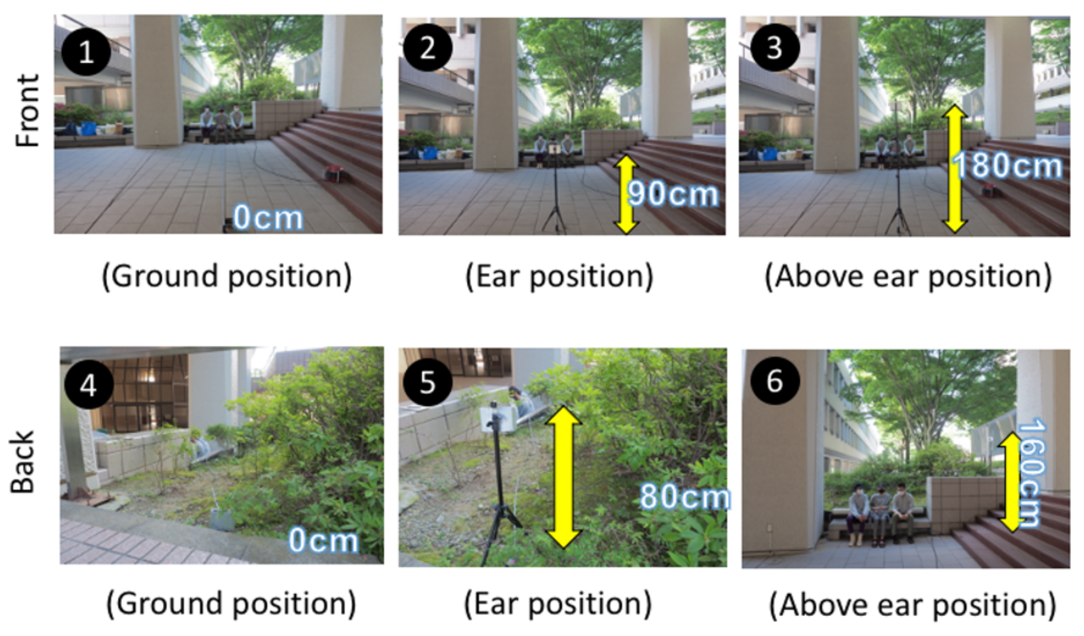


Figure6.15　Participants in the experimental field of 5-meters condition

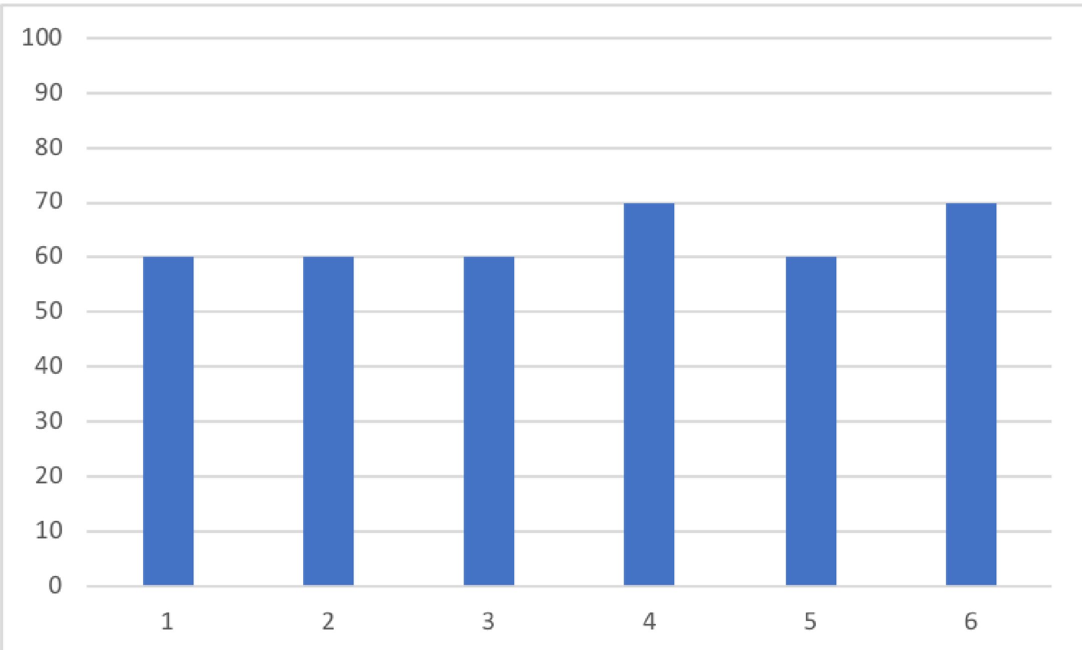


Figure6.16　Experimental result of the speaker’s position of 5-meters condition

## 6.2 Vibration Stimulus

### 6.2.1 Measurement on Force Intensity of the Floor Surface

According to our observations and preliminary experiments, increasing the force intensity can affect participants sensation. However, due to the restrictions of the solenoid, the force load cannot be increased. Hence, I designed the force intensity in each designed rod level. I defined the resolution of the actuator's base to calibrate the force intensity from the rod's height in the plane vertical of all rod stages.

In the experimental procedure, I applied force load by actuating the rod in each level through the user's foot (Figure 6.17, 6.18). I measured the force value in each rod' s stage using a force sensor placed above the rod (Figure 6.19).

#### 6.2.1.1 Experimental Condition

In this section I defined the experimental condition mentioned in Table 6.4. I have set up three stages to measure the height of the rods.

Table6.4 Experimental condition

| Subject | Condition |
|---|---|
| Rod' s height | (1) Low stage at 0 cm<br>(2) Medium stage at 0.5 cm<br>(3) High stage at 1 cm |

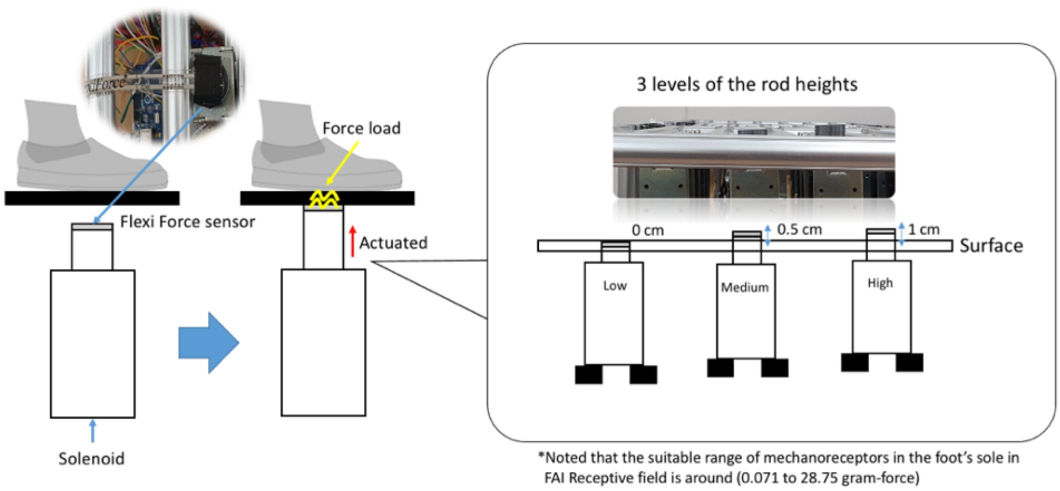


Figure6.17 Measurement on force intensity

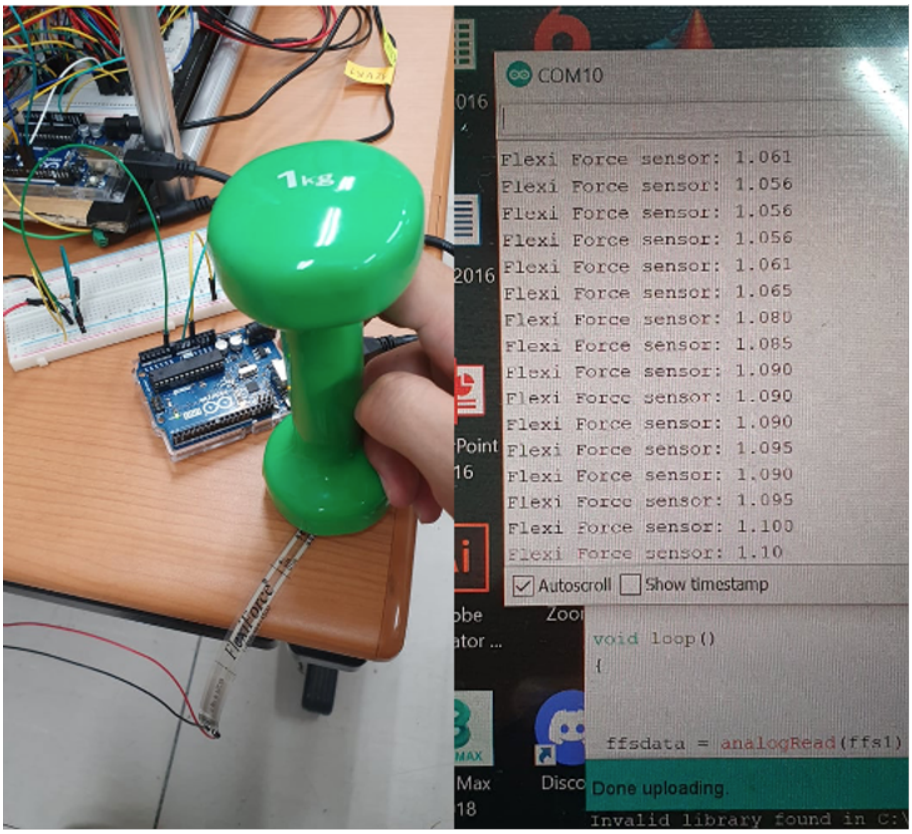


Figure6.18 Calibration using Flexi Force sensor with fixed weight for 1 kg

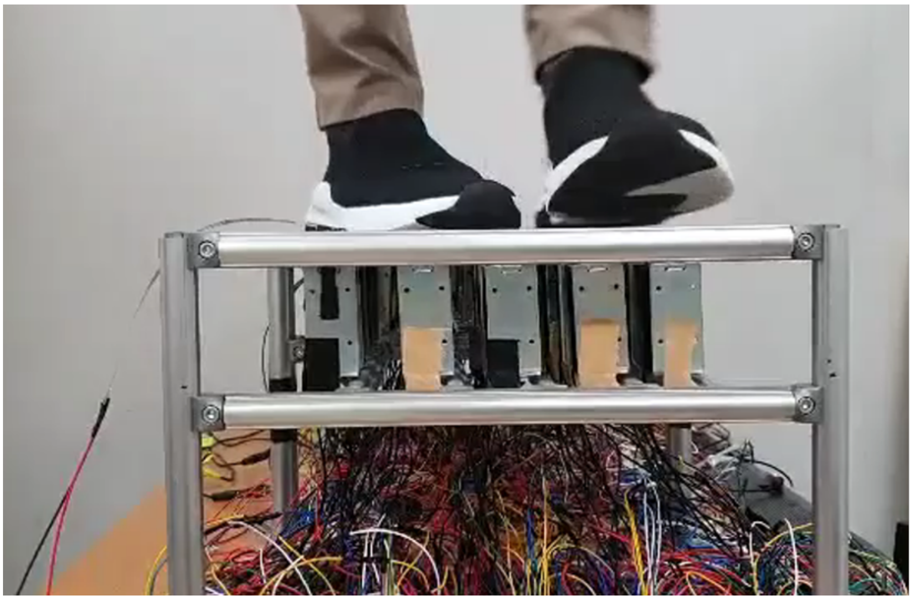

Figure6.19 Force measurement procedure

#### 6.2.1.2 Result

From the results, I can design the force intensity performing on the floor surface with the wave patterns to impact the feet perception in each scenario. The force intensity following the closest range of mechanoreceptors in the foot’s sole [70].

Table6.5 Results of the force intensity of a floor surface

| Subject | Condition | | |
|---|---|---|---|
| High levels | Low(0cm) | Medium(0.5cm) | High(1cm) |
| Average rate | 23 gram-force | 37 gram-force | 51 gram-force |

### 6.2.2 Accuracy Evaluation of the Floor System

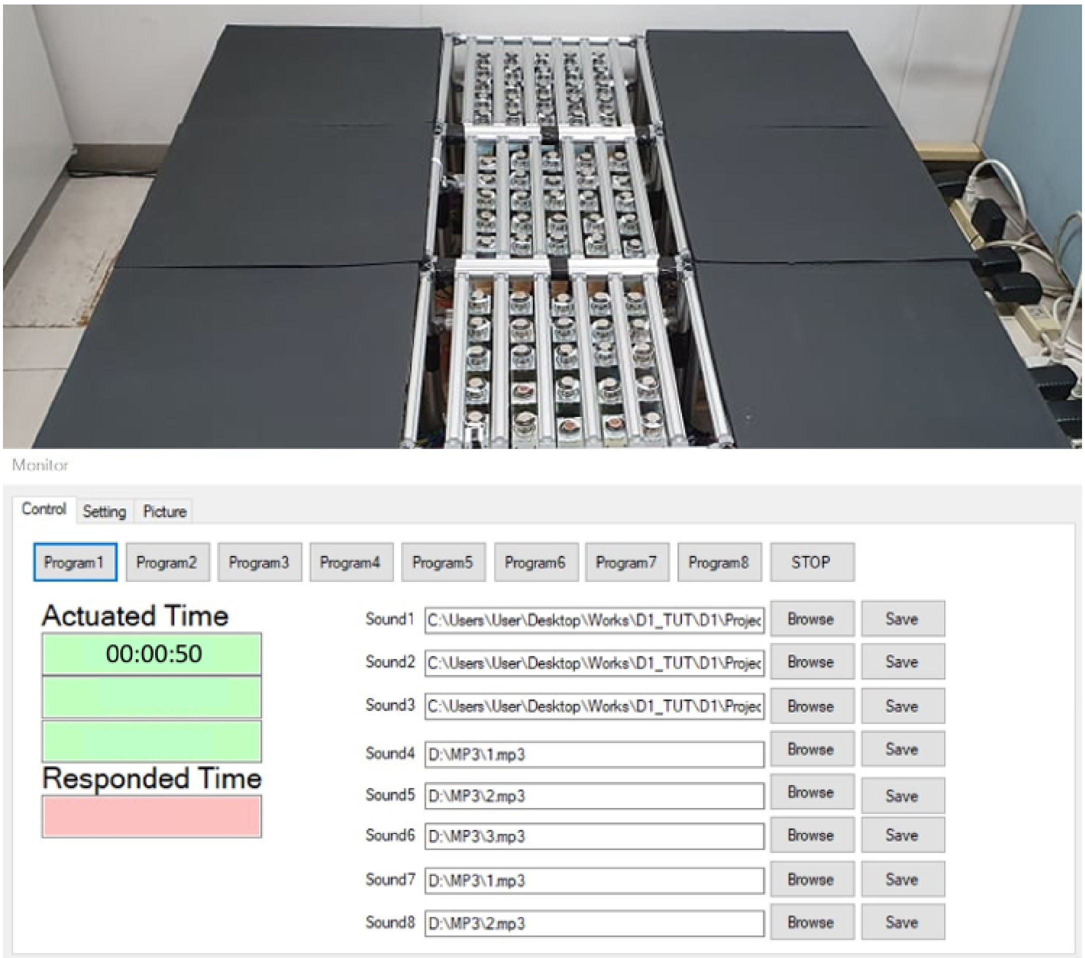


Figure6.20 (Above) Actuator rod array. (Below) The monitoring page of the GUI software interface.

I examined the functionality and effectiveness of the system to determine whether it could control the movement of the rod using a global wave pattern (Figure 5.12) in the horizontal and vertical setting stages. Moreover, it was necessary to examine whether the system had the potential to control the rhythmic wave pattern. If the system worked, it could then transmit the haptic phenomenon to people's feet.

#### 6.2.2.1 Experimental Condition

In this section I defined the experimental condition mentioned in Table 6.6. I assembled 75 solenoids using 5 x 15 actuator rods. I employed three vibration wave patterns with three interval speeds and tested them using a GUI generator. I conducted ten examinations of all the rods to determine the accuracy rate of each one.

Table6.6 Experimental condition

| Subject | Condition |
|---|---|
| Device | 75 solenoids using 5 × 15 of actuator rods |
| The vibration wave patterns | (1) Forward<br>(2) Backward<br>(3) Left, and (4) Right |
| Controller | I used a GUI generator to generate the wave patterns (Figure 5.12). |
| Interval speed | (1) Low (10)(100 ms)<br>(2) Medium (20 Hz)(50 ms)<br>(3) High (80)(12.5 ms) |
| Time | Ten times to determine the accuracy rate of each rod. |
| Floor stage settings | Vertically and horizontally |
| Data collection | I collected 1 (wave pattern) × 4 (wave lines) × 3 (interval speed) × 2 (setting stages) × 10 (times) = 240 trial data per actuation rod. |

I defined the speed of the solenoid at each rod's speed on the GUI and measured it using the time processing of an Arduino function that returned the time (ms) that had passed since the program started, and whether the actuation time was within the defined threshold or not.

I defined the threshold, when the actuator rod responded as it actuated itself within the defined speed variables at 10 Hz (100 ms), 20 Hz (50 ms), and 80 Hz (12.5 ms), respectively. The feasible number of accuracy rates could be expressed as $(n \times 100)/N$, where n is the accuracy rod, that is, when the actuator responded as it actuated itself within the defined speed. And N is the total number of actuator rods.

#### 6.2.2.2 Result

The experimental results of the average accuracy rate for the vibration wave pattern in four directions (forward, backward, left, and right) of all the actuator rods in the vertical setting stage was 97.33%, the error rate being approximately 2.67% (Figure 6.21). The average accuracy rate for the directional wave pattern in the four directions of all the actuator rods in the horizontal setting stage was 96.5%, the error rate being approximately 3.5% (Figure 6.22). I concluded that the interactive floor could be controlled using the GUI generator; via an Arduino 5 × 15 control of the rod arrays, using directional wave patterns in four directions of the vertical and horizontal setting stages. The results showed the potential of controlling the rhythmic wave pattern, including the interval speeds of the system, which meant that the haptic phenomenon could be transmitted to people' s feet. I can assumed that people may perceive the tactile sensation from the system. So that the system can notify people' s behavioral responses.

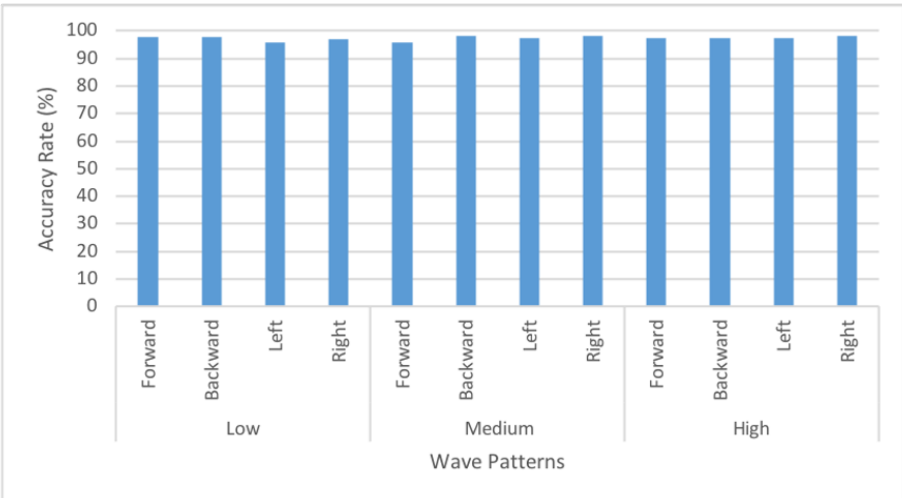


Figure6.21 Vertical accuracy from the directional wave pattern

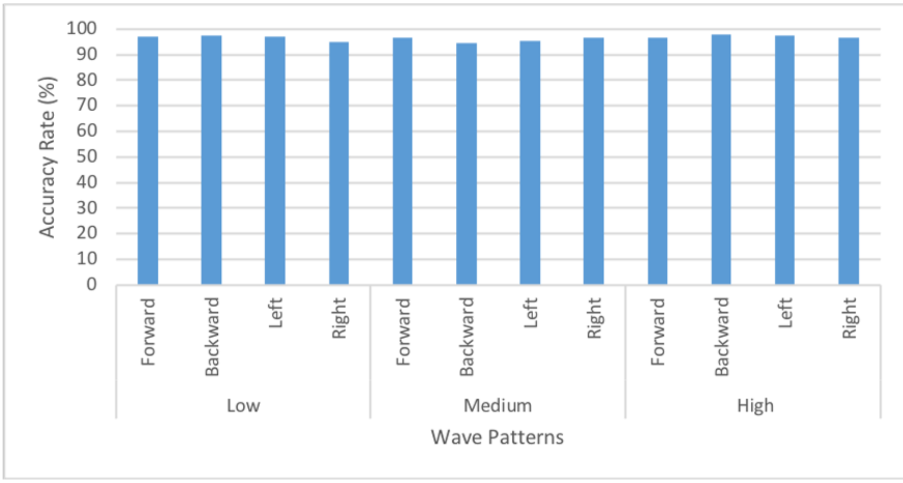


Figure6.22 Horizontal accuracy from the vibration wave pattern

### 6.2.3 Experimental Scenario1: The Signal Change

The purpose of the experiment [22] is to examine if the system can "prompt" the examinee of a signal change. I simulated the situation when people are waiting for the traffic light to change in a crosswalk. While they are focused on their smartphones without realizing the change in signals (Figure 6.23). In this experiment, I considered producing the stimulus using vibration under the feet. I proposed the floor surface to notify people of the change in signals.

The experimental procedure, participants are instructed to stand in front of the default red signal without receiving notification at the start. The participant is allowed to move in the desired direction.

#### 6.2.3.1 Experimental Condition

In this section I defined the experimental condition mentioned in Table 6.7. Participants were asked to wear shoes, use a smartphone, and wear headphones. I used three different interval wave speeds, with each stimulus being presented twice. Additionally, I prepared vibration wave patterns to stimulate participants in the experimental setting.

Table6.7 Experimental condition

| Subject | Condition |
|---|---|
| Wearable | A participant instructed to wear shoes-on. |
| Smartphone and headphone conditions | A participant instructed to use a smartphone and headphone. |
| Interval wave speeds | (1) Low (1 Hz)(1000ms)<br>(2) Medium (2 Hz)(500ms)<br>(3) High (10 Hz)(100ms). |
| Time | Each stimulus is presented twice |
| Duration of stimulation | 2 seconds |
| Wave pattern | The forward wave (Figure 5.12) will be generated with the changed green signal (Figure 6.23, right). |
| Data collection | The experiment involved 20 participants (10 female and 10 males; average age: 21.85 years). I collected 3 (interval speeds) $\times$ 1 (times) = 3 trials per participant. |

I defined that the threshold when the participant moving forward after the activation of the actuator is considered to be nudged by n, and the total number of participants is N. The feasible number of participants who are nudged can be expressed as $(n \times 100)/N$.

#### 6.2.3.2 Result

Figure 6.24 shows the experimental results of the participants who were prompted by the design vibration stimulus. The results indicated that a high-speed condition is superior to others. The result was not highly rated. I suspected that the low rate was the result of the individual perception based on each wave speed parameter. Difference in interval wave speed and traffic light stimulation can prompt participants as they look around to recognize the situation. I expect to further improve and investigate favorable wave speed ratio by designing various speed parameters.

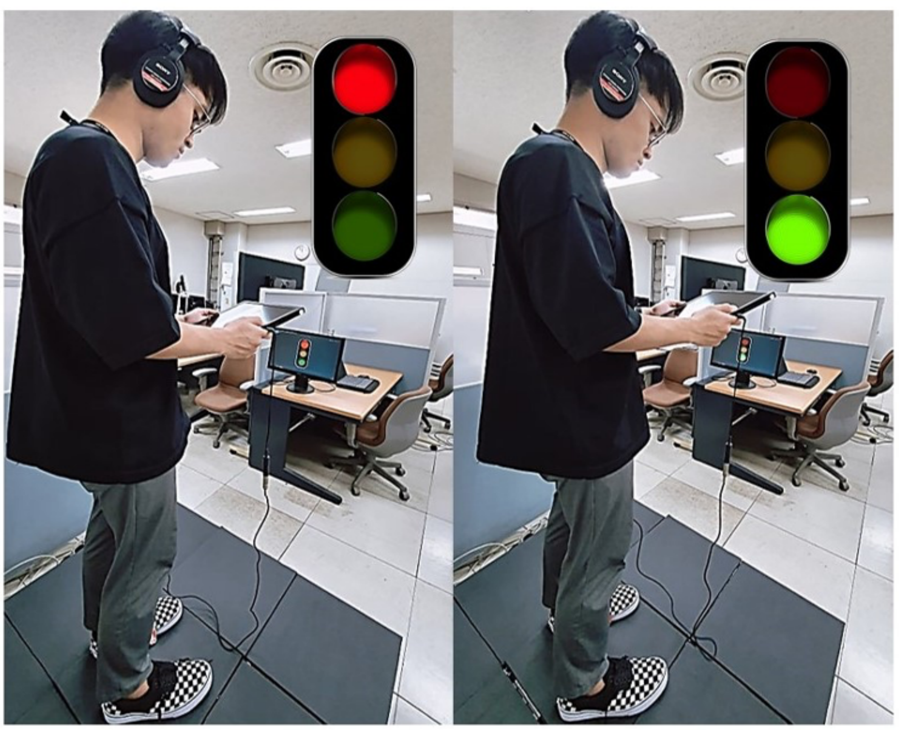

Figure6.23　Simulated environment of the traffic light scenario

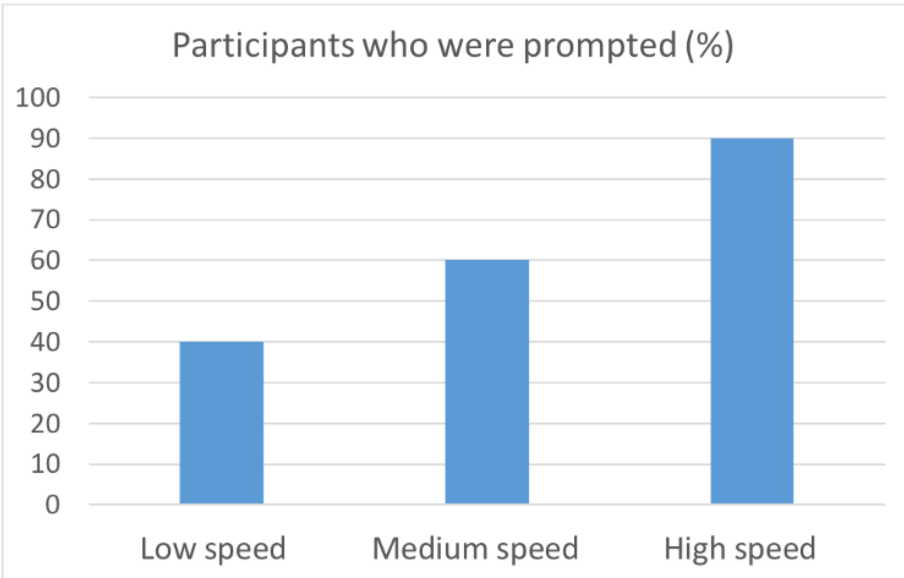


Figure6.24　Results of the field experiment

### 6.2.4 Experimental Scenario2: The Opposite Door in an Elevator Scenario

The purpose of this experiment [85] is to examine whether the system could prompt participants and make them aware that the door of the elevator is on the opposite side. I simulated a situation where people in the elevator were occupied and did not pay attention to the surroundings, thereby not realizing that the door opened on the opposite side (Figure 6.25). In this experiment, I considered producing a stimulus by using vibration patterns beneath the feet. I proposed an interactive floor to prompt awareness of the people regarding the door position of the elevator.

#### 6.2.4.1 Experimental Condition

In this section we defined the experimental condition mentioned in Table 6.8. In this experiment, subjects were instructed to wear shoes, use smartphones, and headphones. I prepared three intervals of increased speed, with each stimulus presented twice.

Table6.8 Experimental condition

| Subject | Condition |
|---|---|
| Wearable | The subjects were instructed to wear shoes and use smartphones and headphones. |
| Three increased interval speed | (1) Low (10–20 Hz) (100–50 ms)<br>(2) Medium (20-40 Hz) (50–25 ms)<br>(3) High (40–80 Hz) (25–12.5 ms) |
| Time | Each stimulus was presented twice. |
| Data collection | The experiment involved 20 participants (10 female and 10 males; average age: 21.85 years. I collected 1 (directional wave pattern) $\times$ 3 (interval speed) $\times$ 1 (times) = 3 trials per participant. |

In the experimental procedure, a participant was instructed to wear shoes with-/without using a smartphone and headphone. In the beginning he would stand on the ac Floor2 between the default closed door displayed on both screens, and no notification was provided when they arrived at their desired floor (Figure 5.2). A capacitive sensor installed under the floor surface was used to generate the isolated wave pattern included the increased speed and force intensities (Figure 5.12) in the horizontal setting of a floor. When the participant stepped onto the floor surface, the elevator departure scene was displayed on both screens for 10 s. The door opening scene was then displayed on the screen behind, the wave speeds will be generated when the door opens in 2 s if he does not exit. I selected the departure time to simulate the real situation of an elevator departure. Besides, I chose a stimulus period based on Visual and Audio Reaction Time (VRT and ART) [91] according in general when a person who is not disturbed by a smartphone looks at the digital sign and hear the sound alert in the elevator that noticed him to exit. Each participant was allowed to perform the action they desired. The experiment included twenty participants (ten females and ten males; average age: 21.2 years).

A threshold was defined based on human reaction times (RTs) to vibrotactile stimuli [91]. When the participant responded to the surrounding situation as they turned towards the open door of the elevator within 2 s after a vibration, they were considered to have been prompted (by n), with the total number of participants being N. Thus, the number of reacted participants was expressed as (n $\times$ 100)/N.

#### 6.2.4.2 Result

The result is shown in Figure 6.26. I examined if participants reacted to the stimulus. The results indicate that using the high interval speed range (40–80 Hz) (25–12.5 ms) is superior to the other conditions with 95% of them reacts. However, the results were not highly rated. I suspect that the low rate was the result of individual perception based on each wave speed parameter. I observed that gradually increasing the interval speed and using elevator stimulation could prompt participants to look around, turning to recognize the opposite door in the elevator scenario. However, I still need to improve the application scenario by evaluating it using more appropriate speed parameters and wave patterns. Furthermore, I anticipate an extension of stimuli on how to equip and range digital means into the daily environment in future studies.

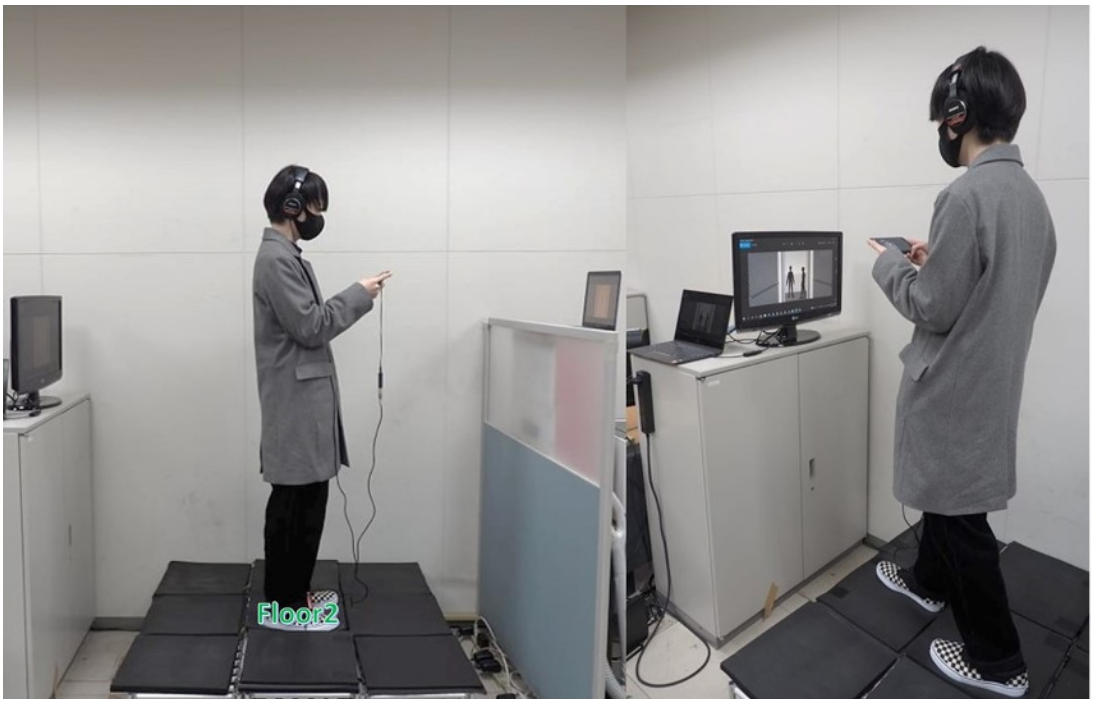


Figure6.25　Simulated environment of the elevator scenario

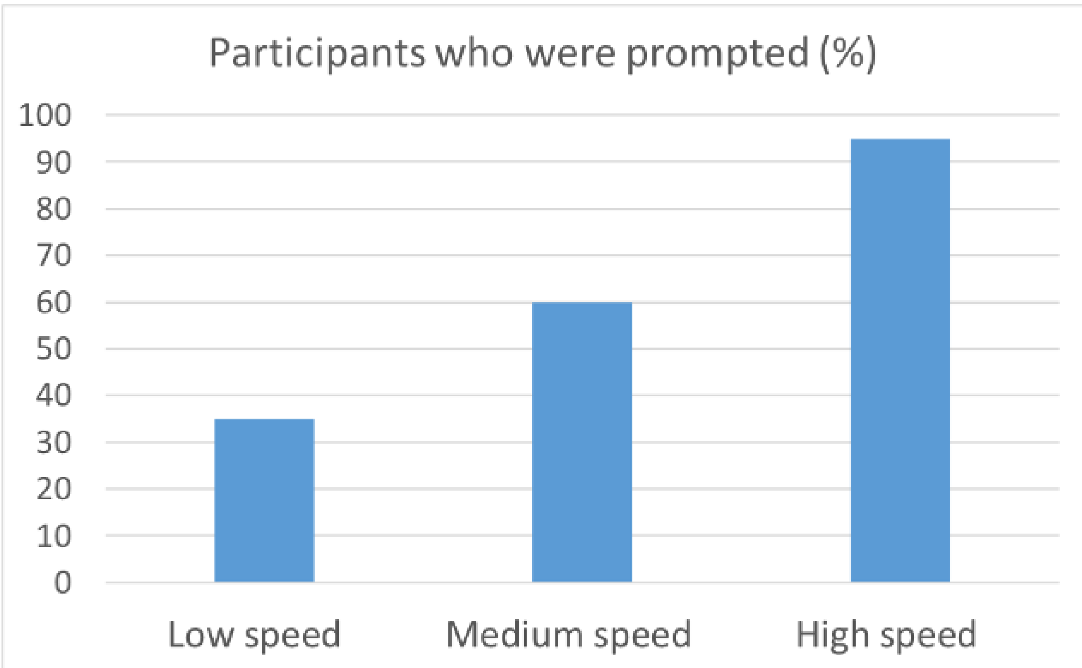


Figure6.26　Results of the field experiment

### 6.2.5 Experimental Scenario3: Maintaining the Distance in a Queue

The aim of this experiment [85] is to examine whether the system could prompt the awareness of a participant regarding environmental changes. Two situations were simulated to examine the part of the situation (Figure 5.3); (1) A person waits in a queue while he is distracted by the smartphone usage, and (2) A person waits in a queue without using a smartphone while he is otherwise occupied by surrounding. In this experiment, I considered producing a stimulus by changing the vibration speed under the foot according to the specified speed position. An interactive floor was proposed to prompt a person to keep maintaining his positions in the queue.

#### 6.2.5.1 Experimental Condition

In this section I defined the experimental condition mentioned in Table 6.9. In this experiment, participants were told to wear shoes and to use smartphones and headphones. I created decreasing interval speed ranges, with each stimulus being presented twice. A vibration wave pattern will be performed in the forward line of a vertical stage setting.

Table6.9 Experimental condition

| Subject | Condition |
|---|---|
| Wearable | The subjects with/without wear shoes and use smartphones and headphones. |
| Diminishing interval speed ranges | (1) Low (20–10 Hz) (50–100 ms)<br>(2) Medium (40–20 Hz) (25–50 ms)<br>(3) High (80–40 Hz) (12.5–25 ms) |
| Wave pattern | A vibration wave pattern (Figure 5.12) in the forward line of a vertical stage setting. |
| Data collection | The experiment involved 20 participants (10 females and 10 males; average age: 21.85 years). I collected 3 (interval speed) $\times$ 1 (rhythm speed set) $\times$ 1 (times) $\times$ 2 (condition) = 6 trials per participant. |

In the experimental procedure, a participant was instructed to wear shoes with-/without using a smartphone and headphone. In the beginning he would stand on a dummy floor on the left side of the queue, as if they were preparing to queue up. Later, they were instructed to stand in the center of the active floor (ac Floor1). Vibrations will then generate when a participant is in the queue. At the same time, on the front screen, by default, people are seen lining up (Figure 6.27, 6.29). A capacitive sensor was installed on the ac Floor. The isolated wave pattern (Figure 5.12, above) was used in a vertical setting of a floor. When the participant stepped onto the ac Floor surface from ac Floor1 (start position) to ac Floor2, decrease speed parameter sets on each ac Floor were generated gradually wherein the wave speed vanishes when a person moves towards the target position (ac Floor3). Each participant was allowed to perform the action they desired. The experiment included ten participants (one female and nine males; average age: 21.2 years).

I defined the thresholds based on the human reaction times (RT) to vibrotactile stimuli [91]. When the participant responded to the surrounding situation, moving to a target position within two seconds of a vibration finishing, they were considered to have been nudged (n), the total number of participants being N. The feasible number of nudged participants could be expressed as $(n \times 100)/N$.

#### 6.2.5.2 Result

The result is shown in Figure 6.28. I examined if participants reacted to the stimulus under the gadget usage condition, the results indicated that the high interval speed (40–80 Hz) (25–12.5 ms) was the most effective, with 80% of them reacts. However, the results were not highly rated. i suspect that the low rate was the result of individual perception based on each wave speed parameter.

Besides, in Figure 6.30 shows the experimental results for the participants who reacted to the stimulus under the state in which no gadgets are used. The result indicated a vibration of higher frequency scored a better result. However, the results were not highly rated. I suspect that the low rate was the result of individual perception based on each wave speed parameter. This resulted a higher rating than that of the gadget usage function. Using the diminishing high interval speed based on distance in the social distance scenario prompted participants to use both conditions, as most of them kept moving forward while queueing. The application scenario could be improved by examining it with more appropriate speed parameters and wave patterns. In addition, I examined the expansion of stimuli on how to equip and arrange the function into the living environment in future studies.


Figure6.27 Simulated environment of a lineup scenario with gadget

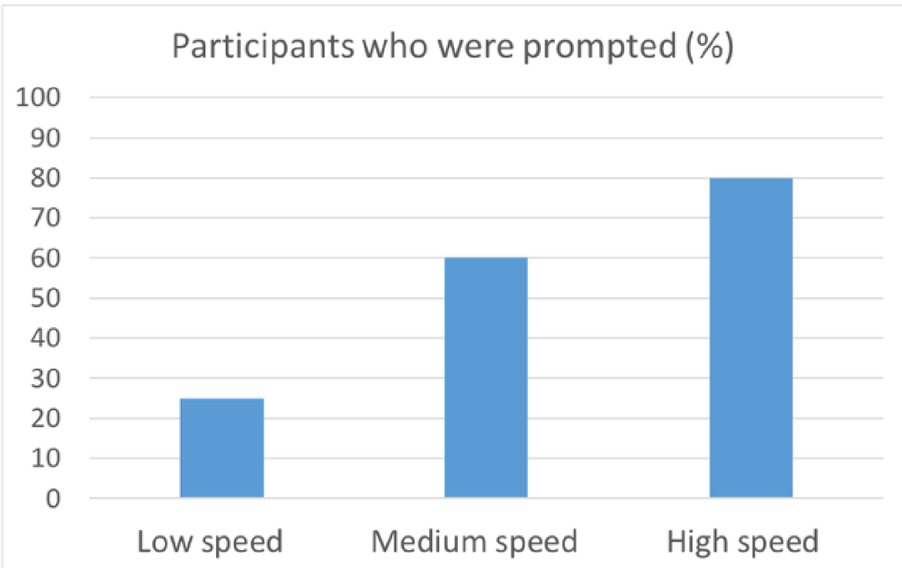


Figure6.28 Results of the field experiment


Figure6.29 Simulated environment of a lineup scenario without gadget

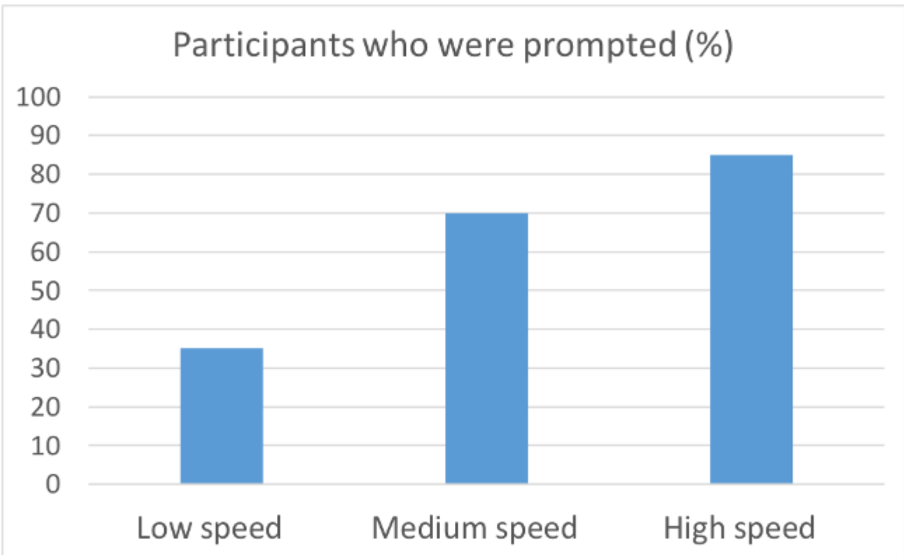


Figure6.30 Results of the field experiment

### 6.2.6 User Studies

#### 6.2.6.1 Examination of the Simple Floor Prototype to User' s Responses

I observed and simply examined by increasing the force intensity of a simple floor prototype. I examined on how it can present participants with a sensation as a fundamental for the actual prototype design.

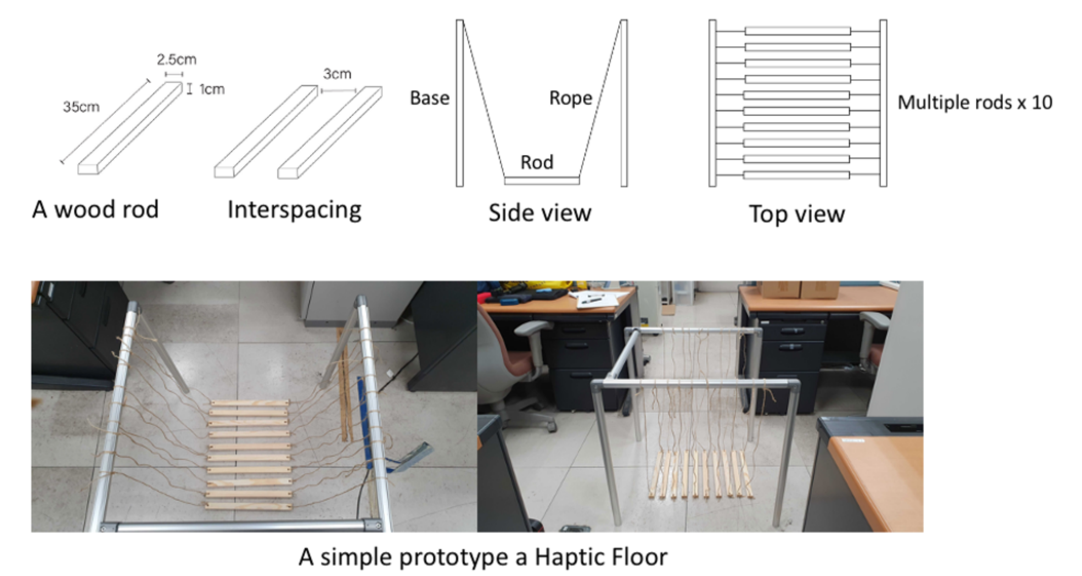


Figure6.31 The system assembly

In the experimental procedure, I performed the 2 designed wave patterns; pattern 1: Increasing the interval speed gradually higher from back to front, and vice versa. Pattern 2: Increasing force intensity gradually stronger from back to front, and vice versa.

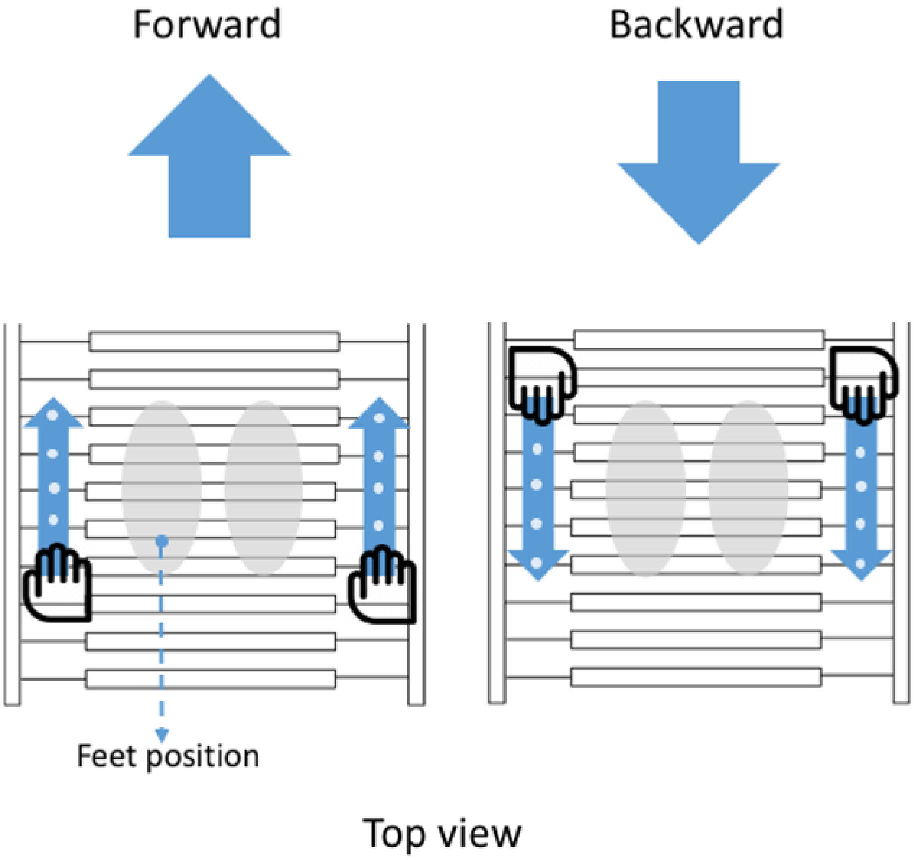


Figure6.32 The designed pattern

#### 6.2.6.2 Experimental Condition

In this section I defined the experimental condition mentioned in Table 6.10. In this experiment, participants were asked to wear shoes, use smartphones, and wear headphones. They were then instructed to walk on wooden platforms for a set amount of time. The length of the wave cycle for each pattern was manually defined for 5 seconds. Participants were performed 2 wave cycles, with each wave pattern presented in 10 random trials. The interval time between trials was approximately 1 second, controlled manually.

Table6.10 Experimental condition

| Subject | Condition |
|---|---|
| Wearable | The participant asked to cover their eyes and ears. |
| Shoe condition | The participants were asked to wear shoe. |
| Wave pattern | (1) Forward pattern<br>(2) Backward pattern |
| Duration of a stimulation | I manually defined the length of a wave cycle for 5 seconds of each pattern. |
| Wave cycle | The participants will be presented in 2 wave cycles each. |
| Time | Each wave pattern was presented in 10 trials in a random set. |
| Sex | The experiment involved 10 participants (1 female and 9 males; average age: 21.2 years). |
| Control condition | The interval time was set at 1 second roughly using hands control. |
| Control condition Data collection | I collected 2 (wave patterns) $\times$ 10 (trials) $\times$ 1 (shoes condition) = 20 trial data per participant. |

The experimenter interviewed the participants and collected the data.

Figure6.33　Participants in the experimental field

#### 6.2.6.3　Results

In this proposal, I performed a simple wave movement by changing of applying the interval speed and force intensity of the rod’ s movement. As for the participant’ s interview, most of them were able to sense the change of movements in different forms.

I found that by gradually increasing the speed of the wave interval in pattern 1, the participants were able to perceive the increased wave movement that makes them aware of the speed changes. In pattern 2 the participants are slightly confused by the meaning of increasing force intensity on the back. I assumed that this approach has the potential of conveying sensation to users and it could be further developed and applied the feature to the floor surface prototype weather in central or partial parts.

# Chapter 7

# Discussion

In this proposal, I investigated a person' s instinctive reaction to the design stimulus of each approach. I integrated multi-stimulation by digital means utilizing the proposed interactive environment that seamlessly integrates in an environmental context. To evaluate how effectively of my approach if it can prompt people in different scenarios such as in the pedestrian crossing situation (Figure 5.1), the opposite door in an elevator situation (Figure 5.2), the safe distance in the seat situation (Figure 4.1), and maintaining a safe distancing in a queue situation (Figure 5.3). Since, I was unable to conduct all of the experiments in a real-world setting. I carried out the experimental scenarios while taking into account the actual circumstance, which was replicated in both simulated and real environments.

In this section, I discussed about evaluating the proposed approaches and the application scenario's results. Besides, the system evaluation and the concept were addressed following the subsection below.

## 7.1 Evaluation of Each Approach

In this proposal, I employed the different digital function techniques, including vibrations and sound approaches. Each of which affects the way the participant perceives things in a specially designed situation. I investigated how the approach impacts effective response to a person.

### 7.1.1 Vibration Approach

Regarding the experimental scenarios utilizing the vibration approach, my initial intention aiming to solve public manner's issues in example scenarios. That is, to give cautions by using the directive touch to employ them for conveying warning messages at the spot of event. Generally, people were not giving enough attention or in some cases not at all to the given cautions such as voice announcement or display. So that, the conventional media as those cautions had become part of the background context in their environment.

In this proposal, I examined the proposed approach utilizing vibration stimulation to observe how effective our approach is in example situations. Regarding the experimental result, I observed that a person able to feel the change in speed from direct contact of the vibration with the feet in the context of a specific situation. This has an advantage over other types of stimulation in cases where the person is disturbed in everyday situations. When they are disturbed by the surrounding light and sound, the person will not be able to perceive it. Thus, utilizing vibration approach can be a direct command that touches the skin and stimulates immediate perception that impacts the desired human behavior in these situations.

### 7.1.2 Sound Approach

By using sound approach, I discovered that people can understand the meaning and imagination according to the sound source that I designed in a specific context. In example scenario of an outdoor bench, I chose to use mosquito sounds that affect people's minds, such as making them fear/anxiety. I know that designing the interaction of directional speakers utilizing 3D audio effect in the specific situation can impact on a person perception better if the interaction design is designed appropriately.

Concerning the speaker mechanism design to the person response, it emitting sound toward the target person that may resonate with the non-targeted person. Installing acoustic panels depending on the circumstances can also provide better results. Additionally, calibrating the speaker' s position to suit the physical characteristics of an individual' s height is difficult. Regarding our findings, people who are between 1 to 1.3 meters tall when seated (measured from the position of their feet to ears) hear the sound more clearly than those who are physically above or below that ranges. I plan to incorporate the speaker' s mechanism structure into a two-axis servo direction controller that detects the human' s position automatically.

### 7.1.3 Observation

Based on the graphs of experimental results, most scenarios indicated the higher the frequency of design stimuli becomes the better the examinee is prompted to aware of environmental changes. I assumed that if we make the stimuli frequency still higher, I could get a much higher score ideally. I expect to further examine the examinee with the higher parameter speeds of the design stimuli whether they can feel the prompt in their environmental context. Besides, I hypothesized that the utilization of multiple stimuli condition can provide a better prompt value than an isolation stimulus in the certain situation based on the experimental outcomes. Besides, I assumed utilizing the diverse cognitive components of the sensory-motor task (e.g., biophysical and synaptic processes, recurrent and feedback connections, and learning) through the rhythm, time perception, and beat induction of the vibration and sound approaches. They represent temporal information for sensory-guided action based on the interval-produced process [71]. This could make participants more susceptible to cognitive psychology. It substantially affects their abilities to act to the desired responses as a prompt in the certain situation.

This finding had demonstrated the idea's practicality, and that the system would work with people by designing various stimuli according to their context. If an appropriate design is provided in a feasible system, it can be expected to be considered for use in a real environment. My findings imply that designers can employ and investigate several stimuli to create a diversified stimulus in order to deliver more varied sensations (e.g., touch, visual, and hearing) for prompting in the designed particular context.

## 7.2 Evaluation of the Scenarios

### 7.2.1 The Safe Distance in the Seat Scenario

In the in the safe distance in the seat scenario (Figure 6.5). I set when the examinee sits onto the actual bench, the increased speed parameters of the mimic sound will be generated by using the capacitive sensor installed beneath the target seat to detect the examinee's position. I attempted designing stimuli as impact a person feel anxiety or fear of something happens (e.g., mosquito is flying around) at the point for prompting people to get up and have a safe distance between the seat. To successfully perform the experiment, I validate whether the examinee reacts to the design stimulus. Results shown in Figure 6.6 indicated that the proposed 3D sound technique can prompt a person using the high rhythmic and volume condition to react to the surrounding as they looked around and get up from the chair to determine the situation. The result shows my proposed method is superior to other condition. I assumed that using the mimic sound source with the high rhythm and volume parameters through the proposed 3D sound technique can prompt participants in the social distance scenario as most of them kept moving away from the bench. Results indicated that the proposed method has a higher rating than the conventional warning sound included the surround technique. I suspect that people are familiar and understand the meaning of simple warning sounds in general which causes them to be not aroused in this specific situation. I consider our approach of using nudges to work on the instinctive nature of humans. When they are occupied with emerging into the environment/engaging in conversation and trying to grasp its meaning, a simple warning signal would not be able to sufficiently capture their attention. This would work for such circumstances and the decision was made to prompt people aware of the change in sound source, volume, and timing of the sound that subconsciously induces situational awareness. Additionally, when embedded the system in the environment the harmful effects of the designed mosquito sounds benefit all close enough to hear. Further user explorations showed that the special experience offered by the 3D sound system could arouse a person' s desired response thought the mosquito flying around effects. A side effect could also be to alter people' s desired behavior to have a social distance between seats in the public space. The application scenario can be improved in future studies by investigating it with a more appropriate sound source, loudness, and timing characteristics depending on the designed behavioral strategy. I will investigate the extension of multiple stimuli usage in border situations.

From the interaction design aspect, I envision a situation beyond our designed scenario when there is only one person sitting in the middle before and someone coming to the right or left after. In this case, the system will still prompt the middle seater to get up even if the middle seater sits first. Since the Coronavirus pandemic is a significant worldwide health issue that is causing a shift in human behavior in the living environment, the distance must be taken into account first. Regarding the experimental condition, a cushion was put on a bench surface, allowing participants to sit in the correct position and enabling the system to be operated. Generally, I envision the sitting position as incorrect, I assume that the results may change slightly; however, it may not have much effect. Given that typical benches are designed to seat only two or three people, the entire seat can be outfitted with my system. In the case that the benches vary from the typical design, the system should be designed according to the circumstances. Moreover, I considered using the capacitive sensor for outdoor environments because it would be more precise than another approach, such as the image processing, in detecting the target person' s position in uncontrollable environments. For example, when the light changes, the program may become confused. Additionally, people passing by can render image processing ineffective. Hence, I decide to employ the sensor in this situation to reduce interference.

### 7.2.2 The Signal Change Scenario

Through the design specification, as for prompting a person in a crosswalk scenario (Figure 6.23). To successfully perform the experiment, I validate whether the examinee reacts to the design stimulus while they are focused on using smartphone device. Results shown in Figure 6.24 indicated that the floor can effectively prompt a person of the environmental changes as he looks around to determine the situation. Later on, he noticed the signal that changes in a crosswalk, this caused him to decide themselves to start crossing the road. So that, he was considered to be prompted. The application scenario, on the other hand, needs to be improved by evaluating it with more appropriate speed settings. I suspect that the low rate was caused by individual assessments of each wave speed characteristic.

### 7.2.3 The Opposite Door in an Elevator Scenario

In prompting the opposite door in the elevator scenario (Figure 6.25), I validated whether participants had reacted to the stimulus. The results shown in Figure 6.26 indicate that an interactive floor prompted most participants while they were distracted by the smartphone to observe their surroundings that impact the desired subsequent action by using the high wave speed set. Because, the designed stimulus works for prompting in the elevator scene, participants may imagine the phenomenon while the floor is vibrating as when people come in and out. A person, later on, adjusted his specific behavior as he turned towards the opposite door of the elevator, so he was considered to be prompted. This desired subsequent action is a result of his observation at his surroundings and observing signal changes. However, the application scenario must be improved by evaluating it using more appropriate speed parameters. I suspect the low rate was owing to individual perceptions based on each wave speed parameter.

### 7.2.4 Maintaining the Distance in a Queue Scenario

In social distancing in a queue scenario (Figure 6.27, 6.29). To perform the experiment successfully, I validated whether examinees had reacted to the stimulus. The results revealed that they responded by moving to the target position following the increasing wave speed stimulation. However, the results were not rated highly. I suspect that the low rate was owing to individual perceptions based on each wave speed parameter. I assumed that when the wave speed changes from being stronger to weaker, this can induce a person' s instinctive reaction desired in a specific situation because most responded to move to the target position while queuing. In general, when a person is occupied in reading and seeing information, another notification would not be able to sufficiently capture their attention. This would work for such circumstances, and the decision was made to use a stimulus to prompt a person to be aware of the change in speed of under-foot vibration. In this case, the designed vibration is not a phenomenon felt in a natural situation, but it uses a metaphor of a vibration that provides when something' s wrong in a video game-like manner. With such a designed stimulus, I assumed that a person may feel anxious upon experiencing changes in the environmental context. The designed stimulus would alter a person' s behavior such that they observed situational changes in the queue. A person, later on, takes the desired subsequent action to move to the ideal position where the wave fades. The application scenario can be improved by examining it using more appropriate speed parameters. As a result of these findings, both scenarios demonstrated their potential for an approach to designing and using stimuli to which people respond feasibly.

## 7.3 Evaluation of the Systems

The major advantage is that an interactive environment can prompt a person's instinctive reaction that affects them to take the desired subsequent action in specific situations. Another advantage is that it can produce any wave pattern of the vibration, including the isolated wave patterns (forward, backward, left, and right) along with the higher increased interval speeds, rhythm grouping, and force intensities. Besides, it can produce any rhythmic sound pattern. The proposed system is designed to be able to create the environmental occurring that can impact human behavior responses in a situational context. For example, I can generate rhythmic vibration and sound patterns with interval speed parameters based on the user's position as detected by the sensor to achieve the designer's expectation on the desired human behavior in the situational context.

It is challenging to implement interactive environment, because it requires the system that have to be controlled multiple stimuli in unison. Although, this proposal examined insights into human responses to stimuli in relation to specific situations, there were several limitations that must be considered when conducting future research. Because this proposal was not conducted in a real-world situation, it might have been challenge for participants to imagine themselves in a specific situation characterized by specific stimulation modality, which indicates the possibility of obtaining different data if the study was to be conducted on-site in those situations. I must improve the application scenarios using more appropriate parameters and patterns of the designed stimulation. Additionally, the proposal had university students, with an unequal number of male and female respondents, which may have affected the results. Using a larger sample size with a more equal gender balance may yield results that can be validate the results more broadly.

To make the system more practical in the real-world setting, there are many engineering challenges that need to be addressed to incorporate the system into a real environment, such as the scale of the system in terms of area. As I examined the floor on a limited scale because it was initially placed in front of participants to produce a haptic and audio signal, my method is limited to equipping systems on a large-scale ubiquitous of the digital function. In reality, I envision that if people interact with the larger systems, they can be induced to respond more naturally. Additionally, I took into account the difficulties in controlling the response to a sizable group of people that may use the number of sensors or cameras to detect a group of people in a real situation to facilitate widespread interaction. I need to consider making use of the system's robustness; a steel frame and more potent actuator and a directional sound system capable of transmitting directional sound over a greater distance. This may be able to support the number of people in a real situation. I expect to design the concept of seamless integration digital functionality using expanded stimuli for broader situations. There are further challenges to enrich and expand our approach of examining the human response utilizing multiple stimuli for a certain situation will be expanded.

## 7.4 Discussion on the Concept

Regarding my concept of designing the stimulus, I intended to not manipulating a device for conveying information, but integrating the digital stimulus into the environmental context without the need for operation or command. That is, I expected the design stimulus may prompt the awareness of people to their surrounding naturally. My approach is proposed to convey messages to people who are absorbed in their smartphones, and also to whom do not pay attention to etiquette warnings, without relying on human awareness or morals. However, my methods need improvement, including stimulating human behavior by using appropriate parameters to design the interaction of the digital system, and implementing specifically for each different stimulus. That is, Find a good pair of context and stimulus. If the design is suitable, I expect my method to yield results efficiently. Based on this, I proposed my concept as a proposal for an alternative attempt, rather than an improvement on the conventional methods of presenting information.

In comparison, my approach has advantages and aspects needing further improvement compared to conventional ones. As a conventional media such as digital signage, voice announcement or smart phone applications tended to directly covey information to people. That is, they required people intentional interaction such as operation or command which it will benefit to notice people to receive information in general. However, it does not seem to be effective warnings for such a situation. Because these media make an effort to appeal to people' s reason, they will ignore the message if they do not want to obey.

The significance of my design concept is in creating an ambient digital function that seamlessly integrates into the situational context. I utilize digital functions to produce a variety of stimulation modalities through my concepts and system designs. My approach is effective when a stimulus is well-designed to be combined with the surrounding context. Besides, for making digital functionalities in the surrounding environment, there are two major subjects in designing it. That is, (1) design functions to prompt people to react unintentionally without needing their attention and (2) seamlessly integrate functions into environments, both physically and in people's behavior. In this study, I do not pursue the create a highly effective warning in this research. That is out of my scope here. Furthermore, my concept showcases examples of ambient digital functionality and explores the potential and value of integrating digital features into living spaces. Despite a somewhat individualistic view of daily activities, my research also contains topics related to social motivation as a future challenge. To generate a social change impact, I created a virtual representation of a social motivation or competition and alter people's behavior such as making virtual messaging and environmental changes. Furthermore, the employment of fun or entertaining components was the most commonly studied method. I showcase methods to use an interactive environment to create enjoyable experiences based on daily activities. Some concepts include challenges to encourage exploration of the environment for the purpose of unintentionally guiding people in the right direction, while others link the activity to art installations in urban parks that can contribute to the attractiveness of the environment and stimulate people's creativity.

While my approach can influence desired behavioral responses, it is challenging to evaluate the naturalness of people's feelings toward my proposed stimuli in a specific context. To address this, I refer to the "naturalness experiment" [92]. This type of study involves exposing individuals to experimental and control conditions that are determined by nature or other factors outside the control of the investigators. The process governing the exposures is similar to random assignment [93], so natural experiments are observational studies and are not controlled in the traditional sense of a randomized experiment (an intervention study).

To observe the outcome, I interviewed twenty participants about how realistic they found the stimuli in a real outdoor bench setting. After the experiment, I asked participants about their reactions to the situational changes in their environment. Based on their feedback, most of participants felt in the way that I expected (e.g., most participants reported feeling mosquitoes flying around in the outdoor environment), which designed stimuli led the majority of them to believe that they were experiencing a real natural phenomenon. From the observational study, I can assume that designed stimuli can impact people and lead them to feel as if an actual natural phenomenon is occurring, which influences their behavior. Thus, I can conclude that designed stimuli matched the setting.

However, the proposal also acknowledged its own limitations, suggesting that the inability to control variables in natural experiments may hinder me from drawing firm conclusions. In my future research, I need to take into consideration of natural experiments before conducting any experiments. I should rely on "grouping" that occurs naturally or on criteria that were set without considering the research from the outset, in order to identify the differences in the variables of interest between the experimental and control groups.

## 7.5 Other Application Cases

In this section, I discuss the idea of applying a similar approach to the other application cases than warning. My concept demonstrates the potential and value of contributing to the same core idea to seamlessly integrate an ambient digital function in other cases. For instance, I come up with the expanded idea of designing the "psychological barrier strategy" strategy; I make a virtual representation of motivating factors and alter desired behaviors. I employ the core idea to create enjoyable experiences based on everyday activities in addition to "fun/entertaining / attractiveness" strategy. The explanation of my design intervention techniques may be contributed by these design ideas.

### 7.5.1 Psychological Barrier Strategy

Though I take a rather individualistic approach to everyday activities, I also explore ideas related to social motivation. To influence people's responses to behavior in the environment, I illustrate a virtual motivation model that can convey messages that are either positive or negative.

I ilustrate the situation for prompting a person to move and draw a massage in public place (Figure 7.1). These days, living a modern lifestyle can be stressful. I observe people becoming overwhelmed by the demands of modern living. It's possible that people lack the drive to engage in activities or look after themselves. Even though my concept has a somewhat individualistic view of daily activity, it includes sketches related to social motivation. This is usually accomplished by using a virtual representation of a cheering community or messages from fellow exercisers (message to strangers).

Various technological supports were envisioned to design these experiences: to intrigue people to naturally involve to a design space, I take advantage of the floor's touch screen; engage with the LED panels, which can lead any user get comfortable with the surroundings. This strategy is especially attractive to people of all ages since the cheerful features appeal to a broad audience. That is, it can impact social motivation as well as user can exercise their moves while drawing inside themselves and also encouraging others through messages to public places or hand-drawn emojis. I expect that this system will be able to inadvertently convince people to do more activities as well as inspire people with the motivated messages.

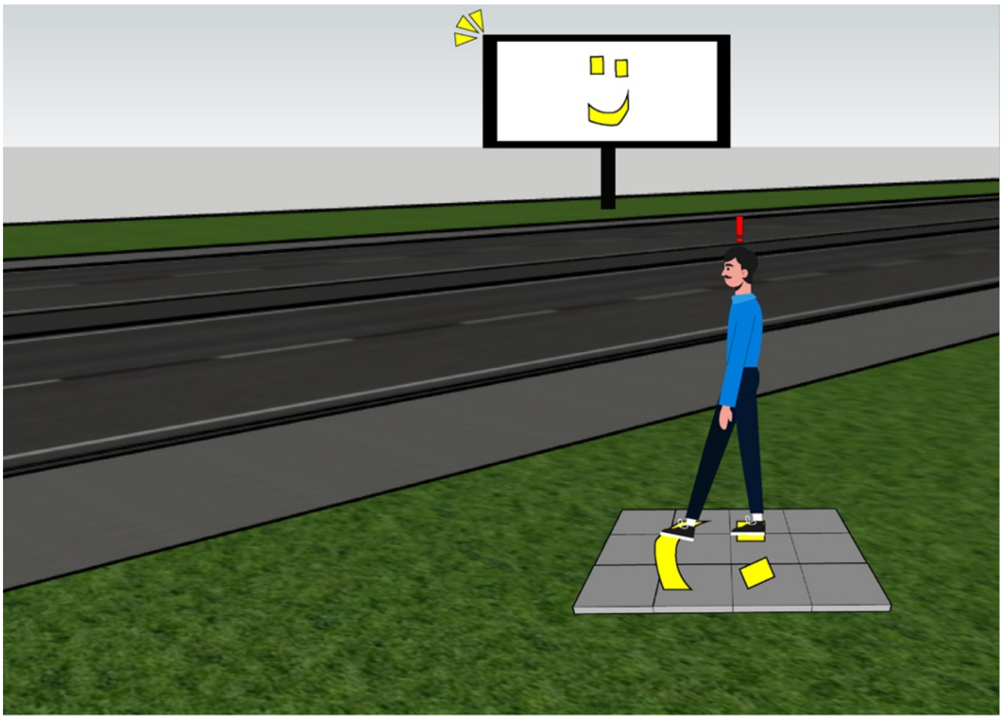

Figure7.1　Move to draw

I imagined the negative message scenario (Figure 7.2). a situation in which a person uses his phones or talk without being aware of a public manner in public spaces. As smartphone usage is a pressing concern to worry about, such as texting while walking or even addiction to it.

My idea is to create a sense of embarrassment for inappropriate actions in public. When a person walks too slowly or stops to answer their phone, he will earn a negative cheer from the virtual audience. In order to create this sensation, I design a virtual representation of sound by sending a person messages implying that he should not misbehave a public manner in a particular situation. Technological supports were envisioned to design this experience: the use of the 3D directional speakers to deliver the designed sound stimulation to stop the unpleasant behavior of the smartphone addiction. I proposed the design stimulus may impact their feeling toward the public manners that cause the desired behavioral response as a person stop using a smartphone while walking in public spaces.

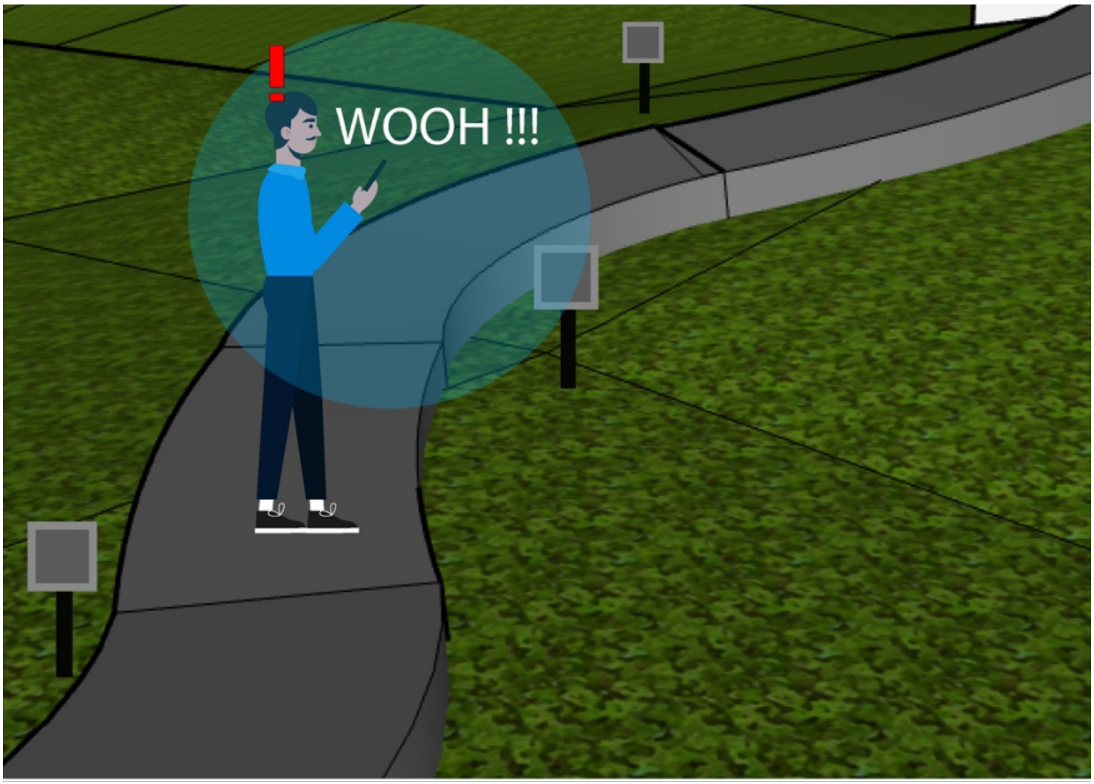


Figure7.2　Negative message

I envision an immerse surface scenario (Figure 7.3). In situations where people perform daily activities such as jogging, they may not be alert. To encourage running even more for people's challenging workouts, I want to prompt with the emotions of excitement and anxiety.

My idea is to create such a sensation by using technological supports to design this experience: I design the changed surface' s stimulation that is seamlessly integrated into the outdoor activities. Using an interactive floor surface, which the whole surface can be moved up and down in the walk lane. I proposed the system can prompt a person to observe the changes in a floor environment. When a person walk slowly the floor surface will gradually fall faster from behind. This may cause him to imagine that something is happening (e.g., the floor slowly collapses from the backward). I expected human behavior by using the design stimuli to cause the desired response as a person walks or runs more quickly.

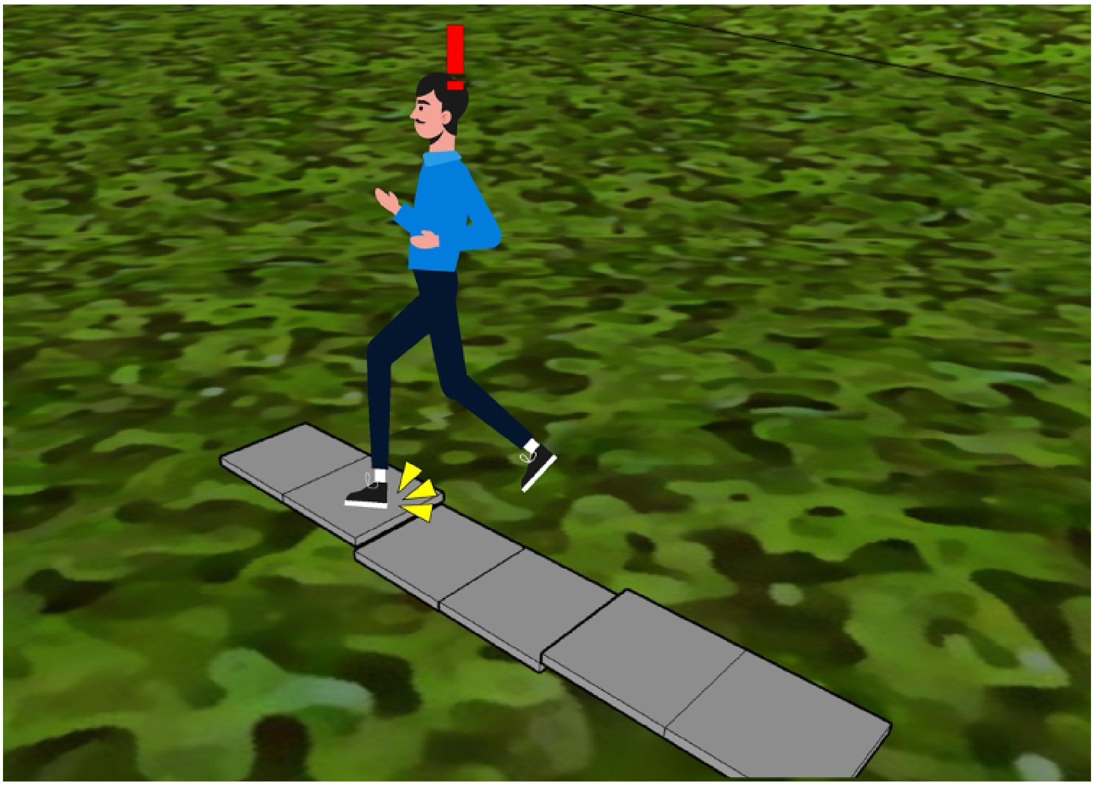

Figure7.3 Immerse surface (fall down if you run too slow)

### 7.5.2 Fun/Entertainment Strategy

Most commonly explored strategy is the use of fun or entertaining elements or gamified elements. My idea focused on designing a stimulus and seamlessly integrating the approach into living environments to create playful experiences based on daily activities.

I proposed to prompt a person to jump an exciting/fun obstacle in public space (Figure 7.4). Some concepts include challenges in order to stimulate exploration of the environment. People may believe the cracked floor is real due to the exaggerated natural phenomena. This mimicked phenomenon may produce excitement and positive sensations, so that it will allow people to interact with this stimulus. When someone jumps over this designed digital stimulus to avoid the threat, it might affect how they react.

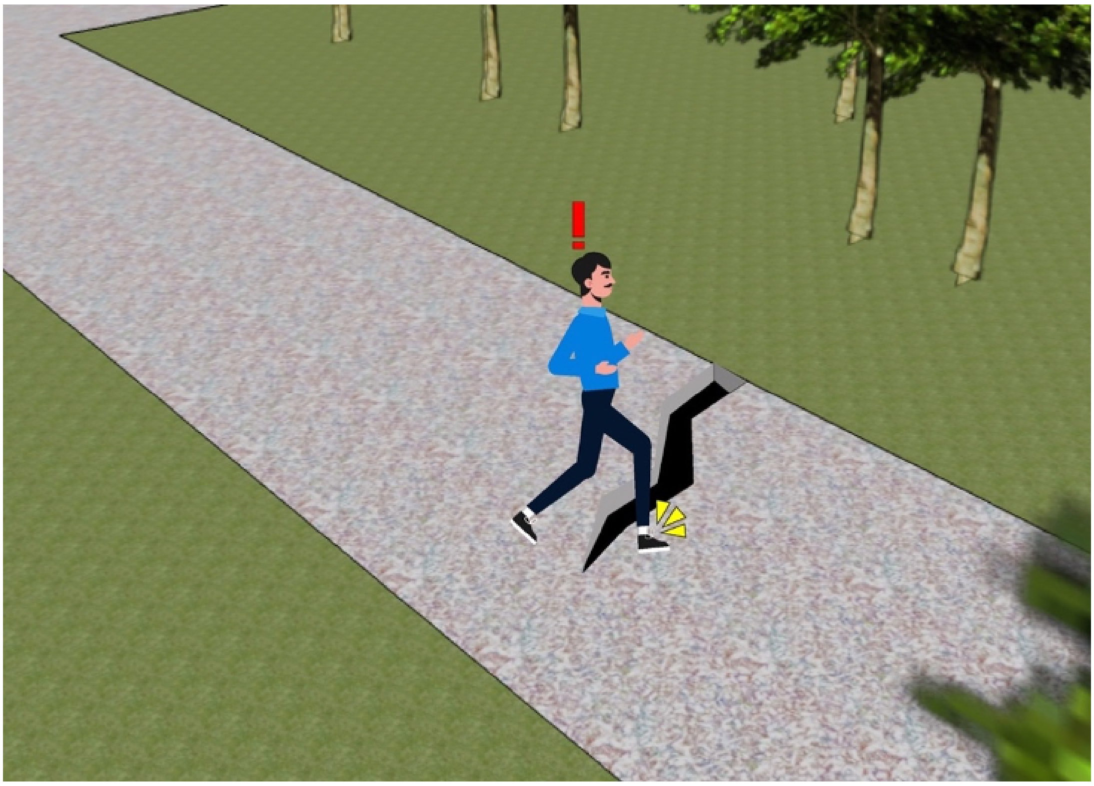

Figure7.4 The floor is cracking

I envision a situation to intrigue people outdoor activities by creating art installations in urban park forms (Figure 7.5). This illustration of my approach can impact the attractiveness of the environment and encourage people's creativity. For example, creating an experience that contextualizes environments by imitating light and sound of a wave of water. A person is supposed to feel amused and intrigued by this design, which will encourage them to walk following it.

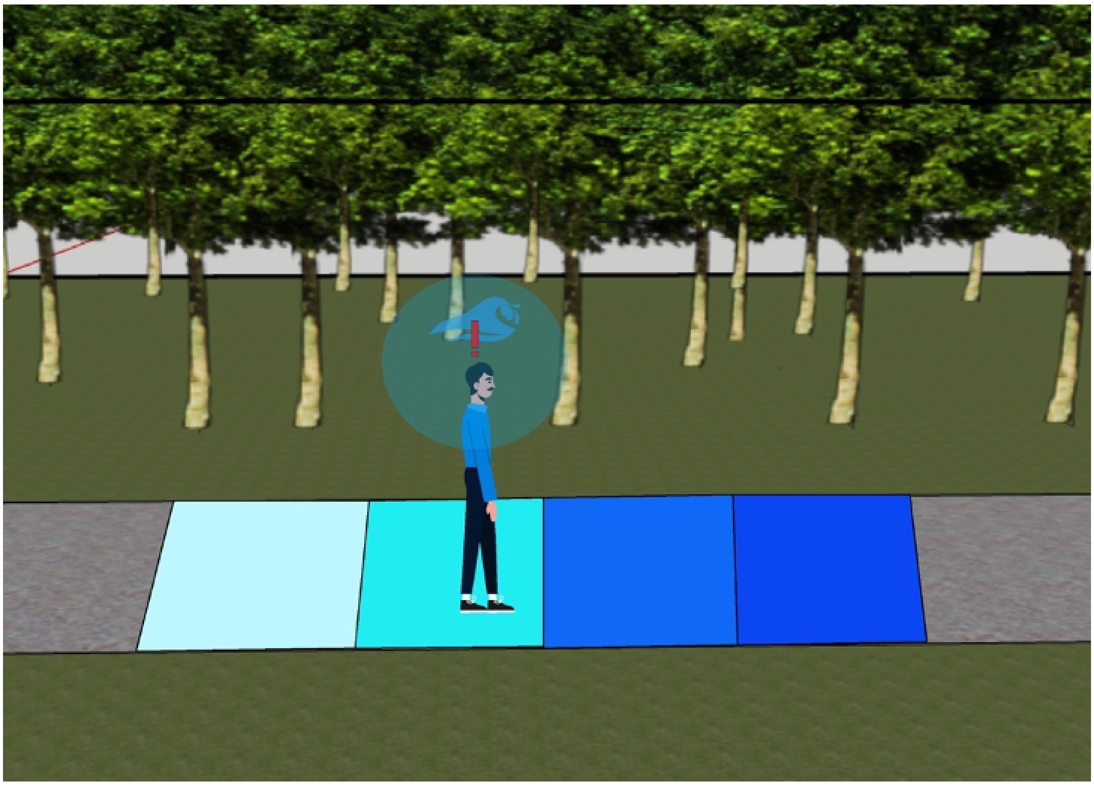

Figure7.5 Guided way

My idea is to design the strategy that is especially attractive to people of all ages since the entertaining features appeal to a broad audience while also triggering social interactions. Existing gamified outdoor spaces are mostly aimed at children, thus there is a desire to develop treatments that are not limited to this demographic. Various technological supports were envisioned to design these experiences: to step in, the use of a capacitive sensor; the usage of a capacitive sensor to interact with LED panels and sound can provide an immersive media such as, visual and sound effects for intriguing people in the park without needing for an additional system. The novelty effect of some of these notions, on the other hand, may disappear with time.

# Chapter 8

# Conclusion

I designed and created a series of multiple stimuli to prompt people's awareness of their environment when they engage in inappropriate behavior. I attempted creating a digital stimulus to which they will react spontaneously rather than communicating a message or information. The experiment shows the system function as I intended in reacting to the design stimuli. As a demonstration of the proposed approach to design a stimulus by utilizing digital functionality. When implementing the concept, it is important to design interactions that seamlessly integrate into the context to consider the design of "ambient digital functions". I believe it is essential to seamlessly integrate the system with living environment, and not just from a physical setup standpoint. A design for human-computer interaction should be included as part of a seamless integration. I think of it as people naturally interacting as they spend their daily lives, regardless of the function' s existence. I demonstrated my approach utilizing the digital functionality in various application scenarios, prompting people to take a specific response or refrain from taking a specific action by providing them with stimuli.

Regarding to the performance evaluation of the system functionality. The results demonstrated the effectiveness of an interactive environment system when used to set up in a particular context. Similar to how I can control the majority of the rod's movements by setting a global wave pattern in the horizontal and vertical setting stages. This also included the design of sound patterns that can deliver the sound in defined interval times and sequence of speakers. The GUI generator controls the multi-stimulation using digital means in unison. I confirmed that the system can produce the designed stimuli to be able to convey a variety of phenomena to people's feelings by psychologically. This inducing their instinctive response through the use of multiple designed stimuli which blended in the design context.

In the process, I attempted to design a stimulus to impact people' s behavior rather than merely conveying a message or information to instruct people directly. My concept is similar to the nudge concept, i.e., designing the environment context to influence a human to take the desired action. However, my concept differs from a bias-induced heuristic in that it influences them to make (presumably) good decision-making from the available choices mentioned in the behavioral economics and nudging, utilizing a more psychological effect, while my approach does more instinctive response. I merely borrow the nudge concept in the aspect where it works non-consciously. Hence, I design a stimulus in a way a person would react instinctively, which suits in each context. However, I need more examinees to make the concept and experiments more reliable in future work. Based on my discussion, I confirmed that my approach can be designed and use stimuli to which people respond. On the contrary, the ability to apply the system to a real-world setting is not something that can be claimed in the current state of this study due to three challenges: First, the experiment itself was only carried out in a small-scale setting, and the outcomes were obtained from a situation that is very different from a real-world scenario. Second, the results themselves do not go far enough to demonstrate such a superior effect. Lastly, to integrate the system into a real environment, numerous engineering issues must be addressed, such as the stability and control of the larger system. I suggest that it is possible to work with people by designing various stimuli according to their context, in conjunction with the design of stimuli presented in my proposal to contribute the approach by combining the multi-stimuli. If an appropriate design is provided in a feasible system, it can be expected to be considered for use in a real environment. In addition, this proposal emphasizes the importance of ideas through concrete implementations and experiments.

All-in-all, I expect that I can expand the use of stimuli by applying my concept of integrating digital functionality as a part of the living environment. In order to consider the design of "ambient digital functions", it is important to design interactions that blend into the context. Besides, the contribution of this study is that the importance of such ideas is made clear through concrete implementations and experiments. I examine the human response in broader situations to encourage them to take or refrain from a specific action. This would be integrated into the real situation where digital functions are becoming more naturally immersed into particular contexts, such that individuals naturally interact in their daily activities without being conscious of the function's purpose.

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