FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

The Effect of Sound Design on the Serious Game *Venci's Adventures* Experiences

Zijing Cao

Mestrado Integrado em Engenharia Informática e Computação

Supervisor: Gilberto Bernardes de Almeida

Co-Supervisor: Eduardo Magalhães

July 28, 2022

The Effect of Sound Design on the Serious Game *Venci's Adventures* Experiences

Zijing Cao

Mestrado Integrado em Engenharia Informática e Computação

July 28, 2022

Abstract

Sound design is an essential part of serious game design. The present thesis aims to investigate the sound design effects on people's experiences in serious games. First, based on the selected series game *Venci's Adventures*, three different versions of the game were produced: the serious game with sounds (standard sound version), the serious game without sound (no sound version), the serious game with an additional auditory notification besides the normal sounds (notification version). By using these three versions of games, two experimental conditions and the corresponding questionnaires were built up. In total, 23 participants were arranged to join these two experiments randomly. During the experiment, after all participants played the specified versions of serious game, they were asked to finish the corresponding questionnaires to measure their experiences.

In the end, by comparative analyzing the experimental through the method called analysis of variance (ANOVA), three conclusions were obtained: 1. Compared to the no-sound version of the serious game, the standard sound version gives players more good game experiences and fewer bad game experiences. 2. Compared to the standard sound version of the serious game, the additional auditory notifications in the education part of the notification version game have significantly positive effects on capturing and maintaining players' attention. 3. The specific type of sound, Earcons, created by using musical notes and the sine tone, can be used as the auditory notification to improve players' attention in serious games.

Keywords: Sound design; Serious game; Player experiences

Resumo

O design de som é uma parte essencial do design de jogos sérios educativos. A presente tese visa investigar os efeitos do design de som nas experiências das pessoas em jogos a sério. Primeiro, com base no jogo da série seleccionada *Venci's Adventures*, foram produzidas três versões diferentes do jogo: o jogos sérios educativos com sons (versão de som padrão), o jogos sérios educativos sem som (sem versão de som), o jogos sérios educativos com uma notificação auditiva adicional para além dos sons normais (versão de notificação). Ao utilizar estas três versões de jogos, foram criadas duas condições experimentais e os questionários correspondentes. No total, foram organizados 23 participantes para se juntarem a estas duas experiências de forma aleatória. Durante a experiência, depois de todos os participantes terem jogado as versões especificadas de jogos sérios educativos, foi-lhes pedido que terminassem os questionários correspondentes para medir as suas experiências.

No final, através da análise comparativa da experiência através do método denominado análise de variância (ANOVA), foram obtidas três conclusões: 1. Em comparação com a versão sem som do jogos sérios educativos, a versão de som padrão dá aos jogadores mais boas experiências de jogo e menos más experiências de jogo. 2. Em comparação com a versão sonora padrão do jogos sérios educativos, as notificações auditivas adicionais na parte de educação do jogo da versão de notificação têm efeitos significativamente positivos na captação e manutenção da atenção dos jogadores. 3. O tipo específico de som, Earcons, criado através da utilização de notas musicais e do som seno, pode ser utilizado como notificação auditiva para melhorar a atenção dos jogadores em jogos a sério.

Palavras-chave: Design de som; jogos sérios educativos; Experiências dos jogadores

Acknowledgements

The present thesis is intended to be a result of my Master's degree in Multimedia, and it is written at the Department of Informatics Engineering of the University of Porto in the spring of 2022. The thesis topic was inspired by my supervisor, professor Gilberto Bernardes de Almeida, and my co-supervisor, professor Eduardo Magalhães. With their help, I have learned the basics of Interactive music and sound design. I would like to thank my supervisor, professor Gilberto Bernardes de Almeida. He motivates me with his supportive attitude and encouragement. Next, I would like to thank my co-supervisor, Eduardo Magalhães. He taught me how to use the software with some specific techniques and application methods step by step. From the time I started to work on sound design and write my thesis, he helped me solve problems with his extensive knowledge.

I would also like to thank Mr. Alexandre Miguel Aniceto, the CEO of company *Emvenci Portugal Limitada* for providing a good team and platform.

Finally, I would like to thank my parents, Mr. Cao and Mrs. Li, for their company and financial support during my master's degree. Also, to my fiancé Dr. Tian for his nine years of companionship. They have always encouraged and supported me to overcome difficulties and pursue my dreams. Their love and understanding mean everything to me.

Zijing Cao

Contents

List of Figures

List of Tables

LIST OF TABLES

Abbreviations

ADT	Abstract Data Type
ACR	Absolute Category Rating
ANOVA	Analysis of variance
GC	Game character
GEQ	Game Experience Questionnaire
GM	Game Models
GMSQ	Game Mode Specific Questionnaire
GMSQ-SN	Game Sound Attention Questionnaire
GEQ-S	Game Sound Experience Questionnaire
GMSQ-S	Game without Sound Attention Questionnaire
GEQ-NS	Game without Sound Experience Questionnaire
HMD	Head-mounted display
No sound version	The serious game without sound
Notification version	The serious game with an additional auditory notification besides the normal sounds
QoM	quantity of motion
Standard sound version	The serious game with sounds
VAME	Verbal attribute magnitude estimation
VR SG	Virtual reality serious game
WWW	*World Wide Web*
3D	Three-dimensional

Chapter 1

Introduction

This chapter will outline the background and motivation for this work. In addition, it presents the assumptions and objectives of the investigation. Finally, the methodology applied and the structure of the paper will be presented to provide a comprehensive overview of the study.

1.1 Context and motivation

The present thesis explored the sound design effects on people's experiences in serious games. The main research focus is on people's perceived experience and attention.

In recent years, serious games (those used for purposes other than entertainment) have been extensively used as educational tools [Abt87] in the teaching systems related to safety and security [RS11, IPA21], medicine, and nursing [WSS15, DS06, Dic06, HA11], climate change [LH17, RSS16], and so on. When developing a serious game, sound design is one of the most important parts. This is because the properly designed sound in a serious game not only enhances the player's gaming experience but also helps maintain participants' sustained attention, which is one of the four main pillars in learning identified by cognitive science [DHT17]. Many experiments[Dak09, LLY17, JCC+08, Yew12, Son01, TAM11] shown that sound interaction design can increase player immersion and emotional engagement in virtual worlds. In addition, during the past decades, some researchers demonstrated and investigated the attraction of sound to people's attention. Jennett et al. [JCC+08] proved that a well-designed sound could attract and guide people to interact with an immersive environment. Based on a project named 'My Sound Space', Martin Ljungdahl Eriksson et al. [EPAH18] investigated the effects of sound space in directing cognitive attention. In 2021, by doing experiments in a virtual retail environment, Kjetil Falkenberg et al. [FFE+21] investigated a special sound, i.e., peripheral auditory notifications, and illustrated that it could attract attention from the people who are aware of such sounds in advance less compared to those who are not. Another special sound, the alarm sound, was investigated in the Refs. [SS77, GPCD03], where authors pointed out that it can attract people's attention and lead them to appropriate responses.

All these previous studies showed that sounds can affect people's emotions and attention. Then, two questions smoothly appear:

1. Can a proper sound design enhance the perceptual experience and make the game more appealing to people?

2. By adding several special audio notifications, can well-designed sounds capture people's attention during educational questions in serious games, so that people can get better learning during the learning part of the game?

To investigate and answer these two questions, I mainly divided my master thesis into two parts. In the first part, different sounds were produced and compiled into the selected serious game. Mainly three different versions of the game were produced: the serious game with sounds (standard sound version), the serious game without sound (no sound version), the serious game with an additional auditory notification besides the normal sounds (notification version). In the second part, two experimental conditions and the corresponding questionnaires were designed to investigate people's experiences in the different versions of the serious games. By using analysis of variance (ANOVA), the present thesis systematically analyzes how different designed sounds affect people's perceived experience and attention in serious games. The obtained results and conclusions can be used to improve the teaching quality of serious games.

All my investigations are based on the serious game *Venci's Adventures*, which is being developed by company *Emvenci Portugal Limitada*. It utilizes 2D platforming mechanics, cybersecurity themes, obstacles, and stories to teach players how to solve multiple cybersecurity problems. Players will follow the *Venci's* family as they solve cybersecurity-themed problems. There are several levels in the game. Each of them represents a cybersecurity issue. Players will control the protagonist of each episode and help this protagonist overcome cybersecurity issues. During this process, people will learn knowledge about cybersecurity.

1.2 Problems, hypothesis and research goals

Many studies have shown that sound design can affect people's experiences in multimedia environments. However, the effect of sound design on people's perceived experience and attention in the context of serious games has not been thoroughly investigated. The aim was primarily to see if the sound design in serious games positively impacts people's perceptual experience. On the other hand, whether the additional inclusion of auditory notifications based on normal sound design can attract attention. This project proposes the following hypothesis: 1. Sound design in serious games positively impacts people's perceptual experience. 2. The additional inclusion of auditory notifications based on standard sound design can attract attention.

Central research questions:

1. Can a proper sound design in serious games positively impact people's perceptual experience?

2. Can people's attention in a serious game be improved by inserting well-designed auditory notification in the important episodes of a serious game with a standard sound?

1.3 Methodology

In this chapter, the methods used in the sound design part and the experiment design part of the present thesis will be introduced. For the sound design part, the methods used to design different soundscapes and sound effects in the four scenarios of the serious game will be described. Then the methods used to design the auditory notifications for the educational scenes of the serious game will be summarized. For the experiment design part, I will first describe the method I used to build up two experiments. Then the method used for analyzing the experiment results will be introduced.

1.3.1 Method used in the sound design part

The main methods used in the sound design part are literature review, survey, and practical and empirical methods. Based on the literature review method, I learned about the human auditory perception system and auditory display. The sound production part is finished by using the investigative, empirical, and practical methods.

The method used in the technical part of the sound design is two software: Unity and Reaper. There are three categories of sounds: mono, 3D sound effect, and soundscape. During the designation of the auditory notifications, the questionnaire method is used to evaluate which notification is the best.

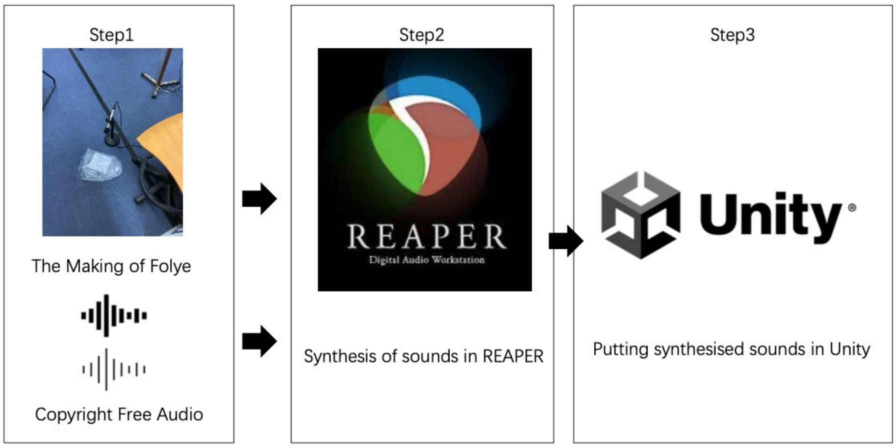

Figure 1.1: Production process of mono sound and soundscape.

In the serious game, the action sounds of the player-controlled character Arthur, e.g., the sound of the footstep, jumps, and falls, are represented by the mono sounds. The suitable mono sounds are generated in the following two ways. The first way is to search and re-edit the existed copyright-free sounds which are suitable for the specific action of Arthur. The second way is to create the foley sound by myself. One example is that I generated the sound of footsteps on the grass by gently pressing down on a plastic bag. The equipment used to make this sound is shown in Figure 1.1. For the 3D sound effects, I edited the copyright-free 3D sounds by using the StereoEncoder as shown in Figure 1.2 and the function binaural decoder in REAPER.

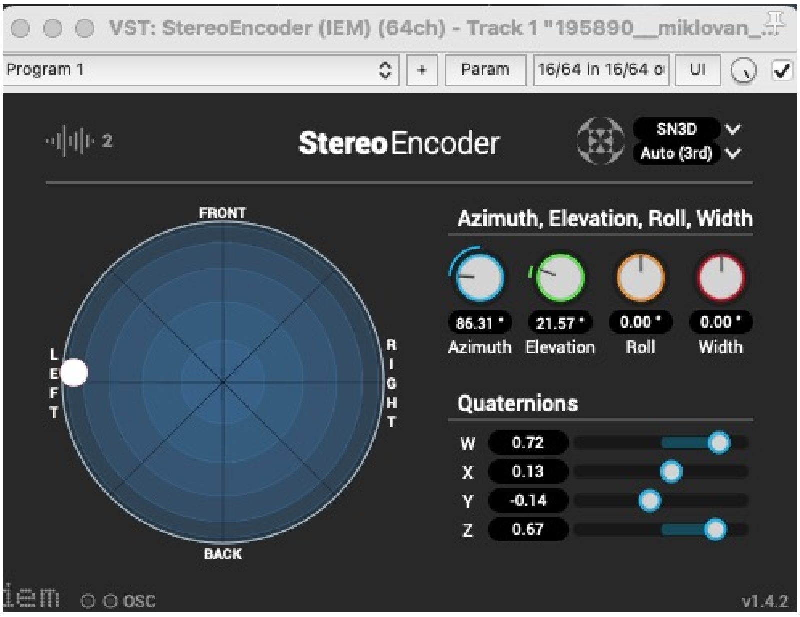

Figure 1.2: Interface of the plug-in 'StereoEncoder' in the software REAPER.

The soundscape was synthesized in REAPER by the existed using both myself produced foley sound and copyright-free sound. One example is that I made a foley sound by recording the sound of water wringing a towel and using it as a part of the soundscape in forest scene of the serious game. The soundscape was designed by following the way shown in Figure 1.1.

The auditory notifications were generated by the MIDI keyboard. First, two different tones used for the moments when the players give the correct and incorrect answers were picked up through in total 22 different tones by using the questionnaire method. Then I modify and re-edit them to get the auditory notifications. More detailed process is shown in Figure 1.3.

1.3.2 Method used in the experiment part

Guided by pragmatism, the experimental part of the present thesis followed an exploratory sequential design. In total, two experiments are conducted to collect quantitative data, and the resulting data will be analyzed through an analysis of variance (ANOVA).

Questionnaire

Participants in the first group completed a questionnaire based on the Game Experience Questionnaire (GEQ) [JGP18, IDKP13, IDKP+07]. The GEQ measured gamers' experiences in seven areas: immersion, flow, competence, positive and negative emotions, tension, and challenge. The items in the questionnaire are presented in a narrative format. The specific assessment is in terms of

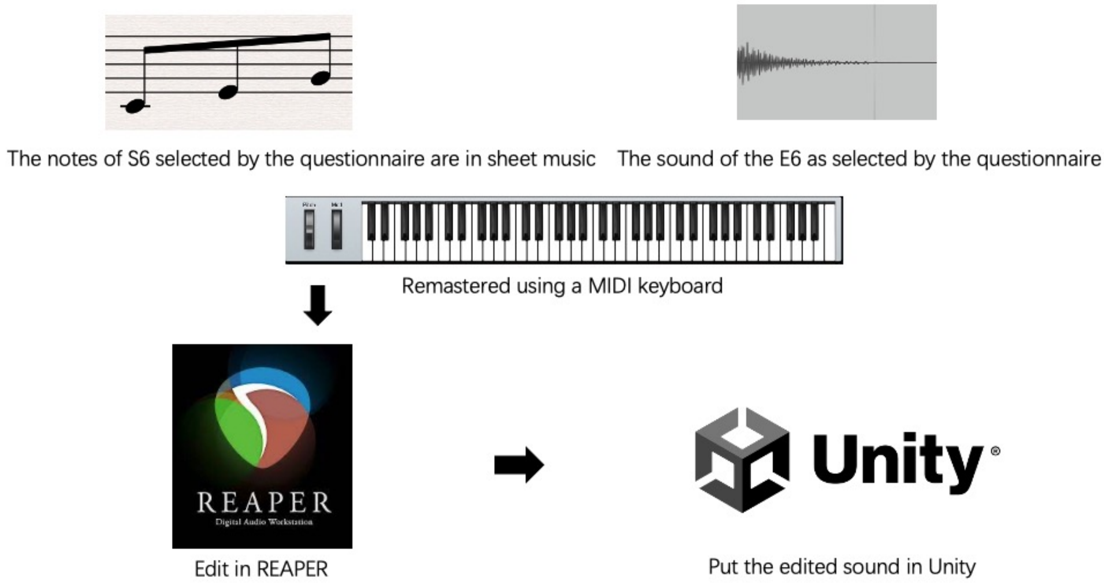

Figure 1.3: The production process of auditory notifications.

competence, through the player's evaluation of their performance and achievement of the game's goals. In terms of immersion, it is assessed through the player's connection to and feelings about the game. Flow is evaluated by whether the player loses track of the passage of time and their effort during the game. The player assesses tension through specific negative emotions. Challenge is assessed by indicating to what extent the home finds the game difficult or challenging. Positive emotions are assessed through positive emotional experiences. Negative emotions are related to negative emotional experiences.

The second group used a questionnaire based on the Game Mode Specific Questionnaire (GMSQ) [RMFV19] to collect users' perceived attention after the game experiment. The GMSQ was designed to measure the experience of both sound technology and immersion. Unlike the measurement of immersive experience in the GEQ, the GMSQ focuses on measuring the impact of sound in making the player focused on the gameplay process.

Data analysis

To compare the differences in the results between the groups, I used an analysis of variance (ANOVA) to analyze the data obtained. ANOVA is a widely-used method for investigating the means for two or more data and for examining differences in the means of dependent variables related to the effects of controlled independent variables [MNB17]. The P-value calculated in the ANOVA table represents probabilities and are used as a measure of evidence to reject the original hypothesis. If the p-value is less than or equal to the significance level, the original hypothesis is rejected, and it is concluded that not all overall means are equal. If the p-value is greater than the significant level, then there is insufficient evidence to reject the original hypothesis [Fie13]. Normally, the value of the significant level is set up as 0.05.

The main workflow of the present thesis is summarized in figure 1.4

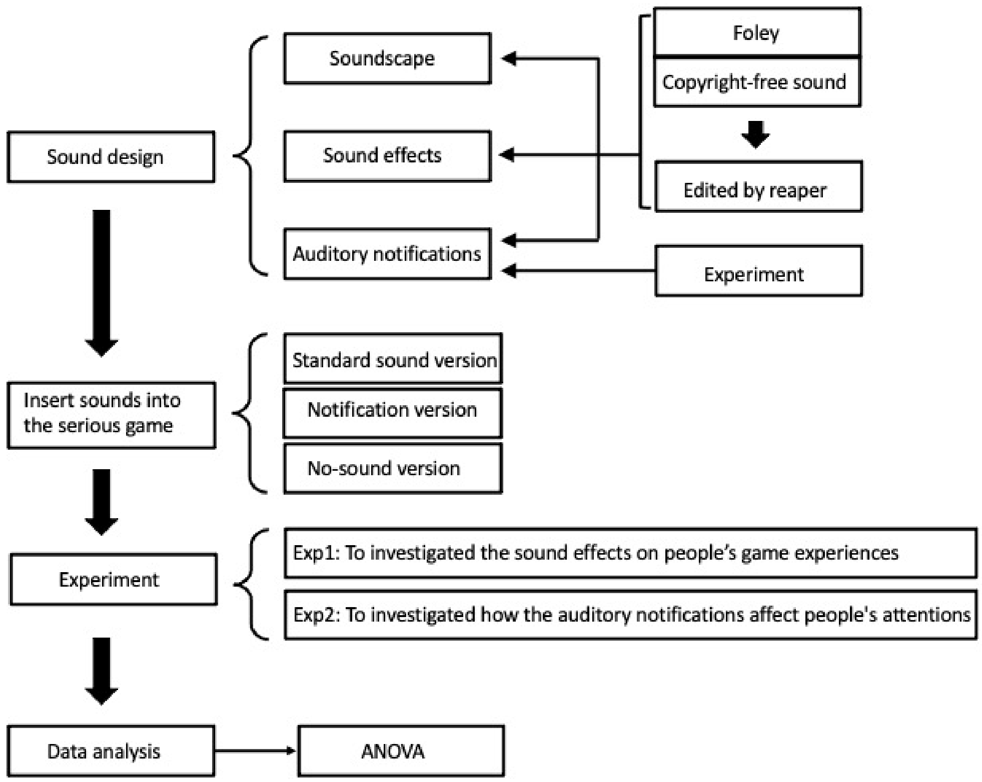

Figure 1.4: Workflow of the present thesis.

1.4 Dissertation structure

The present thesis is divided into five chapters, followed by the bibliography and appendices.

Chapter 1 presents the context and motivation, the research questions and hypotheses proposed, and a brief overview of the research methods used in the present investigations.

Chapter 2 establishes a brief literature review about the previous publications that holds related topic of the present thesis. I mainly focused on reviewing the sound design method and the user experience experimental design methods.

Chapter 3 described my sound design of the serious game *Venci's Adventures* in detail. The sound elements, software, and game audio system are introduced. Moreover, several important technologies are explained.

Chapter 4 presents the set-up, execution, and the evaluation of the experiment. The questionnaire used in the experiment and survey results are attached. Moreover, a detailed and careful analyze of the survey result is included.

Chapter 5 concludes the thesis with a general reflection, conclusion and the future work of the thesis. An emphasis on the most important elements of the research is given.

Chapter 2

Literature Review

To successfully carry out both the sound design and experiment parts of the present thesis, I divided the literature review into two parts. In the first part, I went through published papers related to sound design. In the second part, I read through the publications focused on designing and launching experiments to investigate people's experiences under different sound designs. Correspondingly, the main part of the present chapter is also divided into two parts. Each of them focuses on one of the two parts of my thesis.

2.1 Sound design method

Many studies have investigated and proved that sound can influence people's experiences. From silent movies to video games, sound design has adapted its technologies and creative strategies with the media's changes. The sound design increases the emotional resonance between the story and people [Yew12]. Sound design can convey the effect of the space and increase the sense of reality and interaction with the virtual environment [HB96]. This sense of reality plays an important role in arousing users' emotions in the virtual environment. Sonnenschein [Son01] indicates that sound in a virtual environment can bring emotional interaction to people. Emotional interaction in a virtual environment can get a more profound sense of presence and convey a greater immersion. In this case, sound design plays an essential role in conveying and regulating emotions. In Toprac and Abdel's article [TAM11], they provided a theoretical basis for studying how the game sounds affect emotions. They offered empirical evidence for using sound effects to increase players' fear, suspense, and anxiety. At the same time, they proved that sound effects could increase the player's sense of dread.

In the virtual environment of serious games, to achieve a better user experience, we must take into account all aspects of knowledge. In this chapter, I will first focus on the sound design methods and divide it into three main parts: auditory display, human perception, and soundscape. Then the sound production method will be briefly reviewed.

2.1.1 Auditory display

When we look at sound design, we first need to understand auditory displays. Auditory display uses sound to communicate information from the computer to the user. It aims for enabling people to understand the variations and structure of the data on which the display is based [MB04]. Sound technology plays an important role in auditory displays, and presents sound based on data and interaction. Auditory displays use non-verbal audio to represent information. We can convey information to the user through sound. According to Ref. [Kra94], auditory display builds a bridge between the information source and the information receiver , as shown in Figure 2.1.

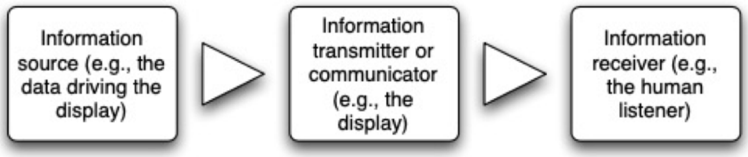

Figure 2.1: The work flow of the communication system connecting the information source and the information receiver (image reproduced from Ref. [Kra94]).

Nowadays, auditory display is used in a wide range of disciplines, as shown in Figure 2.2. Sonification is a key component of auditory display. It is a technology that presents sound based on data and interaction. Sometimes, people also use sonification to translate the relationship of data or information into sound, enabling the use of human auditory perception to understanding data relationships [HHN11].

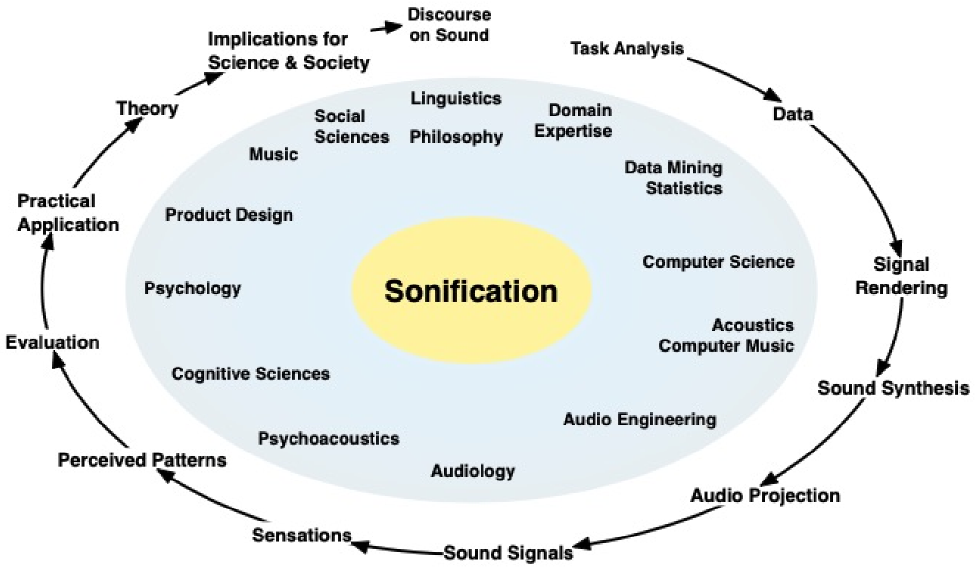

Figure 2.2: The interdisciplinary circle of the sonification and auditory display (image reproduced from Ref. [HHN11]).

To better introduce the sound design approach, I will review how to produce sounds based on the knowledge in the auditory display.

2.1.2 Human perception

In terms of human perception, the human ability to perceive in the auditory environment is based on what we have learned since birth. We use this ability to acquire and predict information. Spangenberg [SGS05] and others mention that we can use auditory perception to predict which sounds appear in relation to the background. Our auditory perception has a significant influence on our attention. When background sounds appear in the same context as the environment, our attention is focused on the incongruent sounds [GS11]. We can design sounds with non-diegetic sounds to attract the user's attention. For example, in the Inês [SPB21] survey it was mentioned that alert tones as a non-diegetic sound can attract the user's attention. Such dissonant sounds are easier to recognize than background sounds. Human auditory perception helps us to extract what we want to pay attention to from a complex acoustic environment. The famous cocktail party effect, for example, demonstrates that people can move their attention through complex auditory environments [Gru96, Che53].

In addition, the human ability to perceive the position of sound has a significant impact on sound design. Kirsten and Richard et al. [CHMH07] mentioned that the two human ears have different reception times for the sounds generated at different spatial locations, as shown in Figure 2.3. When designing sounds, the location of the sound is determined by consciously using the time delay, amplitude difference, and pitch information of each ear. In Gardner and Martin's experiments [GM95] , they designed the sound to achieve an accurately three-dimensional audio by using and a real-time processing audio filter to work out the exact interaction of the user's head with the sound waves using a real-time processing audio filter.

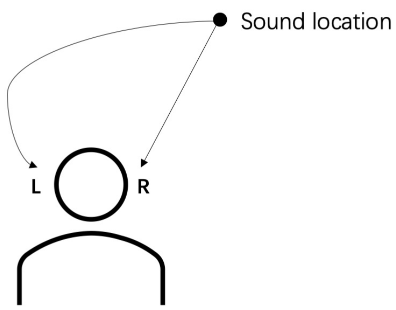

Figure 2.3: The way people receive a sound when the sound source is located on the right-hand side.

2.1.3 Soundscape

Aspects of soundscape design need to consider the features required for localization, distance perception, and recognition of objects [AHT89]. These features facilitate the presentation of a more realistic 3D soundscape. Leplâtre [Lep02] mentioned that background sounds provide information about the state of the world, which can help the user to locate sounds in a particular environment. We need the physical elements of the player's real-world to be integrated into the structure of the game. For example, the location-aware games mentioned by Dede [Ded09] superimpose the virtual world onto the physical world, where the player can feel the virtual and physical worlds merging together. To maintain a balance between the game's atmosphere and the locational environment. The sound files used by Paterson [PNJ+10] in his soundscape design were spatialized using a binaural simulator. He created a sense of space by changing the sound source from the actual placement or by adjusting the volume of the binaural simulator left and right, for example, setting up whispering around the player or adding the sound of movement. In addition, he integrated the virtual and real world by mixing ambient and game sounds. After achieving this, when the player enters a natural area, sounds of the natural environment appear alongside the player's drone sounds. This function allows the player to perceive some sounds as part of a physical location. Several examples of sound designs for specific physical locations are shown in Figure 2.4.

Location	*Ghosts*	*Intended Mood*	*Background Sound*	*Sound Effects*
Stairway to Hell (stairway going down into a tunnel)	Leper	Fearful, dark, uncertain	Low frequency rumbling drone using randomised overlapping minor intervals	Chains, moaning Shallow breathing Fire sounds Footsteps
Schoolhouse Lane (laneway next to medieval church)	Ghostly children	Eerie, open space	Wind with infrequent low damped percussive booms	Children playing in the distance School bells whispers

Figure 2.4: Example of sound design for two physical locations: stairway to hell and schoolhouse lane (image reproduced from Ref. [PNJ+10]).

These soundscapes can represent the physical location of the game space and narrative. The inclusion of artificial reverberation in a game's soundscape design can help create an 'ambient' sound field. Some previous studies [Beg94, Rum12] found shown that some sound reflections are able to contribute to spatial awareness and perception of the sound sources' size and distance. Moreover, Hollier [HRB97] proved that the reverberant ambient sounds can increase immersion and player engagement.

2.1.4 Sound production

In terms of producing sound, we categorize sounds and sound designs in different ways. The sample of sound will be created after the desire of sound has been defined. For example, Paterson [PNJ+10] categorized sound design in their project by classifying the required sounds into four types: supernatural sounds, ambient sounds, music sounds, and user interface sounds, as shown in Figure 2.5. From a design perspective, the sound design in a computer game is similar to that in a file, which can be divided, divided into background sounds, effected sound, and dialogue with user interface elements added.

These sound samples were mainly derived from auditory icons and earcons. Auditory icons and earcons play an important role in sound design. The purpose of the auditory icon is to provide a link between events and users in a computer application. It represents objects and events in an application by using the sounds in everyday life. We can obtain sound samples from field recordings or imitate daily sounds with homomorphic spectral modulation. Brazil [Bra09] mentioned that the specific everyday sounds can be recorded and stored as a sound file. Paterson [PNJ+10] produced sound samples from stereo field recordings for their game. In addition, It is also possible to simulate sounds or model real-world events using physical modeling [Smi92, VDDKP01, vdDP96].

However, the real sounds from everyday life are difficult to be stored. Many of them can be recorded, but hard to restore authenticity. When some objects and events do not have a corresponding sound in the real world, usually the synthetic sounds will be produced by earcons. Indeed, earcons are used to emphasise the tone and its symbolic value. Long before the advent of radio, horn sounds were used to transmit commands [Upt68]. These horn sounds represented different pitches and rhythms. For sound design, Blattner et al. [BSG89] used rhythms, pitch structures, registers, and sine waves, as shown in Figure 2.6 to represent information about the encoded files and operations. In Leplâtre's [Lep02] mobile phone menu system simulations, he designed more complex musical principle, such as harmonies and sustainments for the system. Additionally, dthe designers, who use sound in user interfaces to design the auditory displays and systems need some related techniques to generate and manipulate sound. Applications and researches in auditory displays require sound synthesis and manipulation algorithms to control the sound outcome.

In general, based on the above descriptions in Chapters 2.1.1-2.1.4, for the first experiment in the present thesis, I set up different sounds by designing different soundscapes and sound effects in the serious game *Venci's Adventures*. For the second experiment in the present thesis, the earcons

Paranormal	***Environmental***	***Musical Elements***	***User Interface***
footsteps	animal sounds	minor scales	old AM radio sounds
floorboards creaking	church bells	chromatics	white noise
bangs	laughing	pitched and unpitched drones	audio static and interference
high pitch metallic squeal	children playing	drums	metal detector sounds
breathing	school bell	ghostly pan-flute	dial clicks
screams	paper flying around	augmented intervals	Geiger metre clicks
whispers	thunder	tremolos	button sounds
faraway voices	wind	irregular rhythms	sonar sound
growls	rain		compass sounds
scratching	traffic		transitional sound
moaning	dog barking		
modulated voices	chimes		
rattling chains	birds		
battle sounds	leaves		
ghost dialogue	wind in trees		
	people talking		
	fire		

Figure 2.5: Example of four sound categories: paranormal, environmental, musical elements, and user interface (image reproduced from Ref. [PNJ+10]).

design method described in Chapter 2.1.4 was used to develop different auditory notifications. More detailed information about the two experiments and their sound designs are described in Chapter 3 and Chapter 4.1, respectively.

2.2 Experiment method

To explore the sound effects on human perceptions, previous researchers designed and implemented mainly three types of experiments:

1. To properly design and use questionnaires to collect participants' experiences during the experiments. Then, sound effects on human perceptions can be investigated by analyzing the questionnaires' results. In Ref. [PNJ+10], a questionnaire was designed to explore the

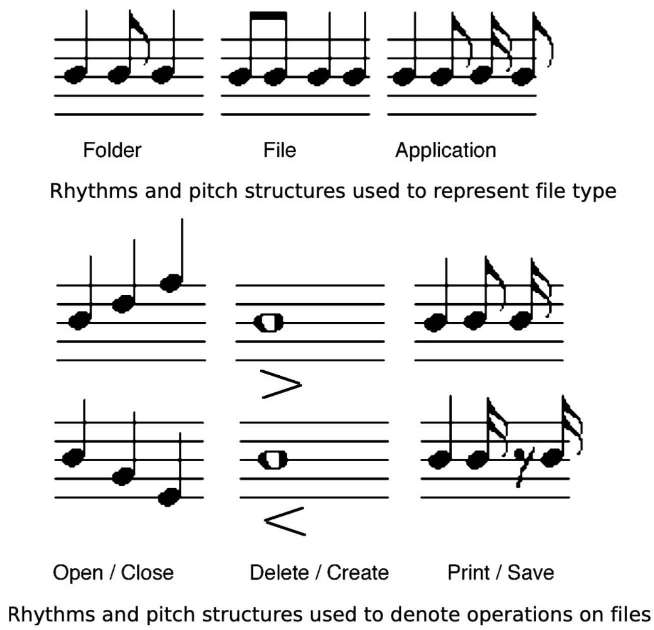

Figure 2.6: Two examples of rhythms and pitch structures (image reproduced from [BWE94]).

impact of sound on immersion and emotion engagement in augmented reality (AR) games. Scott and Sean [LZ04] used a questionnaire to investigate the effect of musical soundtracks on video gaming experiences. To examines sonic interaction in an augmented reality audio game, Emmanouel and Nikolaos et al. [RMFV19] designed three questionnaires to collect participants' experiences in different aspects.

2. To properly design a system to capture participants' physiological information. Then, sound effects on human perceptions can be studied based on the obtained physiological data. Kjetil and Emma et al. [FFE+21] designed a system to collect participants' head movements under the different sound environments during the experiment to investigate sound effects on people's attentions. In Ref. [JZSE17], by using a system to capture participants' micro-motion, authors studied the influence of different sounds on human standstill.

3. To build an experiment by using both the questionnaire method and the physiological information capture system. For example, Luca and Roberto [TB15] designed a system to capture the sound of people walking footsteps together with a questionnaire to evaluate how the involved auditory feedbacks affect the people's pattern of emotional walking. In Ref. [IPA21], the authors used a system to measure heart-rates of participants together with two questionnaires to investigate the impact of wayfinding cues on disaster preparedness in a virtual reality serious game (VR SG).

More detailed information is shown in tables B.2-B.7.

After obtaining data through questionnaires or physiological information capturing systems, different data analysis methods were used in the previous publications. In Ref. [PNJ+10], the authors evaluated the sound effects by directly counting the percentage of different answers in the questionnaire. Kjetil and Emma et al. [FFE+21] used the Student T-tests and Chi-square tests methods to analyze all their obtained measurements. For all the other publications [TB15, IPA21, LZ04, RMFV19], the well-known data analysis method called Analysis of Variance (ANOVA) was used to further investigate their collected questionnaire results and measurements.

In general, I decided to use the questionnaire method to collect people's experiences in the serious game *Venci's Adventures* with different sounds, and then use ANOVA method to analyze the questionnaire results and investigate how different sound designs affect people's experiences in serious games. The detailed information of experiment design and data analyze method can be found in Chapters 1.3.1 and 1.3.2, respectively.

Chapter 3

Sound Design

The present chapter focuses on the sound design part of serious game *Venci's Adventures*. Firstly, in Chapter 3.1, a brief description of the serious game including its story line and main parts are described. Then, Chapters 3.2 and 3.3 provide the design process of the soundscape and the sound effects I implemented in the serious game. Finally, the design process of the auditory notifications added in the educational scenes of the serious game are given in Chapter 3.4.

3.1 Content of the serious game

The present thesis is based on the serious game *Venci's Adventures* developed by the company *Emvenci Portugal Limitada*. This serious game uses 2D platforming mechanics and a cyber security-themed story line containing several cyber security problems to help players to improve their cyber security knowledge. The game has four scenarios: beach, forest, cave, and temple. Each contains a cybersecurity problem. During the game, players will control the protagonist of each scenario to overcome cyber security issues. In this process, players will gain knowledge about cyber security. In the end of the last three scenarios, there is an education part where the player will be asked to answer several questions to help them test their own learning outcomes. The simplified story line of the serious game is sketched in figure 3.1.

3.2 Soundscape design

When designing soundscapes, some representative sounds directly recorded from the real world are implemented in the serious game based on the scenario. These sounds can help players locate the specific environment and make them feel the virtual and real worlds merging. The similar sound design methods are also used in Ref.[Lep02, Ded09].

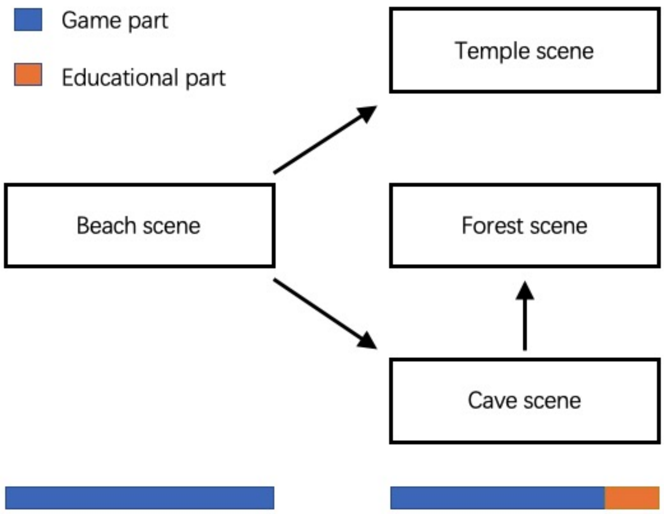

Figure 3.1: Simplified story line of the serious game *Venci's Adventures*.

3.2.1 Beach scene

The first soundscape I designed is for the beach scene, as shown in Figure 3.2.

Figure 3.2: A cut of slice of the beach scene in the serious game *Venci's Adventures*.

To increase the user's sense of immersion, the soundscape of the beach scene mainly consisted of the following elements:

1. the recorded sound of ocean waves;
2. the recorded sound of the wind;
3. the simulated sound of people playing on the beach;
4. the sound of birds chirping in the distant forest.

I first search and download the individual stereo sound sample for each above-mentioned sound element. Then, by using the digital audio workstation Reaper, I synthesized these sound samples together and obtained my designed soundscape.

The soundscape narrative for the beach scene is as follows. As the player controls game character (GC) to enter the beach scene, he can hear the waves and wind sounds. Then, when GC passes people playing on the beach, the player can hear the waves and people playing on the beach. The sounds of people playing on the beach are designed with the function fade in and out as GC passes by. Finally, when GC reaches the end of the beach scene, the player will hear both the sound of the waves and the birds chirping sound in the forest. The sounds of the birds in the forest are added to inform the player in advance of the next scene, the forest.

3.2.2 Forest scene

The second soundscape I designed is for the forest scene, as shown in Figure 3.3.

Figure 3.3: A cut of slice of the forest scenes in the serious game *Venci's Adventures*.

To increase the player's sense of immersion, the soundscape of the forest scene includes the following elements:

1. the recorded birdcall and insect sounds in forests;
2. the recorded sound of the wind blowing the trees swaying;
3. the recorded sound of the waves in the beach scene.

I first search and download the individual stereo sound sample for each above-mentioned sound element. Then, by using the digital audio workstation Reaper, I synthesized these sound samples together and obtained my designed sound scape.

The soundscape narrative for the forest scene is as follows. As the player-controlled character GC leaves the beach scene and enters the forest scene, the player will hear the growing sounds of birds chirping in the forest and the fading sound of the waves. Then, when the player controls GC to reach the middle of the forest scene, the player will hear the wind blowing the trees and chirping the birds and insects in the forest. Finally, as GC reaches the end of the forest scene, an educational part appears. The player will be asked to answer some cyber-security questions by pushing the handles. In the education part, the player will hear the birds chirping in the forest in the distance. This type of sound can make players feel that the forest scene will soon end.

3.2.3 Cave scene

The third soundscape I designed is for the cave scene, as shown in Figure 3.4.

Figure 3.4: A cut of slice of the cave scenes in the serious game *Venci's Adventures*.

Considering that the cave scene is below the beach scene, the content of its soundscape was designed to include the following sound elements:

1. the electronically synthesized sound of dripping water;
2. the recorded sound of the wind in caves and its echoes.

By using Reaper to synthesize these two sound element, the soundscape for the cave scene is obtained.

The soundscape narrative for the cave scene is as follows. As the player-controlled character GC leaves the forest scene and enters the cave scene, the player will hear the fading sound of birds together with the waves sound and the growing sounds of wind and its echoes in the cave. Then, as GC reaches the middle part of the cave, the player will hear the sound of dripping water, the wind, and the wind's echoes in the cave. Finally, after GC reaches the end of the cave scene, an educational part appears. The player will be asked to answer several cyber security questions. Only when the player successfully solve these questions, he can pass through this scene. During the educational part, the player will hear the wind sound in the cave fading away.

3.2.4 Temple scene

The forth soundscape I designed is for the temple scene, as shown in Figure 3.5.

Figure 3.5: A cut of slice of the temple scenes in the serious game *Venci's Adventures*.

The soundscape of the temple scene mainly consists of the recorded wind sounds. When the player-controlled character GC arrives at the temple scene by cable car, the player can hear the wind sound recorded in the high mountains. When GC gets into the temple and arrives at the educational part of the temple scene, in order to better simulate the indoor feeling, the player can only here the faint wind sounds.

3.3 Sound effect design

Besides the four soundscapes introduced above, I also designed some sound effects to give players a better sense of immersion. All sound effects implemented in the serious game are shown in Table 3.1. There are mainly two types of sound effects. One type is designed for the player-controlled character Arthur: the sound effects of Arthur's footsteps, jumping, falling, getting the puzzle, and dropping the puzzle. The other type is designed for the specific items that the GC will pass by. The first type of sound effect is mono, while the second type is 3D effect. All these sound effects are produced based on the digital audio workstation Reaper.

The sound effects implemented in the beach scene are summarized as follows. Some specific locations and objects are marked as A, B, C, D, E, and F in figures 3.6,3.7,3.8,3.9,3.10. When the character GC passes the location A in figure 3.6., the player will hear a 3D non-diegetic sound of a seagull call. In figure 3.7., when GC passes by people at the locations B and C, the player will hear the corresponding sounds of people's drinking and the sound of a seller promoting hats, respectively. As GC passes the location D shown in figure 3.8., the player can hear the 3D sound of a collapsing stone pillar.

Table 3.1: Different mono sound effects and 3D sound effects used in the present thesis.

Mono sounds effect for GC	3D sound effects for Items
Run on grass	
Run on wood	
Run on stone	
Run on water	
Run on sand	
Land on grass	
Land on wood	
Land on stone	Seagulls
Land on water	Mosquitoes
Land on sand	Flies
Jump on the grass	Stone pillar collapses
Jump on wood	Stone fall
Jump on stone	Handles
Jump on water	A platform on the move
Jump on sand	Misty
Fall on grass	People who drink
Fall on wood	Hat man
Fall on stone	
Fall on water	
Fall on sand	
Get the puzzle	
Miss the Puzzle	
Cable car	

Figure 3.6: The location where the 3D sound effect for the seagulls in the beach scene is inserted on the locations marked by the red rectangle with the capital letter *A*.

The sound effect implemented in the forest scene is shown in figure 3.9. When GC passes by the location E in figure 3.9., the player can hear the 3D sound of a mosquito. In addition, there is another place in the forest scene where the same sound design for the fly sound is used.

Figure 3.7: The locations where the 3D sound effects for the drinking man and hat man in the beach scene are inserted on the locations marked by the red rectangles with the capital letter *B* and *C*, respectively.

Figure 3.8: The location where the 3D sound effect for the collapsed stone pillar in the beach scene is inserted on the location marked by the red rectangle with the capital letter *D*.

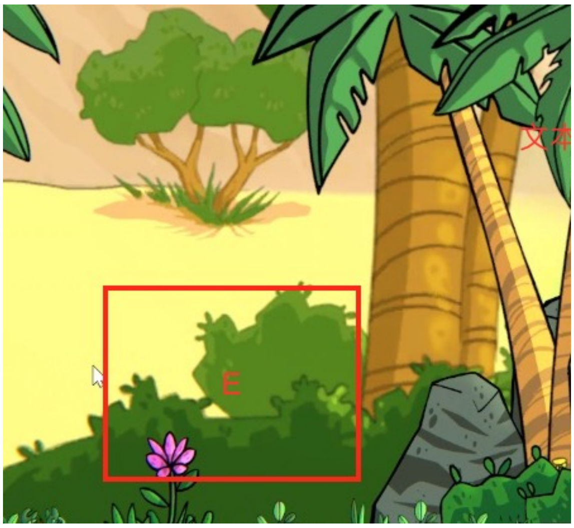

Figure 3.9: The location where the 3D sound effect for the mosquito in a forest scene is inserted on the location marked by the red rectangle with the capital letter *E*.

Figure 3.10: The location where the 3D sound effect for the moving platform in the cave scene is inserted on the location marked by the red rectangle with the capital letter *E*.

As shown in figure 3.10., in the cave scene, the player will hear the movement of the obstacle when GC pass by it. The similar situation also happens in the temple scene.

3.4 Auditory notification design

There are educational parts in the three scenes, i.e., forest, the cave, and the temple, of the serious game *Venci's Adventures*. To improve the educational effect of the serious game, I designed several auditory notifications for these three educational parts, which can remind the player whether their answer is correct or not.

The design of the auditory notifications is based on the design of Earcons, which are generally short, structured musical messages. Many multi-media designers use it to alert the player to events that require attention [BSG89, PEL86, BRK96, Lep02].

Based on the guideline of Earcons design reported by Blattner, Sumikawa and Greenberg [BSG89], I used musical timbres and sine tones to produce in total 22 auditory notifications with both rhythmic both pitch structure. 11 of these notifications are made to notifying the players their answers are correct (the S-part notification), while the others are made for the situation when players' answers are wrong (the E-part notification). In order to objectively pick out the best notifications, I designed a small questionnaire survey. A total of 23 participants volunteered to take part in this survey. Every participant will follow the three steps below to finish the survey.

- STEP1: The participant will be asked to provide demographic information, including age level, gender, and experience with online educational testing.
- STEP2: The participant will listen all the notifications made for moment when the player gives a correct answer (the S-part notification). Then, the participant will answer the question "When you answer a question online, do you think that if the sound played now would let you realize that your answer was correct?" based on a Likert scale ranging from 1 (Not at all) to 7 (Very much) [Lik32, Tah19].
- STEP3: The participant will listen all the notifications made for moment when the player gives an incorrect answer (the E-part notification). Then, the participant will answer the question "When you answer a question online, do you think that if the sound played now would let you realize that your answer was wrong?" based on a Likert scale ranging from 1 (Not at all) to 7 (Very much).

For the 23 participants, there are 5 females and 18 males with age between 18 and 54. More specifically, 4.3% of the participants were younger than 20 years old, 82.6% are in the age between 21 and 30 years old, and the rest 13.1% are in the age between 31-40 years old. One good thing is that around 65.2% participants had experience about the online educational testing and are familiar with the online questionnaire. After all the questionnaire results are collected, I calculated the averaged scores for all the S-part and E-part of notifications and show all results in Figure 3.11 and Figure 3.12. Based on Figure 3.11, one can clearly see that, between the 11 notifications in the S-part, S1-S11, S6 has the highest averaged score. This means that sound of S6 can give the strongest hint to the participants to realize their answer is correct. For the E-part notifications, Figure 3.12 shows that the sound of E6 got the highest mean score among the 11 notifications E1-E11. This means that sound of E6 can give the strongest hint to the participants to realize their answer is wrong. The detailed information of the musical tone S6 and the sine tone E6 are shown in Figure 3.13 and Figure 3.14, respectively.

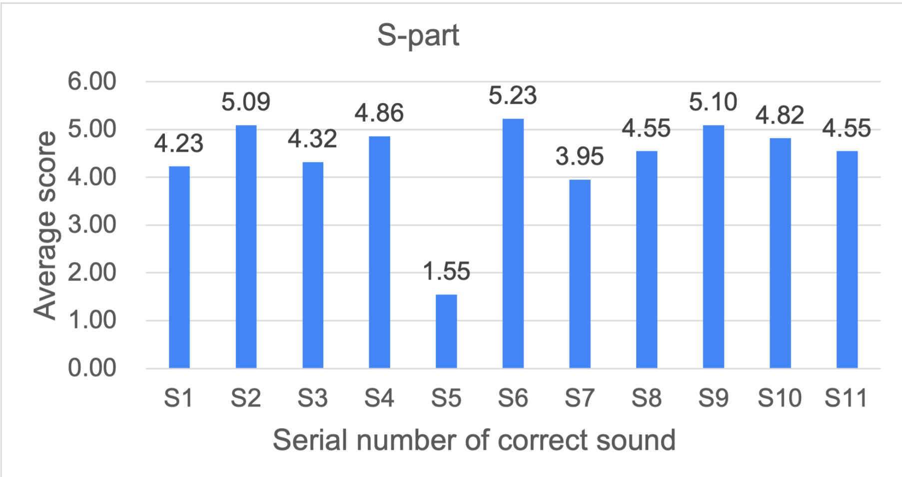

Figure 3.11: The averaged score of the 11 sound samples in the S-part of the auditory notifications which are designed for representing players choose the correct answer in the education part of the game.

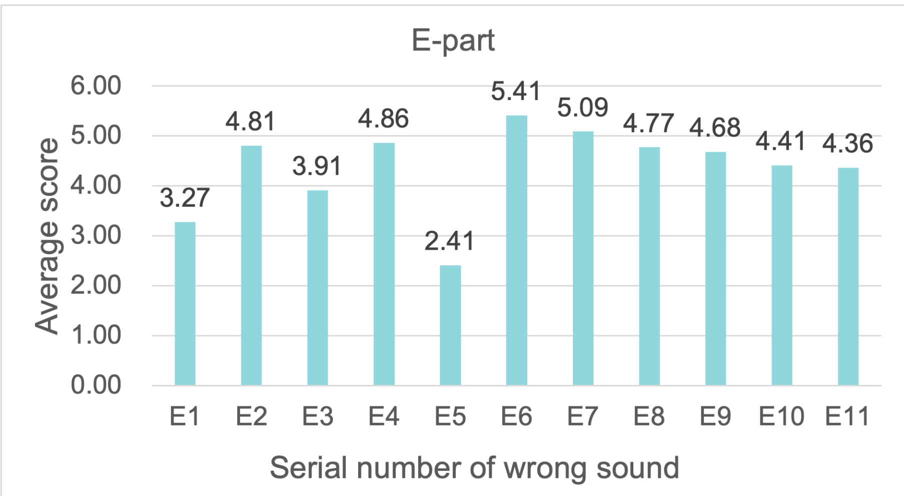

Figure 3.12: The averaged score of the 11 sound samples in the E-part of the auditory notifications which are designed for representing players choose the wrong answer in the education part of the game.

Figure 3.13: Rhythms and pitch structures of the sound sample S6.

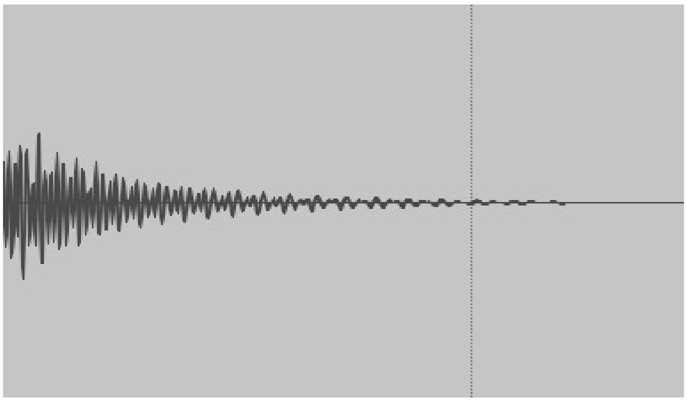

Figure 3.14: The sine tone curve of the sound sample E6.

To make the final auditory notification more impressive, I used MIDI keyboard and Reaper to make the sound of the sounds S6 and E6. The specific adjustments are described based on the educational parts of the serious game.

In the temple scene, the education part is shown in Figure 3.15, where the player needs to control the character GC to select the correct spelling of the web domain by stepping on the underground press button. In this part, I designed the sound of notes for the push buttons. When GC steps on each of the five buttons, in turn, the player will hear the corresponding sound of the note 'do re mi fa sol' as shown in Figure 3.16. If the final spelling is correct, the player can hear the coherent sound 'do mi sol' as shown in Figure 3.13. Otherwise, the player will hear the wrong sine tone.

Figure 3.15: A cut of slice of the educational part in the temple scene of the serious game *Venci's Adventures*.

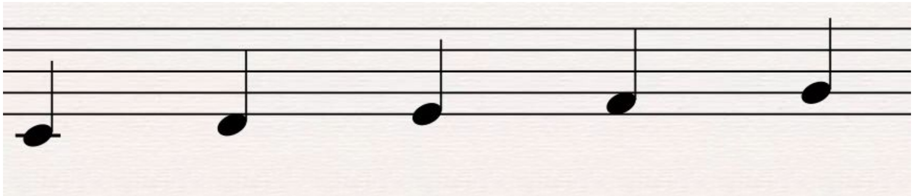

Figure 3.16: Rhythms and pitch structures of the sound slice 'do re mi fa sol'.

Chapter 4

Experiment and Evaluation

In the present chapter, two experiments are described in the aspects of the design process, the execution procedures, the result collections, and the result data analysis. Three sections are set up: 1)Experiment overview, where the experimental design process will be described; 2)Procedure, where the experimental set-ups, participants, and execution procedures will be introduced; 3)Results, where the experimental results, the corresponding analysis, and further discussions of the results will be presented.

4.1 Experiment overview

To investigate the sound design effects on people's experiences in serious games, two experiments were made in the present thesis. Both of them were based on the serious game *Venci's Adventures*. In total, 23 employees from the company Emvenci Portugal Limitada joined experiments. The first experiment was used to evaluate people's perceived experiences in the serious game with and without sound. The serious game version without sound (the no-sound version) and the version with sound (the standard sound version) were used. The second experiment was used to assess if properly designed auditory notifications can improve people's attention in the serious game. It based on the serious game version with sound (the standard sound version) and the version with an additional auditory notification besides the normal sounds (the notification version). After participants completed two experiments, they were asked to complete series of well-designed questionnaires to measure their game experiences. The obtained questionnaire results were investigated by using the data analyze method Analysis of Variance (ANOVA).

In the present sub-chapter, the information of three versions of the serious game, the pre-experimental questionnaire, and the formal questionnaire will be described. To measure the user's perceived experience and attention in the serious game, three different versions of the serious game *Venci's Adventures* were designed: the version with standard sounds (standard sound version), the version without sound (no-sound version), and the version with an additional auditory notification besides the standard sounds (notification version). The basic information of these three versions is shown in Table 4.1. The further detailed information can be found in Chapter 3.

Table 4.1: Information of the main sound components in the three different versions of the serious game: the standard sound version, the no-sound version, and the notification version.

Sound	Standard Sound Version	No-sound Version	Notification Version
Background Sounds(soundscape)	Yes	No	Yes
Sound Effects	Yes	No	Yes
Auditory Notification	No	No	Yes

Before starting the formal questionnaire, a pre-experimental questionnaire will be made to help grouping participants to avoid repeated and unbalanced measures effects. In this pre-experimental questionnaire, the demographic information, including age level, gender, and hearing impairment was collected for each participant.Detailed information of questionnaire is shown in Table 4.2.

Table 4.2: Questions of the questionnaire used in the pre-experiment part for both the first and second experiments.

Q1	Q2	Q3
What is your gender?	In which age group do you belong?	Do you have a hearing impairment?

For the experiment used to test if a properly designed sound can positively impact people's experience in the serious game, a questionnaire is developed based on the questionnaire design method game experience questionnaire (GEQ) used in Refs.[IDKP13, IDKP+07]. A detailed description of GEQ is provided in chapter 1.3. In this questionnaire, user-perceived experiences are collected on seven aspects: Immersion, Flow, Competence, Positive and Negative Affect, Tension, and Challenge. The similar collection method was also used by Grimshaw et al. [GLN08] to measure players' subjective experience of sound immersion. Detailed information of questionnaire is shown in Table 4.3.

Table 4.3: Questions of the questionnaire used in the main part of the first experiment.

	Question	Game without Sound Experience Questionnaire (GEQ-NS)	Game Sound Experience Questionnaire (GEQ-S)
Competence	Q1	Games without the sound design made you feel very skillful in playing the game.	Games with the sound design made you feel very skillful in playing the game.
	Q2	Games without the sound designed made you feel fast at reaching the game's targets.	Games with the sound designed made you feel fast at reaching the game's targets.
Immersion	Q3	Games without the sound design to keep you interested in the game's story.	Games with the sound design to keep you interested in the game's story.
	Q4	Games without the sound design enrich your gaming experience.	Games with the sound design enrich your gaming experience.
Flow	Q5	Games without the sound designed to immerse you in the game entirely.	Games with the sound designed to immerse you in the game entirely.
	Q6	Games without the sound designed to keep you deeply concentrated in the game.	Games with the sound designed to keep you deeply concentrated in the game.
Tension	Q7	Games without the sound design annoyed you.	Games with the sound design annoyed you.
	Q8	Games without the sound design make you feel irritable.	Games with the sound design make you feel irritable.
Challenge	Q9	Games without the sound design pressured you.	Games with the sound design pressured you.
	Q10	Games without the sound design made you have to put a lot of effort into it.	Games with the sound design made you have to put a lot of effort into it.
Positive Affects	Q11	Games without the sound design make you feel good.	Games with the sound design make you feel good.
	Q12	Games without the sound design make you enjoy the game.	Games with the sound design make you enjoy the game.
Negative Affects	Q13	Games without the sound design gave you a bad mood.	Games with the sound design gave you a bad mood.
	Q14	Games without the sound design gave you tiresomely.	Games with the sound design gave you tiresomely.

For the experiment used to examine if people's attention during the important educational parts of the serious game can be improved by adding well-designed notification sound to the standard back sound, a questionnaire is developed based on the questionnaire design methods Game Mode Specific Questionnaire (GMSQ) used in Ref. [RMFV19]. A detailed description of GMSQ is provided in chapter 1.3. This questionnaire focuses on measure user-perceived attention. Detailed information of the questionnaire is shown in Table 4.4.

Table 4.4: Questions of the questionnaire used in the main part of the second experiment.

	Game without Sound Attention Questionnaire (GMSQ-S)	Game Sound Attention Questionnaire (GMSQ-SN)
Q1	Without the auditory notifications that represent right or wrong in the choice of questions still maintain my attention.	When I answer the question, the auditory notification maintain your attention.
Q2	Without the auditory notifications that represent right or wrong when choosing a question make me focus more on the question.	The auditory notifications that represent right or wrong when choosing a question make me focus more on the question.
Q3	Without the auditory notifications that represent right or wrong enhance attention to the outcome of my response.	The auditory notifications that represent right or wrong enhance attention to the outcome of my response.
Q4	Rate to what extent without the auditory notification influenced the way you chose your answer during the experiment.	Rate to what extent the auditory notification influenced the way you chose your answer during the experiment.
Q5	Rate the extent to which without the auditory notification representing your wrong choice influenced your attention.	Rate the extent to which the auditory notification representing your wrong choice influenced your attention.
Q6	Rate to what extent without the auditory notification that represents your right choice influenced your attention.	Rate to what extent the auditory notification that represents your right choice influenced your attention.

In both two questionnaires, all participants are asked to use the Absolute Category Rating (ACR) System shown in Table 4.5 to rate their experience independently on a category scale. ACR is recommended by ITU-T P.910 [J.199]. The main methodology of ACR is described in chapter 1.3.

Table 4.5: Absolute Category Rating (ACR) System.

Rating Scale	1	2	3	4	5
Absolute Category	Not at all	Slightly	Moderately	Fairly	Extremely

4.2 Experiment execution procedures

Three procedures were set up to ensure that all participants were fully aware of the project so that we could provide the integrity of the experimental process. Finally, there are brief instructions on data collection and analysis methods to ensure that the analysis is carried out seamlessly.

4.2.1 Recruitment of participants

The serious game *Venci's Adventures* used in the present thesis belongs to the company *Emvenci Portugal Limitada* and is still under development. Due to the limitation from the confidentiality agreement, I am only allowed to find participants from the company's employees. It greatly reduces the number of experimental participants and the corresponding questionnaire data.

The detailed information of participant demographics are presented in figure 4.1. One can see that in total twenty-three participants, 8 females and 15 males, volunteered to take part in my experiments. 21.7% of the participants were between the age group of blow 20. Most of the participants (69.6%) were aged between 21-30 years old and rest were aged between 31-40. One of the participants reported having a hearing impairment, and the authors tested this participant's hearing problem by playing a simple musical tone. The participant's hearing problem was eventually resolved by adjusting the sound volume to a higher level with the participant's consent. All the participants were given detailed instructions.

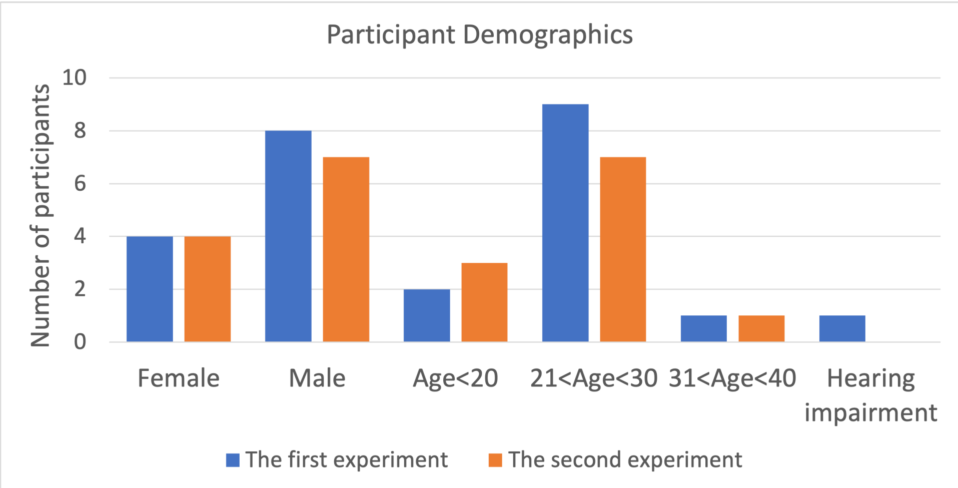

Figure 4.1: Distribution of participants' gender, age and hearing impairment statistics in the first and second experiments.

4.2.2 Experiment execution process

The process of each participant joining in the experiments is mainly divided into the following four steps.

- STEP1: Group preparation

  Every participant will be asked to finish a pre-experimental questionnaire, where the demographic information, including age level, gender, and hearing impairment, will be collected. Moreover, considering that different sounds are the most important part in the experiment, all participants are examined to be free of hearing impairment. Based on the above collected information, all participants are carefully divided into two groups (group1 and group2) to avoid repeated and unbalanced measures effects. Every participant will only be involved in one experiment.

- STEP2: Enrollment

  All participants will be taught the basic operation of the serious game. In addition, all participants will be asked if they are willing to be recorded all operations and reactions when they play the serious game for potential future studies.

- STEP3: Questionnaires

  Participants assigned to a group1 will be asked to first play the standard sound version and the no-sound version of the serious game, and then answer the questionnaire shown in Table 4.3. Participants assigned to a group2 will be asked to first play the standard sound version and the notification version of the serious game, and then answer the questionnaire shown in Table 4.4.

4.2.3 Data Collection

After completing the experiment, the questionnaire results will be organized and stored in a format that facilitates the data analyze method Analysis of Variance (ANOVA). The data obtained for the first group are shown in the supplementary file A.1 and the data obtained for the second group are shown in the supplementary file A.2.

4.3 Result and discussion

This chapter presents the results of the first and second experiments and their corresponding data analysis.

4.3.1 The result of the first and second experiments

The 1st experiment is used for investigating the sound effect in player's experiences in the serious games. Its calculation procedure is shown in the supplementary file A.3, where the method analysis of variance (ANOVA) was conducted to compare the different effects of two serious game versions, i.e., the standard sound version and the no-sound version, on people's perceived experiences. The results obtained from the questionnaires shown in Table 4.3 (GEQ-NS and GEQ-S) are presented in Table 4.6 and Figure 4.2.

In general, comparing to the no-sound version, the standard version of the serious game brings players a better game experience. As shown in Table 4.6, for the 8 questions (Q1-Q6 and Q11-Q12) used to measure the good game experience in different aspects, the smallest mean score of the standard sound version of the serious game beyond 3.2 out of 5. However, the highest score of the no-sound version is even below than 2.5. Moreover, for all other 6 questions (Q7-Q10, Q13, and Q14) used to evaluate the bad game experience in different aspects, the standard sound version has an obviously lower mean score comparing to the no-sound version.

The further ANOVA analysis (P-values) is shown in the 4th column of Table 4.6. Except for the question 10, the value of P is smaller than 0.05 for all other questions. This indicates that, comparing to the no-sound version, the standard sound version has significantly more positive effects on the player's good experiences in the aspect of the feeling of skillful, achievement, interest, enrichment, immersive, concentration, happy and enjoyment. At the same time, it has significantly fewer negative effects on the player's bad experiences including the annoy, irritable, pressure, bad mood, and the feeling of tire.

One special phenomenon is that, for the question Q10 which is used to measure the players' feeling of effort, Table 4.6 and Figure 4.2 indicate that the standard sound version and the no-sound version not only obtain very similar mean scores but also have a P-value=0.232 which is larger than 0.05. The slightly smaller mean score 2.58 in the standard version of the game than 3.08 in the no-sound game proves that the sound can make player feel a little less challenge for the same game. However, the large P-value 0.232 means that, no matter there is standard sound or not, the player didn't feel the effort they payed on the game changes a lot.

Table 4.6: Mean score and the P-value of the 14 questions (Q1-Q14 shown in Table 4.3) used in the first experiment.

	Mean		P-value
	GEQ-S (Standard sound version)	GEQ-NS (No-sound version)	
Q1	3.25	2.42	0.022
Q2	3.75	2.17	0.000
Q3	4.27	1.58	0.000
Q4	4.75	1.42	0.000
Q5	4.17	1.50	0.000
Q6	4.25	1.75	0.000
Q7	1.50	2.75	0.012
Q8	1.58	3.08	0.006
Q9	2.08	3.17	0.025
Q10	2.58	3.08	0.232
Q11	4.17	1.83	0.000
Q12	4.50	1.67	0.000
Q13	1.25	2.83	0.000
Q14	1.50	2.92	0.005

The 2nd experiment is used for investigating the auditory notification effect in user's perceived attentions in the educational part of the serious game. Its calculation procedure is shown in the

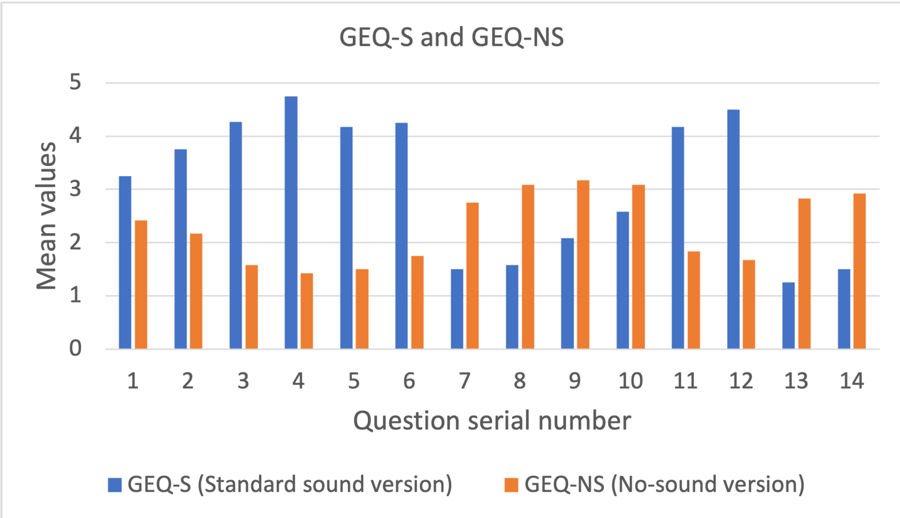

Figure 4.2: Mean score of the 14 questions (Q1-Q14 shown in Table 4.3) used in the first experiment is shown by histogram.

supplementary file A.4, where ANOVA was implemented to study the different effects of two serious game versions, i.e., the standard sound version and the notification version, on people's perceived experiences in the educational part of the serious game. The results obtained from the questionnaires, GMSQ-SN and GMSQ-S, are shown in Table 4.7 and Figure 4.3.

In general, comparing to the standard version, the notification version of the serious game improves the players' perceived attention a lot. As shown in Table 4.7, for all the 6 questions (Q1-Q6) used to measure attentions in different aspects, the lowest mean score of the notification version is larger than 3.6 out of the full score 5. On the other hand, the highest score the standard sound version received is smaller than 2.2. Moreover, Table 4.7 and Figure 4.3 show that the difference of the mean score between the two different versions reaches its maximum in the question 1, which is used to evaluate the auditory notification effects on the maintenance of people's attentions. For this question, the very small mean score 0.539 in the standard version together with the high mean score 4.09 in the notification version illustrate that it is very difficult for players to maintain their attention in the education part of the serious game when there is no notification sound.

The further ANOVA investigations (P-values) is shown in the 4th column of Table 4.7. The value of P is smaller than 0.05 for all questions. The small P value together with the large difference in the mean score for questions Q1-Q6 shown in figure 4.3 indicate that, comparing to the standard sound version, both the auditory notification sounds representing the correct answer and the wrong answer in the notification version have significantly positive effects on maintaining the overall attention, capturing more attentions during the reading, thinking, and reviewing stages in the education part.

Table 4.7: Mean score and the P-value of the 6 questions (Q1-Q6 shown in Table 4.4) used in the second experiment.

	Mean		P-value
	GMSQ-SN (Notification version)	GMSQ-S (Standard sound version)	
Q1	4.09	0.539	0.000
Q2	3.64	2.18	0.000
Q3	3.64	2.09	0.002
Q4	3.64	2.00	0.000
Q5	4.00	1.91	0.000
Q6	3.91	1.82	0.000

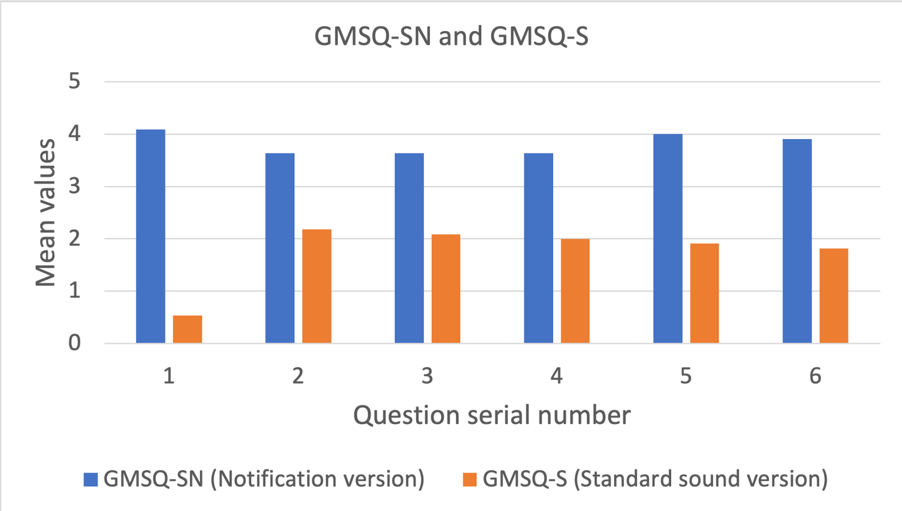

Figure 4.3: Mean score of the 6 questions (Q1-Q6 shown in Table 4.4) used in the second experiment is shown by histogram.

4.3.2 Discussion

In this chapter, mainly four interesting phenomena observed in the first and second experiments are discussed.

1. For the first experiment, as described in the last chapter, comparing to the serious game with no sound, the standard sound version of serious game gives players more good game experiences and less bad game experiences. This might be because that all scenes and movements of the game character have the corresponding sounds in the real world. For example, when players join the serious game and reach the beach scene they will see the sea and birds. These views easily induce players to expect to hear the sound of the waves and the sound of birds chirping. However, in the no-sound version of the serious game, the inconsistency between the players' expectation and the empty sound they heard could make them feel disappointed and have a bad game experience.

2. For the first experiment, chapter 4.3.1 pointed out an interesting phenomenon that players feel they payed a similar level of effort on the no-sound version and the standard sound version of the serious game. There are two possible explanations. The first one is that the existed four scenes of the serious game are too easy for all players. As shown in table 4.6, the mean score for Q10 is not high (smaller than 3.1) in both standard and no-sound versions. It means, players feel they can handle the game without paying very much effort. Under such condition, it is hard for them to classify the difference of challenges between the two versions of game. The other one is that the properly designed sound mainly affect people's subjective experiences during the game, but only limited effect in the objective feelings of games. The amount of effect needed to successfully play through the game is determined by if players know the correct answer in the educational part of the game which is objective.

3. In the second experiment, from its question Q1, an obvious phenomenon reported in the last chapter is that players feel much more difficult to maintain their attention in the education part of the standard version of the serious game comparing to the notification version. One possible reason is that, as mentioned in chapter 1.1, the serious game used in my experiment is still under-development. In the current version of game, there is no clear transition hint between the game part and the educational part. Consequently, there is a good chance players do not realize that they have entered the education section and still be attracted by the other functions or scenes of the serious game. On the other hand, in the notification version, the auditory sounds representing the right and wrong answers can immediately induce player to focus on the education part.

4. According to chapter 4.3.1, another obvious observation from the second experiment is that, comparing to the standard version of the serious game, in the notification version both the auditory notification sound representing the player's answer is correct and the sound representing the player's answer is wrong have significantly positive effects on capturing more attentions during the reading, thinking, and reviewing stages in the education part. This is because all the auditory notifications used in the experiment are carefully selected by an experiment described in chapter 3.4. This experiment guarantees that players will feel pleasant when hear the notification sound represent the correct answer and feel uncomfortable when hear the notification sound represent the wrong answer. These two completely opposite feelings will induce players to pay more attention on reading, thinking, and reviewing questions in the education part to avoid hearing uncomfortable notification sound because of selecting the wrong answer.

Chapter 5

Conclusion and Future Work

In the present thesis, the effect of sound design on serious games are investigated by doing two questionnaire experiments based on the following three versions of the serious game *Venci's Adventures*: (1) a version without any sound (the no-sound version); (2) a version with with soundscape and sound effect designed by myself (the standard sound version); and (3) a version built up based on the standard sound version but with adding the well-designed notification sounds to the educational part of the serious game (the notification version). The results of the questionnaires from these two experiments were analyzed in detail by using the well-known method called analysis of variance (ANOVA). The following four main conclusions were obtained:

1. Compared to the no-sound version, the standard version of the serious game has significant positive effects on players overall perceived experiences in mainly three aspects including competence, flow, and immersion. Meantime, it also brings much less negative experiences to players in the aspect of tension and challenge. This is because the proper sound design in the serious game can satisfy players' expectation for the corresponding sounds of the specific game scene based on their life experience, and further gives players a good game experience. On the other hand, the failure of this expectation in the no-sound version causes players to feel boring and disappointed which means a bad game experience.

2. Based on the first experiment, an interesting phenomenon was observed that players didn't feel much difference about the difficulty and challenge between the standard version and the no-sound version of the serious game. Two possible explanations were also given:

   [a] The existed four scenes of the serious game are too easy for all players to feel the variation of difficulty caused by the different game versions.

   [b] The feeling of the difficult is objective. The sound design mainly affect people's subjective experiences and moods during the game, but not for the objective feelings.

3. Compared to the notification version of the serious game, in the standard sound version players feel much more difficult to maintain their attention in the education part of the

game. I speculated that this is because the absence of a clear boundary between the game part and the question part in the present serious game version makes it hard for players to realize they have already left the game part and entered the education part. However, in the notification version, the auditory notifications can clearly remind players that they have entered the education part and needed to pay attention on questions.

4. Based on the second experiment, both the auditory notification sound representing the players' answer is correct (the S-notification), and the sound representing the players' answer is wrong (the E-notification) have positive effects on capturing more attention from players during their reading, thinking, and reviewing stages in the education part. This is because the my proper designed notification make the S-notification sounds pleasant but the E-notification sounds uncomfortable. When most of the players naturally tend to listen to the pleasant sound and avoid hearing the uncomfortable sound, they will try to answer all questions correctly, therefore, their attention will be more focused during the education part.

In general, to offer players a good game experience, sound design is an important and necessary part in the serious game development. Additionally, the specific types of sound, Earcons, created by using musical notes and the sine tone can be used as the auditory notification to improve players' attention in serious games.

Future Work

To further investigation the phenomena and check the discussions in chapter 4.3.2, the following future works are deserved to be arranged:

1. First, design several scenes of the serious game with clearly different difficulty levels but with the same background sound and the notification sound. Then, redo the first experiment described in the chapter 4 to exam if the explanation (a) in the conclusion point (2) is correct.

2. First, add more questions about the objective feelings to the questionnaire shown in 4.3 which is used in the first experiment. Then, redo the first experiment described in the chapter 4 to exam if the explanation (b) in the conclusion point (2) is correct.

3. Besides comparing the sound version and the no-sound version, it is valuable to investigate what is the good strategy of the soundscape design by comparing the different sound versions, for example, the version with the soundscape produced by using the sound synthesis technique, the version with the soundscape produced by using the foley technique, etc.

4. Continue to develop the serious game and add a clear transition part between the game part and the educational part of the game. Then redo the second experiment described in the chapter 4 to exam if the explanation in the conclusion point (3) is correct.

References

[Abt87] C. C. Abt. *Serious games*. University press of America, 1987. Cited on page 1.

[AHT89] D. H. Ashmead, E. W. Hill, and C. R. Talor. Obstacle perception by ongenitally blind children. *Perception & psychophysics*, 46(5):425–433, 1989. Cited on page 10.

[Beg94] D. Begault. 3-d sound for virtual reality and multimedia" academic press. *London, UK*, 1994. Cited on page 11.

[Bra09] E. Brazil. A review of methods and frameworks for sonic interaction design: Exploring existing approaches. *Auditory Display*, pages 41–67, 2009. Cited on page 11.

[BRK96] S. Brewster, V. Raty, and A. Kortekangas. Earcons as a method of providing navigational cues in a menu hierarchy. In *People and Computers XI*, pages 169–183. Springer, 1996. Cited on page 23.

[BSG89] M. M. Blattner, D. A. Sumikawa, and R. M. Greenberg. Earcons and icons: Their structure and common design principles. *Human–Computer Interaction*, 4(1):11–44, 1989. Cited on pages 11 and 23.

[BWE94] S. A. Brewster, P. C. Wright, and A. D. N. Edwards. A detailed investigation into the effectiveness of earcons. In *SANTA FE INSTITUTE STUDIES IN THE SCIENCES OF COMPLEXITY-PROCEEDINGS VOLUME-*, volume 18, pages 471–471. Addison-Wesley Publishing Co, 1994. Cited on pages ix and 13.

[Che53] E. C. Cherry. Some experiments on the recognition of speech, with one and with two ears. *The Journal of the acoustical society of America*, 25(5):975–979, 1953. Cited on page 9.

[CHMH07] K. Cater, R. Hull, T. Melamed, and R. Hutchings. An investigation into the use of spatialised sound in locative games. In *CHI'07 extended abstracts on Human factors in computing systems*, pages 2315–2320, 2007. Cited on page 9.

[Dak09] Vesna Dakic. Sound design for film and television, 2009. Cited on page 1.

[Ded09] C. Dede. Immersive interfaces for engagement and learning. *science*, 323(5910):66–69, 2009. Cited on pages 10 and 15.

[DHT17] D. Drummond, A. Hadchouel, and A. Tesnière. Serious games for health: three steps forwards. *Advances in Simulation*, 2(1):1–8, 2017. Cited on page 1.

[Dic06] M. D. Dickey. Game design narrative for learning: Appropriating adventure game design narrative devices and techniques for the design of interactive learning environments. *Educational technology research and development*, 54(3):245–263, 2006. Cited on page 1.

[DS06] F. De and I. Sara. Using games and simulations for supporting learning. *Learning, media and technology*, 31(4):343–358, 2006. Cited on page 1.

[EPAH18] M. L. Eriksson, L. Pareto, R. Atienza, and K. F. Hansen. My sound space: An attentional shield for immersive redirection. In *Proceedings of the Audio Mostly 2018 on Sound in Immersion and Emotion*, pages 1–4. Elsevier, 2018. Cited on page 1.

[FFE+21] K. Falkenberg, E. Frid, M. L. Eriksson, T. Otterbring, and S. Daunfeldt. Auditory notification of customer actions in a virtual retail environment: Sound design, awareness and attention. Georgia Institute of Technology, 2021. Cited on pages x, 1, 13, 14, 63, 67, and 68.

[Fie13] A. Field. *Discovering statistics using IBM SPSS statistics*. sage, 2013. Cited on page 5.

[GLN08] M. Grimshaw, C. Lindley, and L. Nacke. Sound and immersion in the first-person shooter: Mixed measurement of the player's sonic experience. In *Audio Mostly-a conference on interaction with sound*. www. audiomostly. com, 2008. Cited on page 28.

[GM95] W. G. Gardner and K. D. Martin. Hrtf measurements of a kemar. *The Journal of the Acoustical Society of America*, 97(6):3907–3908, 1995. Cited on page 9.

[GPCD03] A. Guillaume, L. Pellieux, V. Chastres, and C. Drake. Judging the urgency of non-vocal auditory warning signals: Perceptual and cognitive processes. *Journal of experimental psychology: Applied*, 9(3):196, 2003. Cited on page 1.

[Gru96] K. G. Grunert. Automatic and strategic processes in advertising effects. *Journal of Marketing*, 60(4):88–101, 1996. Cited on page 9.

[GS11] B. Gygi and V. Shafiro. The incongruency advantage for environmental sounds presented in natural auditory scenes. *Journal of Experimental Psychology: Human Perception and Performance*, 37(2):551, 2011. Cited on page 9.

[HA11] M. P. J. Habgood and S. E. Ainsworth. Motivating children to learn effectively: Exploring the value of intrinsic integration in educational games. *The Journal of the Learning Sciences*, 20(2):169–206, 2011. Cited on page 1.

[HB96] C. Hendrix and W. Barfield. Presence within virtual environments as a function of visual display parameters. *Presence: Teleoperators & Virtual Environments*, 5(3):274–289, 1996. Cited on page 7.

[HHN11] T. Hermann, A. Hunt, and J. G. Neuhoff. *The sonification handbook*. Logos Verlag Berlin, 2011. Cited on pages ix and 8.

[HRB97] M. P. Hollier, A. N. Rimmell, and D. Burraston. Spatial audio technology for telepresence. *BT Technology Journal*, 15(4):33–41, 1997. Cited on page 11.

[IDKP+07] W. A. IJsselsteijn, Y. A. W. De Kort, K. Poels, A. Jurgelionis, and F. Bellotti. Characterising and measuring user experiences in digital games. In *International conference on advances in computer entertainment technology*, volume 2, page 27, 2007. Cited on pages 4 and 28.

[IDKP13] W. A. IJsselsteijn, Y. A. W. De Kort, and K. Poels. The game experience questionnaire. 2013. Cited on pages 4 and 28.

[IPA21] S. Irshad, A. Perkis, and W. Azam. Wayfinding in virtual reality serious game: An exploratory study in the context of user perceived experiences. *Applied Sciences*, 11(17):7822, 2021. Cited on pages x, 1, 13, 14, 63, and 65.

[J.199] ITU-T RECOMMENDATION J.148. Subjective video quality assessment methods for multimedia applications. 1999. Cited on page 30.

[JCC+08] C. Jennett, A. L. Cox, P. Cairns, S. Dhoparee, A. Epps, T. Tijs, and A. Walton. Measuring and defining the experience of immersion in games. *International journal of human-computer studies*, 66(9):641–661, 2008. Cited on page 1.

[JGP18] D. Johnson, M. J. Gardner, and R. Perry. Validation of two game experience scales: the player experience of need satisfaction (pens) and game experience questionnaire (geq). *International Journal of Human-Computer Studies*, 118:38–46, 2018. Cited on page 4.

[JZSE17] A. R. Jensenius, A. Zelechowska, Gonzalez S., and Victor E. The musical influence on people's micromotion when standing still in groups. In *Proceedings of the SMC Conferences*, pages 195–200. Aalto University, 2017. Cited on pages x, 13, 63, 68, and 69.

[KC93] R. A. Kendall and E. C. Carterette. Verbal attributes of simultaneous wind instrument timbres: I. von bismarck's adjectives. *Music Perception*, 10(4):445–467, 1993. Cited on page 66.

[Kra94] G. Kramer. An introduction to auditory display. *Auditory display-Sonification, audification and auditory interfaces*, pages 1–77, 1994. Cited on pages ix and 8.

[Lep02] G. Leplâtre. *The design and evaluation of non-speech sounds to support navigation in restricted display devices*. University of Glasgow (United Kingdom), 2002. Cited on pages 10, 11, 15, and 23.

[LH17] J. Lawrence and M. Haasnoot. What it took to catalyse uptake of dynamic adaptive pathways planning to address climate change uncertainty. *Environmental Science & Policy*, 68:47–57, 2017. Cited on page 1.

[Lik32] Rensis Likert. A technique for the measurement of attitudes. *Archives of psychology*, 1932. Cited on page 23.

[LLY17] Phil Lopes, Antonios Liapis, and Georgios N Yannakakis. Modelling affect for horror soundscapes. *IEEE Transactions on Affective Computing*, 10(2):209–222, 2017. Cited on page 1.

[LZ04] S. D. Lipscomb and S. M. Zehnder. Immersion in the virtual environment: The effect of a musical score on the video gaming experience. *Journal of Physiological Anthropology and Applied Human Science*, 23(6):337–343, 2004. Cited on pages 13, 14, 63, and 66.

[MB04] D. K. McGookin and S. A. Brewster. Understanding concurrent earcons: Applying auditory scene analysis principles to concurrent earcon recognition. *ACM Transactions on Applied Perception (TAP)*, 1(2):130–155, 2004. Cited on page 8.

[MNB17] N. Malhotra, D. Nunan, and D. Birks. *Marketing research: An applied approach*. Pearson, 2017. Cited on page 5.

[PEL86] R. D. Patterson, J. Edworthy, and M. C. Lower. *Alarm sounds for medical equipment in intensive care areas and operating theatres*. University of Southampton, Institute of Sound and Vibration Research, 1986. Cited on page 23.

[PNJ+10] N. Paterson, K. Naliuka, S. K. Jensen, T. Carrigy, M. Haahr, and F. Conway. Design, implementation and evaluation of audio for a location aware augmented reality game. In *Proceedings of the 3rd International Conference on Fun and Games*, pages 149–156, 2010. Cited on pages ix, 10, 11, 12, 14, and 63.

[RMFV19] E. Rovithis, N. Moustakas, A. Floros, and K. Vogklis. Audio legends: investigating sonic interaction in an augmented reality audio game. *Multimodal Technologies and Interaction*, 3(4):73, 2019. Cited on pages 5, 13, 14, 30, 63, and 69.

[RS11] U. Rüppel and K. Schatz. Designing a bim-based serious game for fire safety evacuation simulations. *Advanced engineering informatics*, 25(4):600–611, 2011. Cited on page 1.

[RSS16] D. Rumore, T. Schenk, and L. Susskind. Role-play simulations for climate change adaptation education and engagement. *Nature Climate Change*, 6(8):745–750, 2016. Cited on page 1.

[Rum12] F. Rumsey. *Spatial audio*. Routledge, 2012. Cited on page 11.

[SGS05] E. R. Spangenberg, B. Grohmann, and D. E. Sprott. It's beginning to smell (and sound) a lot like christmas: the interactive effects of ambient scent and music in a retail setting. *Journal of business research*, 58(11):1583–1589, 2005. Cited on page 9.

[Smi92] J. O. Smith. Physical modeling using digital waveguides. *Computer music journal*, 16(4):74–91, 1992. Cited on page 11.

[Son01] D. Sonnenschein. *Sound design: The expressive power of music, voice, and sound effects in cinema*. Michael Wiese Productions, 2001. Cited on pages 1 and 7.

[SPB21] I. Salselas, R. Penha, and G. Bernardes. Sound design inducing attention in the context of audiovisual immersive environments. *Personal and Ubiquitous Computing*, 25(4):737–748, 2021. Cited on page 9.

[SS77] W. Schneider and R. M. Shiffrin. Controlled and automatic human information processing: I. detection, search, and attention. *Psychological review*, 84(1):1, 1977. Cited on page 1.

[Tah19] H. Taherdoost. What is the best response scale for survey and questionnaire design; review of different lengths of rating scale/attitude scale/likert scale. *Hamed Taherdoost*, pages 1–10, 2019. Cited on page 23.

[TAM11] P. Toprac and A. Abdel-Meguid. Causing fear, suspense, and anxiety using sound design in computer games. In *Game sound technology and player interaction: Concepts and developments*, pages 176–191. IGI Global, 2011. Cited on pages 1 and 7.

[TB15] L. Turchet and R. Bresin. Effects of interactive sonification on emotionally expressive walking styles. *IEEE Transactions on affective computing*, 6(2):152–164, 2015. Cited on pages 13, 14, 63, and 64.

[Upt68] E. Upton. *A New System of Infantry Tactics, Double and Single Rank, Adapted to American Topography and Improved Fire-Arms*. D. Appleton, 1868. Cited on page 11.

[VDDKP01] K. Van Den Doel, P. G. Kry, and D. K. Pai. Foleyautomatic: physically-based sound effects for interactive simulation and animation. In *Proceedings of the 28th annual conference on Computer graphics and interactive techniques*, pages 537–544, 2001. Cited on page 11.

[vdDP96] K. van de Doel and D. K. Pai. Synthesis of shape dependent sounds with physical modeling. Georgia Institute of Technology, 1996. Cited on page 11.

[WSS15] E. M. Whyte, J. M. Smyth, and K. S. Scherf. Designing serious game interventions for individuals with autism. *Journal of autism and developmental disorders*, 45(12):3820–3831, 2015. Cited on page 1.

[Yew12] D. L. Yewdall. *The practical art of motion picture sound*. Routledge, 2012. Cited on pages 1 and 7.

REFERENCES

Appendix A

Four supplementary files are included in the present appendix.

- Supplementary file 1: The results of the questionnaire used in the first experiment.
- Supplementary file 2: The results of the questionnaire used in the second experiment.
- Supplementary file 3: The detailed calculation information for the first experiment.
- Supplementary file 4: The detailed calculation information for the second experiment

A.1 Supplementary file 1

Group	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14
1	2	4	1	5	2	3	4	4	2	3	3	4	2	2
1	3	4	5	5	4	5	2	1	2	1	4	5	2	2
1	3	5	5	5	5	5	1	1	3	3	5	5	1	1
1	1	1	5	5	3	3	1	1	1	1	3	4	1	1
1	5	5	5	4	5	5	1	4	2	3	5	5	1	1
1	4	4	5	5	5	4	1	1	3	4	4	5	1	1
1	3	3		5	4	4	2	1	1	1	4	4	1	2
1	4	4	4	4	5	5	2	1	1	3	4	5	1	1
1	3	4	3	5	4	4	1	1	2	3	4	4	1	1
1	4	4	4	5	4	4	1	1	1	2	5	5	1	1
1	4	3	5	4	4	5	1	2	4	4	4	3	2	2
1	3	4	5	5	5	4	1	1	3	3	5	5	1	3
2	2	2	1	1	1	2	1	1	1	2	2	2	2	1
2	2	2	1	1	1	1	1	2	3	3	1	1	2	4
2	3	1	1	1	1	1	5	5	3	3	1	1	5	5
2	3	3	2	2	3	3	2	2	4	3	3	2	2	2
2	2	2	2	2	2	1	3	3	3	4	1	1	4	4
2	2	2	1	1	1	2	2	3	2	3	2	1	2	2
2	3	3	2	2	1	3	2	3	2	4	2	2	1	1
2	2	2	2	2	1	1	4	2	4	1	2	1	2	1
2	3	2	3	1	2	2	2	5	5	4	4	3	3	3
2	2	2	2	1	2	2	4	4	3	4	1	1	4	4
2	2	3	1	2	2	1	4	3	5	3	2	3	4	4
2	3	2	1	1	1	2	3	4	3	3	1	2	3	4

A.2 Supplementary file 2

Group	Q1	Q2	Q3	Q4	Q5	Q6
1	4	4	5	5	5	5
1	5	4	4	5	5	5
1	4	3	1	1	3	3
1	4	3	4	2	2	3
1	4	4	4	4	4	4
1	4	3	4	2	5	4
1	3	3	2	4	4	2
1	5	5	5	5	5	5
1	4	4	4	5	5	5
1	4	4	4	4	3	4
1	4	3	3	3	3	3
2	2	1	1	2	1	1
2	1	2	2	1	1	1
2	2	2	4	4	3	3
2	2	3	2	2	2	3
2	2	2	2	2	2	2
2	2	3	2	2	1	1
2	3	3	2	2	2	1
2	1	1	1	1	1	1
2	2	2	2	1	2	2
2	2	2	2	2	3	2
2	2	3	3	3	3	3

A.3 Supplementary file 3

Supplementary file 3: The detailed calculation information for the first experiment.

Descriptives

					95% Confidence Interval for Mean				
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound			
Q1	1	12	3.25	1.055	.305	2.58	3.92		
	2	12	2.42	.515	.149	2.09	2.74		
	Total	24	2.83	.917	.187	2.45	3.22		
Q2	1	12	3.75	1.055	.305	3.08	4.42		
	2	12	2.17	.577	.167	1.80	2.53		
	Total	24	2.96	1.160	.237	2.47	3.45		
Q3	1	11	4.27	1.272	.384	3.42	5.13		
	2	12	1.58	.669	.193	1.16	2.01		
	Total	23	2.87	1.687	.352	2.14	3.60		
Q4	1	12	4.75	.452	.131	4.46	5.04		
	2	12	1.42	.515	.149	1.09	1.74		
	Total	24	3.08	1.767	.361	2.34	3.83		
Q5	1	12	4.17	.937	.271	3.57	4.76		
	2	12	1.50	.674	.195	1.07	1.93		
	Total	24	2.83	1.579	.322	2.17	3.50		
Q6	1	12	4.25	.754	.218	3.77	4.73		
	2	12	1.75	.754	.218	1.27	2.23		
	Total	24	3.00	1.474	.301	2.38	3.62		
Q7	1	12	1.50	.905	.261	.93	2.07		
	2	12	2.75	1.288	.372	1.93	3.57		
	Total	24	2.13	1.262	.258	1.59	2.66		
Q8	1	12	1.58	1.165	.336	.84	2.32		
	2	12	3.08	1.240	.358	2.30	3.87		
	Total	24	2.33	1.404	.287	1.74	2.93		
Q9	1	12	2.08	.996	.288	1.45	2.72		
	2	12	3.17	1.193	.345	2.41	3.92		
	Total	24	2.63	1.209	.247	2.11	3.14		
Q10	1	12	2.58	1.084	.313	1.89	3.27		
	2	12	3.08	.900	.260	2.51	3.66		

	Total	24	2.83	1.007	.206	2.41	3.26		
Q11	1	12	4.17	.718	.207	3.71	4.62		
	2	12	1.83	.937	.271	1.24	2.43		
	Total	24	3.00	1.445	.295	2.39	3.61		
Q12	1	12	4.50	.674	.195	4.07	4.93		
	2	12	1.67	.778	.225	1.17	2.16		
	Total	24	3.08	1.613	.329	2.40	3.76		
Q13	1	12	1.25	.452	.131	.96	1.54		
	2	12	2.83	1.193	.345	2.08	3.59		
	Total	24	2.04	1.197	.244	1.54	2.55		
Q14	1	12	1.50	.674	.195	1.07	1.93		
	2	12	2.92	1.443	.417	2.00	3.83		
	Total	24	2.21	1.318	.269	1.65	2.76		

Descriptives			
	Minimum	Maximum	
Q1	1	1	5
	2	2	3
	Total	1	5
Q2	1	1	5
	2	1	3
	Total	1	5
Q3	1	1	5
	2	1	3
	Total	1	5
Q4	1	4	5
	2	1	2
	Total	1	5
Q5	1	2	5
	2	1	3
	Total	1	5
Q6	1	3	5
	2	1	3
	Total	1	5
Q7	1	1	4
	2	1	5
	Total	1	5
Q8	1	1	4
	2	1	5
	Total	1	5

Q9	1	1	4
	2	1	5
	Total	1	5
Q10	1	1	4
	2	1	4
	Total	1	4
Q11	1	3	5
	2	1	4
	Total	1	5
Q12	1	3	5
	2	1	3
	Total	1	5
Q13	1	1	2
	2	1	5
	Total	1	5
Q14	1	1	3
	2	1	5
	Total	1	5

ANOVA						
	Sum of Squares	df	Mean Square	F	Sig.	
Q1	Between Groups	4.167	1	4.167	6.044	.022
	Within Groups	15.167	22	.689		
	Total	19.333	23			
Q2	Between Groups	15.042	1	15.042	20.791	.000
	Within Groups	15.917	22	.723		
	Total	30.958	23			
Q3	Between Groups	41.510	1	41.510	41.316	.000

	Within Groups	21.098	21	1.005		
	Total	62.609	22			
Q4	Between Groups	66.667	1	66.667	283.871	.000
	Within Groups	5.167	22	.235		
	Total	71.833	23			
Q5	Between Groups	42.667	1	42.667	64.000	.000
	Within Groups	14.667	22	.667		
	Total	57.333	23			
Q6	Between Groups	37.500	1	37.500	66.000	.000
	Within Groups	12.500	22	.568		
	Total	50.000	23			
Q7	Between Groups	9.375	1	9.375	7.569	.012
	Within Groups	27.250	22	1.239		
	Total	36.625	23			
Q8	Between Groups	13.500	1	13.500	9.330	.006
	Within Groups	31.833	22	1.447		
	Total	45.333	23			
Q9	Between Groups	7.042	1	7.042	5.828	.025
	Within Groups	26.583	22	1.208		
	Total	33.625	23			
Q10	Between Groups	1.500	1	1.500	1.511	.232
	Within Groups	21.833	22	.992		
	Total	23.333	23			
Q11	Between Groups	32.667	1	32.667	46.870	.000
	Within Groups	15.333	22	.697		

	Total	48.000	23			
Q12	Between Groups	48.167	1	48.167	90.829	.000
	Within Groups	11.667	22	.530		
	Total	59.833	23			
Q13	Between Groups	15.042	1	15.042	18.470	.000
	Within Groups	17.917	22	.814		
	Total	32.958	23			
Q14	Between Groups	12.042	1	12.042	9.490	.005
	Within Groups	27.917	22	1.269		
	Total	39.958	23			

A.4 Supplementary file 4

Supplementary file 4: The detailed calculation information for the second experiment

Descriptives									
			Std.		95% Confidence Interval for Mean				
	N	Mean	Deviation	Std. Error	Lower Bound	Upper Bound			
Q1	1	12	3.25	1.055	.305	2.58	3.92		
	2	12	2.42	.515	.149	2.09	2.74		
	Total	24	2.83	.917	.187	2.45	3.22		
Q2	1	12	3.75	1.055	.305	3.08	4.42		
	2	12	2.17	.577	.167	1.80	2.53		
	Total	24	2.96	1.160	.237	2.47	3.45		
Q3	1	11	4.27	1.272	.384	3.42	5.13		
	2	12	1.58	.669	.193	1.16	2.01		
	Total	23	2.87	1.687	.352	2.14	3.60		
Q4	1	12	4.75	.452	.131	4.46	5.04		
	2	12	1.42	.515	.149	1.09	1.74		
	Total	24	3.08	1.767	.361	2.34	3.83		
Q5	1	12	4.17	.937	.271	3.57	4.76		
	2	12	1.50	.674	.195	1.07	1.93		
	Total	24	2.83	1.579	.322	2.17	3.50		
Q6	1	12	4.25	.754	.218	3.77	4.73		
	2	12	1.75	.754	.218	1.27	2.23		
	Total	24	3.00	1.474	.301	2.38	3.62		
Q7	1	12	1.50	.905	.261	.93	2.07		
	2	12	2.75	1.288	.372	1.93	3.57		
	Total	24	2.13	1.262	.258	1.59	2.66		
Q8	1	12	1.58	1.165	.336	.84	2.32		
	2	12	3.08	1.240	.358	2.30	3.87		
	Total	24	2.33	1.404	.287	1.74	2.93		
Q9	1	12	2.08	.996	.288	1.45	2.72		
	2	12	3.17	1.193	.345	2.41	3.92		
	Total	24	2.63	1.209	.247	2.11	3.14		
Q10	1	12	2.58	1.084	.313	1.89	3.27		
	2	12	3.08	.900	.260	2.51	3.66		
	Total	24	2.83	1.007	.206	2.41	3.26		

Q11	1	12	4.17	.718	.207	3.71	4.62		
	2	12	1.83	.937	.271	1.24	2.43		
	Total	24	3.00	1.445	.295	2.39	3.61		
Q12	1	12	4.50	.674	.195	4.07	4.93		
	2	12	1.67	.778	.225	1.17	2.16		
	Total	24	3.08	1.613	.329	2.40	3.76		
Q13	1	12	1.25	.452	.131	.96	1.54		
	2	12	2.83	1.193	.345	2.08	3.59		
	Total	24	2.04	1.197	.244	1.54	2.55		
Q14	1	12	1.50	.674	.195	1.07	1.93		
	2	12	2.92	1.443	.417	2.00	3.83		
	Total	24	2.21	1.318	.269	1.65	2.76		

Descriptives

	Minimum	Maximum	
Q1	1	1	5
	2	2	3
	Total	1	5
Q2	1	1	5
	2	1	3
	Total	1	5
Q3	1	1	5
	2	1	3
	Total	1	5
Q4	1	4	5
	2	1	2
	Total	1	5
Q5	1	2	5
	2	1	3
	Total	1	5
Q6	1	3	5
	2	1	3
	Total	1	5
Q7	1	1	4
	2	1	5
	Total	1	5
Q8	1	1	4
	2	1	5
	Total	1	5
Q9	1	1	4

	2	1	5
	Total	1	5
Q10	1	1	4
	2	1	4
	Total	1	4
Q11	1	3	5
	2	1	4
	Total	1	5
Q12	1	3	5
	2	1	3
	Total	1	5
Q13	1	1	2
	2	1	5
	Total	1	5
Q14	1	1	3
	2	1	5
	Total	1	5

ANOVA						
	Sum of Squares	df	Mean Square	F	Sig.	
Q1	Between Groups	4.167	1	4.167	6.044	.022
	Within Groups	15.167	22	.689		
	Total	19.333	23			
Q2	Between Groups	15.042	1	15.042	20.791	.000
	Within Groups	15.917	22	.723		
	Total	30.958	23			
Q3	Between Groups	41.510	1	41.510	41.316	.000
	Within	21.098	21	1.005		

	Groups					
	Total	62.609	22			
Q4	Between Groups	66.667	1	66.667	283.871	.000
	Within Groups	5.167	22	.235		
	Total	71.833	23			
Q5	Between Groups	42.667	1	42.667	64.000	.000
	Within Groups	14.667	22	.667		
	Total	57.333	23			
Q6	Between Groups	37.500	1	37.500	66.000	.000
	Within Groups	12.500	22	.568		
	Total	50.000	23			
Q7	Between Groups	9.375	1	9.375	7.569	.012
	Within Groups	27.250	22	1.239		
	Total	36.625	23			
Q8	Between Groups	13.500	1	13.500	9.330	.006
	Within Groups	31.833	22	1.447		
	Total	45.333	23			
Q9	Between Groups	7.042	1	7.042	5.828	.025
	Within Groups	26.583	22	1.208		
	Total	33.625	23			
Q10	Between Groups	1.500	1	1.500	1.511	.232
	Within Groups	21.833	22	.992		
	Total	23.333	23			
Q11	Between Groups	32.667	1	32.667	46.870	.000
	Within Groups	15.333	22	.697		

	Total	48.000	23			
Q12	Between Groups	48.167	1	48.167	90.829	.000
	Within Groups	11.667	22	.530		
	Total	59.833	23			
Q13	Between Groups	15.042	1	15.042	18.470	.000
	Within Groups	17.917	22	.814		
	Total	32.958	23			
Q14	Between Groups	12.042	1	12.042	9.490	.005
	Within Groups	27.917	22	1.269		
	Total	39.958	23			

Appendix B

In this appendix, the detailed information of Refs. [PNJ+10, TB15, LZ04, RMFV19, FFE+21, JZSE17, IPA21] is shown in Tables. B.1-B.7.

Table B.1: Experiment summary table for design, implementation and evaluation of audio for a location aware augmented reality game.

Title	Design, implementation and evaluation of audio for a location aware augmented reality game [PNJ+10]
Year	2010
Auther	Natasa Paterson and Katsiaryna Naliuka et al.
Experiment purposes	To assess the impact of audio on immersion and emotional engagement.
Experiment method	Questionnaires
Experiment steps	1. Participants will not be informed about the importance of sound design and the objectives of the evaluation. 2. Participants play the selected game. 3. Participants fill in a questionnaire which includes questions that focus on the impact and effect of sound design on emotional response and immersion.
Experiment results	This experiment proved that audio plays an important role in immersing the player in the game space and in emotionally engaging with the virtual world.

No	Condition	Variations
1	Control Condition (CC)	No wayfinding cues
2	Experimental Condition 1 (EC1)	Static wayfinding cues
3	Experimental Condition 2 (EC2)	Dynamic wayfinding cues with visual stimulus

Figure B.1: Three experimental conditions (image reproduced from [IPA21]).

Table B.2: Experiment summary table for effects of interactive sonification on emotionally expressive walking styles.

Title	Effects of Interactive Sonification on Emotionally Expressive Walking Styles [TB15]
Year	2015
Auther	Luca Turchet and Roberto Bresin
Experiment purposes	To investigate the role of sonically simulated ground materials in modulating both production and recognition of walks performed with emotional intentions. The purpose of experiment 1: Investigate the auditory-feedback effects in motor style when people walking with different emotional intentions. The purpose of experiment 2: (1) To investigate what extent the emotional intentions, that are portrayed by the sounds generated by the participants in the experiment 1, could be recognized in a listening test. (2) To check whether the recognition in (1) is moderated by the type of ground material sonically simulated.
Experiment method	1. Questionnaire rated on seven-point Likert scale. 2. Design the microphones-based system to record and recode the sound data. 3. Data is investigated by analysis of variance (ANOVA).
Experiment steps	1. Participants are divided into two groups based on whether or not they were musically trained. 2. Participants were asked to put on headphones and walk along the plank with five different emotional intentions. The five emotions included: happy, aggressive, tender, sad, and neutral. (Experiment 1) 3. Participants were asked to identify the type of sound (solid or aggregate) and name the simulated surface material. (Experiment 2) 4. Participants were asked to fill out a well-designed questionnaire.
Experiment results	Experiment 1: showed that the auditory feedback involved in the two groups of participants influenced the pattern of emotional walking in different ways. Experiment 2: showed that sound conditions did not affect the recognition of emotions from acoustic information alone. Conclusion: (1) Tempo and sound level are two acoustic features for generating and recognizing emotions while walking. (2) Emotion recognition is not related to the level of musical expertise.

Table B.3: Experiment summary table for wayfinding in virtual reality serious game: an exploratory study in the context of user perceived experience.

Title	Wayfinding in virtual reality serious game: an exploratory study in the context of user perceived experiences [IPA21]
Year	2021
Auther	Shafaq Irshad and Andrew Perkis et al.
Experiment purposes	To investigate the impact of wayfinding cues in a VR SG for disaster preparedness.
Experiment method	1. Questionnaire. 2. Heart-rate (HR) measurements. 3. Data is investigated by analysis of variance (ANOVA).
Experiment steps	1. Participants were divided in to two groups by whether or not colorblind. 2. Participants were informed of the task and asked to wear a Fitbit sensor. 3. Participants were randomly placed into one of three experimental conditions: CC, EC1, and EC2, as shown in Figure B.1. 4. Participants were given eight minutes to perform a wayfinding experience based on the immersive experience provided by VR. 5. After participants completed the VR experience, their heart rate was re-recorded by a Fitbit. 6. Participants completed the game experience questionnaire as requested.
Experiment results	1. The contextual cues are an important element in VR SG design. 2. The careful introduction of these contextual cue is improve end-users' tolerance and thus better their overall perceptual experience.

Table B.4: Experiment summary table for the effect of a musical score on the video gaming experience in the virtual immersion environment.

Title	Immersion in the Virtual Environment: The Effect of a Musical Score on the Video Gaming Experience [LZ04]
Year	2004
Auther	Scott D. Lipscomb and Sean M. Zehnder
Experiment purposes	Investigate the impact of a musical soundtrack on the video gaming experience. The experiment purposes can be mainly divided into three points: 1. Do players perceive a game differently due to the presence of music? 2. If so, in what ways does music impact the aesthetic experience of gaming? 3. Do attribute variables (e.g., gender or age level) significantly impact participant responses?
Experiment method	1. Verbal attribute magnitude estimation (VAME) [KC93]. 2. Data is investigated by analysis of variance (ANOVA).
Experiment steps	1. Demographic information was collected from each participant before the experiment. Specific information included: age, level, and gender. 2. The participants will be randomly assigned to one of three experimental conditions. The experimental conditions were: game-with-music, game-without-music, and music-only. 3. After each game session, subjects will respond to a series of 21verbal scales.
Experiment results	The relationship between the specially composed orchestral musical score and the involvement in the RPG video game is very complex and varied.

Table B.5: Experiment summary table for auditory notification of customer actions in a virtual retail environment: sound design, awareness and attention.

Title	Auditory notification of customer actions in a virtual retail environment: Sound design, awareness and attention. [FFE+21]
Year	2021
Auther	Kjetil Falkenberg and Emma Frid et al.
Experiment purposes	Investigate peripheral auditory notifications in a virtual retail environment by evaluating the following aspects: 1. Awareness and attention. 2. Sound design and noticeability. 3. Localization of event sounds.
Experiment method	1. HMD sensor motion capture and interview. 2. Used t-tests and Chi-square tests with 5% significance level.
Experiment steps	1. Participants experience peripheral auditory notifications in a virtual clothing store for Oculus Quest head-mounted display (HMD). 2. Participants will have 25 interactions, as shown in B.2, which do not pass with the distance of the participant's moving head trajectory. Within these 25 interactions, there are different sounds at each of the six main locations. Each of the six sounds was played 3-5 times, with intervals between the sounds ranging from 11 to 35 seconds. 3. Participants will be involved in an interview to answer a well-designed questionnare.
Experiment results	The notification sound will have different effects on the people who aware of the surveillance system than those who are not.

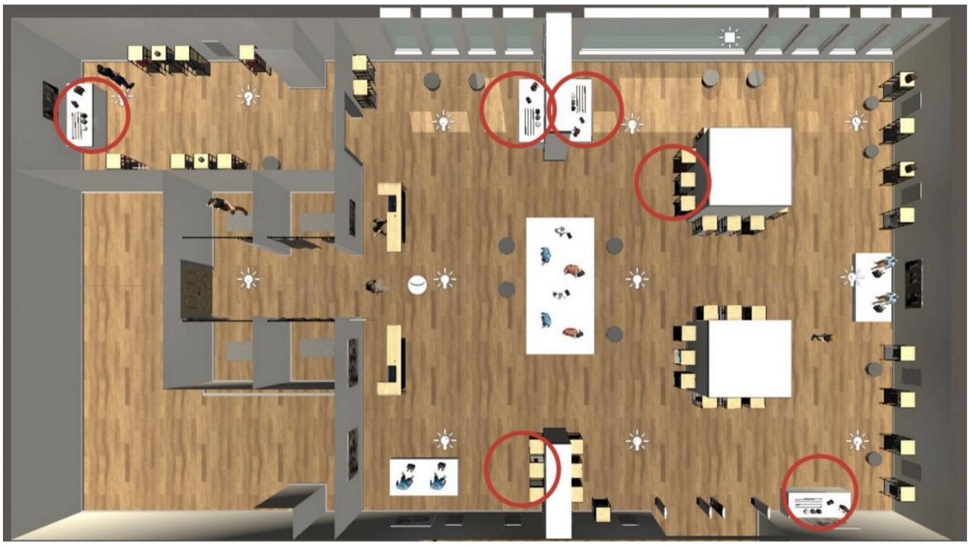

Figure B.2: The locations of the six sources of the alarm-sound are marked with red circles (image reproduced from [FFE+21]).

Table B.6: Experiment summary table for the musical influence on people's micromotion when standing still in groups.

Title	The musical influence on people's micromotion when standing still in groups [JZSE17]
Year	2017
Auther	Alexander Refsum Jensenius and Agata Zelechowsk et al.
Experiment purposes	To explore the magnitude of micromotion and the influence of music on human standstill.
Experiment method	1. Motion capture. 2. Quantitative data analysis.
Experiment steps	1. Participants reported the amount of time they spent listening to and composing music. 2. They will be divided into groups of 5-17 people. 3. Participants will wear a reflective marker (motion capture system) to try to stand as long as possible for 6 minutes: the first 3 minutes of which were silent; the last 3 minutes were music. Participants knew that the music would start after 3 minutes. The music used for the experiment is shown in Figure B.3. 4. Analyze the data.
Experiment results	1. micromotion occurred mainly on the horizontal plane. 2. statistically significant differences were found between no-sound and sound conditions across the dataset. 3. some relationships between QoM data and the self-reported characteristics of physical activity and demographic information. 4. younger participants tended to move more during both nosound and sound conditions.

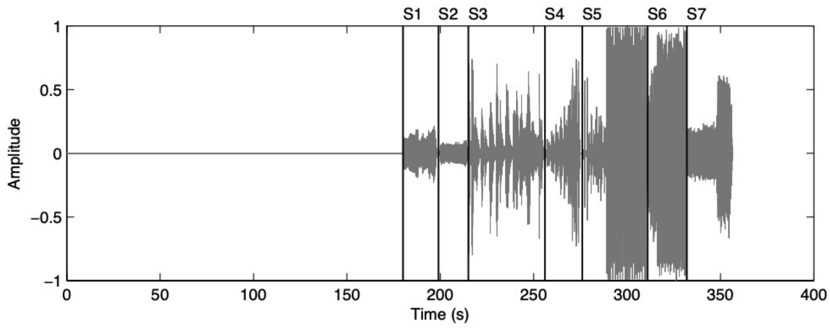

Figure B.3: The figure shows seven short musical excerpts, each lasting 20-40 seconds. The first musical excerpt is a slow and rhythmless orchestral piece. While the last one is a vocal and electronic dance piece. The rhythmic complexity and loudness increased throughout the experiment (image reproduced from [JZSE17]).

Table B.7: Experiment summary table for investigating sonic interaction in an augmented reality audio game.

Title	Audio Legends: Investigating Sonic Interaction in an Augmented Reality Audio Game. [RMFV19]
Year	2019
Auther	Emmanouel Rovithis and Nikolaos Moustakas et al.
Experiment purposes	To investigate sonic interaction in an augmented reality.
Experiment method	1. Questionnaire 2. Data is investigated by analysis of variance (ANOVA).
Experiment steps	1. One or two participants completed the demographic and technographic questionnaire. 2. Introduce the scenario of the game. 3. Participants selected a GM. The participants were briefly explained how to wear the headphones, hold the device, and perform the necessary gestures. 4. After completing one GM, each participant would choose either to try another or to choose to finish the game. 5. Participants completed the game experience questionnaire as requested
Experiment results	1. Three interaction modes were investigated in the paper that can successfully express a challenging game experience understood and enjoyed by diverse audience groups. 2. Increased interaction complexity results in increased game difficulty.