A COMPARATIVE STUDY ON SOUNDSCAPES IN REAL AND VIRTUAL OPEN OFFICE ENVIRONMENTS

A Master's Thesis

by

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Bilkent University 2020

To my parents,

Gülperi and Necip ŞAHİN

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The Graduate School of Economics and Social Sciences

of

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ABSTRACT

A COMPARATIVE STUDY ON SOUNSCAPES IN REAL AND VIRTUAL OPEN OFFICE ENVIRONMENTS

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MFA., Interior Architecture and Environmental Design

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This study presents the findings of indoor soundscape research that was conducted in real (RE), recorded virtual (VE_Rec), and virtual (VE) open office environment settings. The study took place in the architectural office firm, Demay Architecture in Ankara. This study aims to analyze whether the soundscape quality can be measured in virtual open-plan office environments by collecting individual responses with ISO 12913-2:2018. 90 participants were divided into three groups with 30 people in any group. The first group (RE) of participants walked in silence over the course of a predefined route which includes 10 locations, observing the soundscape and the office environment. The second group experienced VE_Rec by watching a recorded video from RE as a virtual soundwalk. Finally, the third group experienced VE by watching a virtually modeled animation video. The same questionnaire procedure was implemented for all groups via Method A (ISO/TS 12913-2):2018. The results showed that occupants mostly perceive the real office environment (RE) more positively than the virtual (VE) and recorded virtual (VE_Rec) office environment in terms of eight perceptual attributes. RE was perceived as more “pleasant” and “calm” while VE_Rec and VE were perceived as more “annoying” and “chaotic”.

Keywords: Open Plan Office, Soundscape, Soundwalk, Virtual Acoustic Environment, Virtual Soundscape Evaluation

ÖZET

GERÇEK VE SANAL AÇIK OFİSLERDE İŞİTSEL PEYZAJ ÜZERİNE KARŞILAŞTIRMALI BİR ÇALIŞMA

Zekiye Şahin
Yüksek Lisans, İç Mimarlık ve Çevre Tasarımı Bölümü
Tez Yöneticisi: Dr. Öğr. Üyesi Semiha Yılmazer

Temmuz, 2020

Bu çalışma “Gerçek”, “Kayıt edilmiş sanal” ve “Sanal” açık ofis ortamlarında gerçekleştirilmiş bir iç mekân işitsel peyzaj araştırmasının sonuçlarını göstermektedir. Tez kapsamındaki bu çalışma, Ankara’da bulunan Demay Mimarlık firmasının açık ofisinde gerçekleştirilmiştir. Tez, ISO 12913-2:2018 standart kaynağı doğrultusunda elde edilen bireysel cevapları kullanarak işitsel peyzaj kalitesinin sanal açık ofis ortamlarında ölçülebilir olup olmadığını araştırmayı amaçlamıştır. Bu amaca ulaşmak için, 90 adet katılımcı otuzar kişiden oluşan üç gruba ayrılmıştır. İlk grubun katılımcıları on adet lokasyon içeren, önceden planlanmış bir rota boyunca sessizce dinleme yürüyüşünü gerçekleştirdiler. İkinci grup gerçek ofis ortamından kaydedilmiş bir video üzerinden sanal bir dinleme yürüyüşü deneyimlediler. Son olarak üçüncü grup katılımcıları ise 3D ortamda modellenip animasyon haline getirilen sanal ofis videosu izleyerek dinleme yürüyüşlerini tamamladılar. Her üç grup için de dinleme yürüyüşleri sonrasında Method A (ISO/TS 12913-2):2018 anket prosedürü uygulanmıştır. Yapılan istatistiksel testlerin sonucuna göre katılımcılar sekiz algısal sıfat bağlamında "Gerçek" ofis ortamını, "Kaydedilmiş" sanal ve "Sanal" ofis ortamlarına göre daha pozitif yönde değerlendirmişlerdir. Gerçek ofis ortamı daha "hoşnutluk verici" ve "sakin" olarak değerlendirilirken, kaydedilmiş sanal ve sanal ofis ortamları daha "rahatsız edici"" ve "kaotik" olarak yorumlanmıştır.

Anahtar Kelimeler: Açık Ofis, Dinleme Yürüyüşü, İşitsel Peyzaj, Sanal Akustik Ortamı, Sanal İşitsel Peyzaj Değerlendirmesi

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CHAPTER I

INTRODUCTION

Nowadays, most offices prefer to work on open-plan offices where many users can work, interact, and communicate with each other through the higher worker density and increased working area (Acun & Yilmazer, 2018). Indoor environments provide users with a variety of functions and each function requires different acoustical features. Among these indoor environments, open-plan offices are the most preferred office styles in the past decade. However, there is no significant evidence demonstrating that open-plan office arrangements raise work productivity. On the opposite, the lack of visual and acoustic privacy and unregulated sound rates mean that job efficiency and workplace satisfaction are dramatically reduced (Acun and Yılmazer, 2018). The determination of acoustical problems in open-plan offices is the widely mentioned topic in the related literature. Most studies argue that open-plan office layout causes a variety of social and physical environmental problems (Yadav et al., 2017). Hongisto et al. (2016) mentioned the lack of privacy and its' negative influence on concentration in open-plan offices. He claims that most of the cognitive office tasks are strongly affected by irrelevant speech and its' impacts on workers’ memories and their increased cognitive workload (Hongisto et al., 2016). These negative influences can cause dissatisfaction from the working sound environment and it can be the reason for negative consequences on health and wellbeing such as noise-related stress and loss of concentration (Acun & Yılmazer, 2018). Besides, distraction and speech privacy can be objectively measured by assessing the intelligibility of speech between work areas. Intelligible speech-based communication affects both the speaker and the listener, since it may confuse a listener who might need to focus on a task and make a speaker nervous about loss of speech privacy (Yadav et al., 2017). Haapakangas et al., (2014) claims that speech intelligibility estimates the subjective responses like acoustic satisfaction, perceived disturbance, personal habitude and subjective (Haapakangas et al., 2014). The harmful effect of background speech can be caused by room acoustic interior design that decreases speech intelligibility, as calculated by the Speech Transmission Index (STI) and STI of speech relies on absorption, displays, background noise frequency and the range between a speaker and a listener (Haapakangas et al., 2014).

There are several studies have mentioned the types of office sounds which specify the term auditory perception. Auditory perception has been shown to affect how we function and navigate around places and how public spaces are used (Calleri, 2018). The soundscape is an approach, is focused on the human auditory perception and interpretation of the sound environment. ISO 12913-1:2014 defines soundscape as the perception and interpretation of an acoustic environment, in context, by an person, or by a community. Soundscapes of built environment approach aimed to design new research findings to show the relationship between soundscape, architecture, and urban design. This connection mediates indoor and outdoor acoustic environments (Aletta and Astolfi, 2018).

1.1 Aim and Scope

Open plan offices aim to provide users with flexible working environments for different office requirements. In this regard, studies on the sound systems of the open-plan offices focus mostly on measuring the physical parameters of the acoustic conditions. However, most of the real open office environments are transferred into the virtual office environments due to the global health and economical continuity issues. Long-standing pandemic period (Covid 19) is the main reason of this transformation. Most of the open office workers and owners are worried about the social distance and hygiene problems in open offices in the consequence of crowded working areas. In this sense, the requirement of virtual open offices and their acoustical assessments have gained importance all around the world. Several studies have also been conducted to analyze how soundscape evaluation is used in real and virtual environments (Acun & Yilmazer, 2018; Acun & Yilmazer, 2019) However, there is not any previous study about soundscape quality assessment in the virtual open-plan office. This thesis aims to represent an approach for assessing the virtual open plan offices regarding their soundscape properties by analyzing the effect of sound source identification, perceived affective quality, assessment of surrounding sound environment, and appropriateness on participants' observation. The equivalent continuous A-weighted sound level (LAeq) was analyzed in-situ via sound level meter Bruel & Kjaer 2230. The scope of the perceptual data, the interview was evaluated with ISO/TS 12913-2:2018 Method A, soundwalk procedure, and the questionnaires were analyzed by using SPSS.

1.2 Structure of the Thesis

The thesis is composed of six chapters. The first chapter is "Introduction," which provides general information regarding the approach to soundscapes and the study's importance. After this, the aim of the study and the thesis structure are given.

The second chapter is "Literature Review". This offers background information on soundscapes, prior indoor soundscape experiments, open-plan workplace acoustics research and soundscape evaluation approaches that include spatial parameter evaluation specifics, ISO/TS 12913-2:2018 Method A and soundwalk procedure; and perceptual data assessment. This also includes context information about the open-plan offices and general information virtual environments; previous studies about virtual soundscape and their assessment techniques.

Third chapter is "Method" which begins with providing details about the study layout and addresses the research questions and hypotheses of the thesis. Afterwards, it provides detailed information in real and virtual office environments by providing information about the site, participants, materials and acoustic environments. The real and virtual open-plan office environments, physical parameter measurement process, and selection of perceptual data are provided.

The fourth chapter is “Results”. It consists of three main sections as sound source identification, perceived affective quality of soundscapes, and assessment of surrounding sound environment and appropriateness. Objective results display the calculation of in-situ acoustic parameters as equal continuous a-weighted sound level (LAeq), subjective results indicate the questionnaire assessment.

Chapter five is "Discussion”. Within this chapter, it contrasts the effects of three acoustic environments with each other and with the previous studies. The findings are addressed in three open office settings, taking into account the variations in physical parameters and perceptual details.

Chapter six is "Conclusion". By this chapter, the thesis ends. It illatively sums up the whole research. This research also provides suggestions for future studies.

CHAPTER II

LITERATURE REVIEW

2.1 Soundscapes

The Soundscape is a term that was originally introduced in the late 1960's by Canadian composer Murray Schafer and soundscape research is growing in quantity and influence (Schafer, 1977). Schaffer categorized the typology of speech as keynote sounds, signals and sound marks into three separate areas. (Schaffer, 1977). Keynote sounds are accepted as background sounds that are defined as widespread and omnipresent sounds. Signals are known as foreground sounds which involve the acoustic alerts to encrypt such messages or information (Westerkamp et al. 2006). Finally, sound markings are the criteria for a particular location to make the acoustic environment unique (Schafer, 1977; Westerkamp et al. 2006; Ozcevik & Can, 2008). Schafer founded the World Soundscapes Project (WSP) in 1969, which is essential to maintain a harmony between the human culture and its sonic environment (Westerkamp et al. 2006; Kang et al.,2016). This project increased the understanding of sound, evaluation and documentation of the ambient sound and is known as the basis for soundscape studies (Westerkamp, 2006). To extend the term soundscape, ISO/TC 43/SC1/WG 54 working group for the "Perceptual Assessment of Soundscape Quality of the International Organization for Standardization" Identify soundscape as the "perception and interpretation of an acoustic environment, in context, by the person or by a community" (Brown et al., 2011).

Identifying and describing sound sources is gaining importance as it provides valuable information about that place's soundscape as the sound sources can be perceived differently from place to place (Acun,2015). To do so, the authors recommended that the acoustic system be taxonomized (Figure 1). Brown et al, (2011), contend that this acoustic taxonomy offers categories of sound sources in different acoustic environments (Figure 1). The acoustic taxonomy system consists of two large divisions known as indoor and outdoor. The outdoor acoustic environmental setting has four sub-categories such as urban, rural, wilderness and underwater (Yilmazer & Bora ,2017). For this framework, outdoor and indoor acoustic principles are similar. In this sense the recent consensus on the soundscape approach indicates that soundscape occurs by human experience (Acun & Yilmazer, 2018). Furthermore, the elements in the sensory system of a soundscape are often described by emphasizing interconnected features, such context, sound sources, acoustic environment, auditory sensation, interpretation, reactions and findings (ISO, 2014; Aburawis & Yorukoglu, 2018).

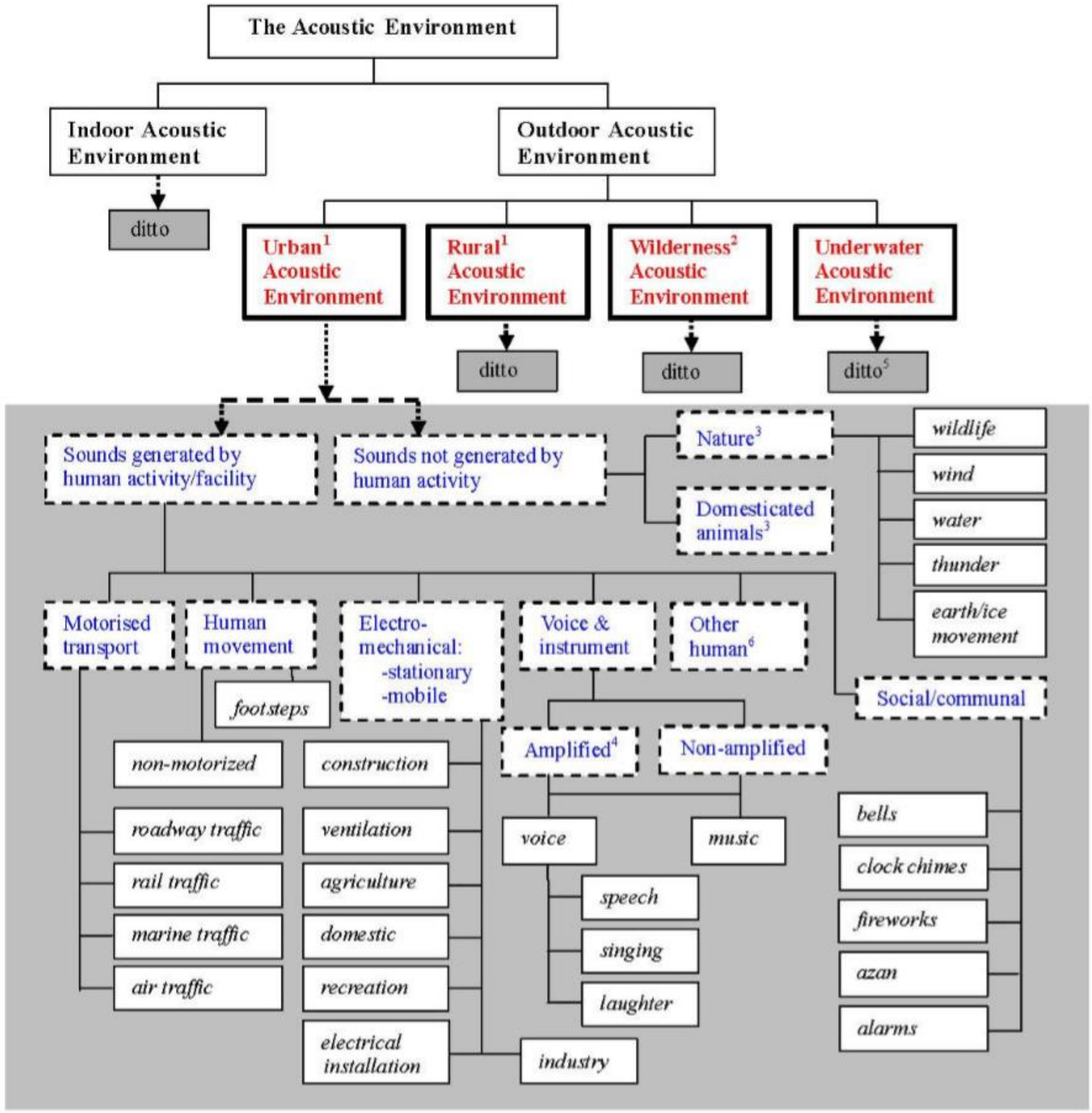


Figure 1. Taxonomy of sound sources (Brown et al., 2011)

The context is accepted as a key element for the soundscape framework. The acoustic environment has an initial role to modify soundscape which is composed of sound sources (absorption, reflection, etc.). In addition, the context influences the soundscape, the auditory sensation and interpretation and the reaction to the acoustic environment (Figure 2) (Acun& Yilmazer, 2018). It may be stated that the soundscape approach is related to the experience of sound and acoustic conditions by individuals and community, rather than the sound energy (Acun& Yilmazer, 2018; Brown et al., 2011; Kang, 2013).

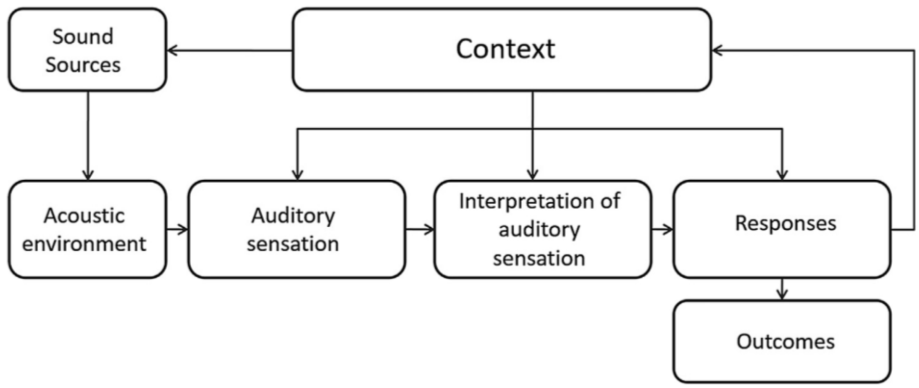


Figure 2. Soundscapes Framework created by ISO,2014 (Brown et al., 2011)

2.1.1 Previous Studies on Indoor Soundscapes

Indoor spaces consist of different materials, architectural geometries, and functions and each of these require different acoustical requirements and activities. In the context of analysing indoor soundscapes, several soundscape experiments have been set in various kinds of interior spaces and these studies took place in different research fields, such as psychology, health, physics, artificial intelligence, urban planning, and sociology (Chandrasekera et al., 2015). Our interest concentrates especially research on soundscape, in both simulated and actual spatial structures. Although most of the soundscape research has generally analyzed urban environment, some researchers have still directed attention to the indoor environments and indoor soundscape analysis covered a wide variety of indoor soundscapes, including hospitals

(Okcu et al., 2011, Mackrill et al., 2013), libraries (Dökmeci & Kang,2012 , Xiao & Aletta, 2016), transportation hubs (Yılmazer& Bora, 2017), open-offices (Acun and Yilmazer, 2018), education facilities (Acun&Yılmazer, 2018), care facilities, worship places (Yılmazer and Acun, 2018), museums (Acun, Yilmazer, and Orhan, 2018)

Okcu et al. (2011) conducted a soundscape study to analyze nurses' wellbeing and work performance related to physical parameters and perceptual data in two clinical healthcare settings. Two Intensive Care Units (ICU) of 20 beds with equivalent diagnosis and treatment model were chosen and named as neurological ICU (new model) and medical-surgical ICU (old model). Nurses were expected to fill out a questionnaire that examined noise annoyance, perceived loudness and performance at work. Although the measured sound levels in two different ICUs were very comparable, the perceived sound environment in the medical-surgical ICU was found more frustrating.

Consequently, the medical-surgical ICU had a detrimental effect on the work efficiency of nurses, health outcomes and level of anxiety. As a recommendation, the advice of experts to create a more comfortable living atmosphere for patients, such as eliminating impulsive noise sources, was realized using sound absorbent finishes and acoustic management techniques for mechanical sound sources such as HVAC systems (Okcu et al., 2011).

Another indoor soundscape research has been conducted in a hospital by Mackrill et al., (2013) to attain participants' subjective responses about hospital soundscape. Semi-structured interviews were performed by 27 people including nurses and patients. Grounded Theory was preferred to categorize subjective responses. Participants had both positive and negative emotions with respect to the soundscapes of the hospital environment. Amongst these emotions coping approaches such as approval and habitude were accepted as the negative soundscapes, the significance of both the physical and cognitive influences was related to the positive soundscapes' perception of people. The result was found that when the individuals accept and habituate the aspect of soundscape coping methods can be adapted to the hospital environment (Mackrill et al., 2013).

Dökmeci and Kang (2012), conducted an experiment that examine three libraries' indoor soundscapes in Sheffield by using objective and subjective analysis. They used acoustic measurements, recordings and social surveys for each library. They aimed to understand the effect of the acoustic and psychoacoustic parameters on soundscape perception by using objective responses (Dökmeci & Kang,2012). Relationships have been revealed between architectural/functional differences and the variances of objective measurements within the indoor sound environment (Dökmeci & Kang,2012).

Xiao and Aletta (2016) aimed to explore acoustic comfort that is based on the quality of the perceived sound environment in modern libraries. The study was performed by four groups of participants, and soundwalk methods took place in four different floors. The sound source identification, sounds pressure level and overall quality of the perceived sound environment was evaluated. The general consistency of each floor for the soundscapes was different irrespective of the amount of sound pressure level. The results showed that the open-plan layout is the determinant factor for the acoustic comfort of libraries (Xiao & Aletta, 2016)

In 2017, Yilmazer and Bora gathered an experiment about indoor soundscape to analyze the effects of the built environment on the pedestrians/passengers and the perception of the auditory environment in the metro station. Sound recordings were made at various places in adjacency of a metro station and a listening test was conducted to determine how spaces could only be identified by the associated sound (Yilmazer&Bora,2017). Consequently, half of the participants were able to specify the space function. Bird, wind and water sound marks were recognized in the urban park close to the metro station. For outdoors, participants were inclined to select adjectives such as pleasant, calming or natural, whereas for indoor spaces they select terms such as unpleasant, stressing, and artificial. On average females can recognize sounds 30 percent more correctly, and the correct identification rate of younger age groups is greater than that of older groups by an average of 10 percent (Yilmazer&Bora,2017).

To analyze the working environment, Acun and Yilmazer (2018) formed a conceptual framework to obtain data from individuals about soundscape perception in open offices. The researchers aimed to examine how participants could overcome unsatisfactory soundscapes by conducting a Grounded Theory survey to capture individuals' subjective responses (Acun & Yilmazer, 2018). For this aim, the study identified acoustical environment and sound sources. 45 employees from two types of offices were attended to the experiment and semi-structured interviews were conducted. Physical measurements were taken both in-situ and in accordance with Odeon Room Acoustics Program 13.10. The researchers underlined that observations of physical parameters alone would not be sufficient to describe the perception of soundscapes by the participants.

The findings revealed how the job was influenced by the sound atmosphere and the personalities of the workers. It was found during the interviews that workers were concerned with silence as well as with the noise (Acun &Yilmazer, 2018). In fact, there was a lack of consistency between sound sources, and this created a poor perception of soundscapes. The authors clarified that participants generated coping methods while they are facing possible office environment problems. They preferred to use headphones to be isolated from the noisy environment. In addition, researchers suggested designing sound masking systems as a solution for open-office environment acoustic problems (Acun &Yilmazer, 2018).

In addition, Gül, Sinal and Odabaş (2019) published a study aimed at delivering acoustic comfort standards by suggesting methodologies and acoustic solutions. The research was undertaken at the BASF Turkish office and researchers planned the office setting on the basis of international standards and LEED Green Building Criteria (Gül, Sinal & Odabaş, 2019).

They analyzed the open plan offices, meeting rooms, private booths and cafeteria for reverberation and HVAC originated background noise levels. In this sense, they developed the sound isolated building elements (Gül,Sinal

&Odabaş, 2019). As a result, they designed sound scatters and sound absorptive baffles. They also tested the effectiveness of these products during the design process (Gül,Sinal &Odabaş, 2019). With the advent of these products, they controlled the possible noise problems in the office environment.

In addition, Ma and Shu (2018) conducted another experiment to investigate the potential restorative effects of soundscape components in a virtual open-plan workplace. There were 75 participants in the assessment of three separate studies under different circumstances. Such conditions are various types of sound, sequences of sound and audio-visual conditions.

While experiment 1 examined the five types of sounds such as flowing water sound, birdsong, footsteps, traffic noise and air conditioner noise, experiment 2 examined the congruity and possibility of additional sound elements that were integrated into the open-plan offices (Ma& Shu, 2018). Finally, experiment 3 used both air-conditioner noise and flowing water sound to analyze them as negative and positive acoustic stimuli (Ma& Shu, 2018). As a result, good soundscape elements (bird songs and flowing water sound) were perceived as pleasant and they had positive restorative effects on people's psychological evaluation. In addition, continuous sound did not have more positive restorative effect than intermittent sound. The combined audio-video conditions had significantly different results between different stimuli (Ma& Shu, 2018).

Another indoor soundscape research conducted by Yilmazer and Acun (2018) analyzed the soundscape of a historical place which is the Haci Bayram Mosque of Ankara to demonstrate if there is a relationship between the soundscape elements, place identity and spatial function of the space. This study utilizes a user-focused grounded theory to record the auditory sensations of participants and interpretations of the indoor soundscape (Acun & Yilmazer, 2018).

The next previous soundscape study was carried out to investigate the sound sources, users' reactions, coping methods in an educational space (Acun & Yilmazer, 2018). This work focuses on the sound atmosphere of four open-plan study areas within the Bilkent University Campus. Generally, because of their potential to merge learning with social events, these spaces are known to be utilized by many students (Acun & Yilmazer, 2018). These four open study areas are located at the dormitories, the Fine Arts Building, the library, and the Faculty of Science Building. With 120 students, a questionnaire survey and in-situ analysis of sound rates (LAeq) were performed to evaluate the subjective responses of the participants to the sound environment. The findings revealed no distinction between the participants' satisfaction with the soundscape, regardless of the sound level (Acun & Yilmazer, 2018).

Acun, Yilmazer, and Orhan (2018) conducted an experiment to explore the subjective perception of the museum visitors' soundscapes describe the relations between the soundscapes and the role of historical features of the Rahmi Koç Museum in Ankara. ODEON Room Acoustics Software was the tool for analysing physical parameters of the museum environment. Perceptual data was gathered from 15 participants using semi-structured interviews based on the perceptual answers. With the Grounded Theory the conceptual structure was developed. The findings revealed that only the noisiest areas can be interpreted as natural due to the context of the soundscapes; so, people need to plan the sound atmosphere much as the physical environment (Acun&Yilmazer and Orhan, 2018).

2.1.2 ISO/TS 12913-2:2018 Data collection and minimum reporting requirements

Sound is regarded an essential element of any area, and perception of soundscape effects the overall experience of users. The International Organization for Standardization (ISO) with the ISO/FDIS 12913-1:2014, provides measurements of physical parameters and evaluation of perceptual data. ISO has released the second phase of the soundscape specification, ISO 12913-2:2018, which focuses on soundscape data collection and minimum reporting requirements. In soundscape studies, the minimum reporting requirements comprise of selecting and classifying participants. Participants should be identified whether they are residents of the site or they are only visitors and age distribution and having expertness are the other significant point to underline (ISO 12913-2:2018). Characterization of the acoustic environment and selecting the data collection method are other important points for designing a soundscape study (ISO 12913-2:2018). The selection of an acoustic environment is the first session for designing a soundscape study. According to ISO/TS 12913-2:2018, an acoustic environment can be real, recorded, or virtual. Additionally, sound sources, weather conditions, and acoustic measurement points have the determinative effect on the soundscape experiments (ISO 12913-2:2018).

2.1.2.1 Assessment of Perceptual Data

To explore and evaluate soundscape, researchers have suggested different methods such as soundwalk, binaural recordings, and psychoacoustic measurements. For more subjective evaluations of soundscapes questionnaires, interviews, and semantic differential scales on perceived sounds are conducted (Yilmazer and Bora, 2017).

In ISO 12913-2:2018, Annex C explains the soundwalk procedure requirements. Soundwalk procedure aims to evaluate the soundscape in a given area. There should be a moderator to conduct a narrative interview and lead the soundwalk session (ISO 12913-2:2018). During the soundwalk participants should listen to the acoustic environment regarding sound sources, the direction of their perceptions, and types of the materials in recent acoustic environment. All the instructions of the soundwalk procedure were mentioned in ISO 12913-2:2018, Annex C. The second part of the soundscape standard provides three alternative data collection methods (ISO 12913-2:2018). The first method (Method A) which is a quantitative method involves a questionnaire test, while the second method (Method B) still employs quantitative approaches with a emphasis on soundwalks. The third method (Method C) uses narrative interviews which are consisted of a complete list of standardized questions to obtain qualitative data from the experiments (Acun and Yilmazer, 2019).

Method A provides data by using a questionnaire that includes four parts (Figure 3). In the first part of the questionnaire (five points ordinary-category scale) ISO classifies the sound sources within the four categorizations such as traffic noises, other sounds, sounds from human beings, and natural sounds. The second part of the method examines the perceived affective quality of soundscapes with eight perceptual attributes (pleasant, chaotic, vibrant, uneventful, calm, annoying, eventful, monotonous). The third part analyses the assessment of the surrounding sound environment. Finally, the fourth part examines the assessment of the appropriateness of the surrounding sound environment (ISO 12913-2:2018).

Method B has consisted of the data collection methods which focuses on how people perceive an acoustic environment in situ (Figure 4). Instructions of soundwalk procedure are divided into three parts, the first one is for the moderator of the study, the second one is for binaural measurement process and the final one is for the participants' of the experiment (ISO 12913-2:2018). Method B has three parts to examine the soundscape of the environment. The first part is the assessment of the sound environment and includes four questions to analyze loudness, pleasantness, appropriateness, and personal impressions of participants. While the second part includes sound source recognition and ranking, the third part consists of subsequent comments of the soundwalk participants' (ISO 12913-2:2018).

Method C is comprised of the interview guideline which refers to satisfaction with the living space, experiences, and spatial identification of sound effect (ISO 12913-2:2018). Annex D specifies how to perform binaural acoustical measurements by using an artificial head. This section clarifies the position of the binaural measurements, selection of the measurement time interval, equalization of measurement and recording requirements (ISO 12913-2:2018).

This thesis will focus on the soundwalk method which is the most used methods for indoor and outdoor soundscape studies and this thesis considers in-situ measurements of Equivalent Continuous A-weighted Sound Level (L_{Aeq}); questionnaire (Method A) in the scope of the perceptual data.

2.1.3 ISO/TS 12913-3 2019: Data analysis of soundscapes

With this recent document, ISO aims to provide guidance on requirements and to provide information on the study of in-situ data obtained by methods as defined in ISO / TS 12913-2:2018. The analysis of qualitative and quantitative data through methods specified in ISO/TS 12913-2, and to get information about which tools are appropriate for which methods, this document should be applied. According to ISO/TS 12913-3:2019, the quantitative data obtained by means of questionnaires in soundscape investigations shall be analyzed depending on the respective level of measurement (nominal, ordinal, interval, and ratio). In addition, any correlation analysis is the suggested tool to analyze the questionnaire data. Inferential statistical tests regarding the level of significance of differences in evaluation between sites and/or correlations shall be carried out and probability values reported (ISO/TS 12913-3:2019). Moreover, the statistical hypothesis testing method shall be reported for Method A that this thesis preferred to conduct. The rating data collected via Method A questionnaires should be linked to the results of the acoustic data analyses in order to identify potential relationships. These relationships may be investigated by means of statistical analyses, linear regression, or ANOVA (ISO/TS 12913-3:2019).

In addition, ISO (2019) suggested to use a two-dimensional model to analyze these eight affective responses (Figure 3). The main dimension is related to how pleasant or unpleasant the environment to evaluate pleasantness. The second dimension is related to the amount of human and other activities. For soundscape, this second dimension is represented by how eventful or uneventful the acoustic environment is perceived to evaluate eventfulness. According to the two-dimensional model, vibrant soundscapes are accepted both pleasant and eventful, chaotic soundscapes are both eventful and unpleasant, monotonous soundscape is accepted both unpleasant and uneventful, and finally, calm soundscapes are accepted both uneventful and pleasant (ISO/TS 12913-3:2019).

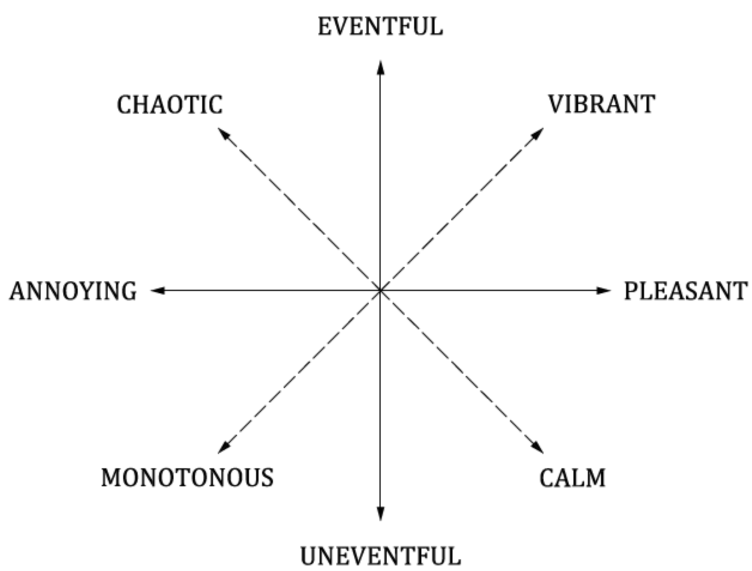


Figure 3: The generality of the two-dimensional model (ISO/TS 12913-3:2019)

In this sense, this thesis analyses the obtained data with suggested statistical tools from the recent data analysis standardization document (ISO/TS 12913-3:2019).

2.2 Acoustics of Open-plan Office Environment

Open-plan offices are among the most common and popular layouts of office in the past decade. Most of the offices prefer to work on open-plan offices where number of staff can work, interact and communicate with each other through the higher worker density and increased working area (Kaarlela et al. 2009; Kim and de Dear, 2013). However, most of the researches claim that open-plan office layout cause a variety of social and physical environmental problems, such as noise distraction and privacy (Yadav et al. 2017). These problems are not only related with increased noise complaints but also various negative consequences occur such as noise-related discomfort, reduced environmental performance and work motivation, decreased attention and work efficiency (Haapakangas et al., 2008; Pejtersen et al., 2006; Banbury & Berry, 2005; Kaarlela et al. 2009). Open-plan workplaces were also linked to increased concerns about absence of psychological stress and decreased job satisfaction (Pejtersen et al., 2011; Kim and de Dear, 2013).

As mentioned before noise is the most detrimental acoustical problem of the indoor environment in open-plan offices (Virjonen et al., 2009). Among various types of noise unattended speech is the most distracting source (Haapakangas et al., 2014). Distraction and speech privacy can be objectively identified by calculating the understandability of speech between workspaces. Intelligible oral communication affects both the speaker and the listener (active or passive), as it has the potential to disturb a hearer who may want to focus on a task and cause anxiety regarding the lack of speech privacy (Yadav et al., 2017). Speech privacy and speech transmission index (STI) are the significant issues and parameters in the open-plan office and its acoustic parameters (Kang S, & Ou, D, 2019). Additionally, the STI is an objective descriptor for subjective speech intelligibility (STI 0.00 = not intelligible, STI 1.00 = perfectly intelligible) (Haapakangas et al., 2014; Hongisto, 2005).

Hongisto et al. (2005) conducted a laboratory experiments that predict the loss of work performance as a function of the STI to suggest the relationship between STI and office performance in Western countries. According to Hongisto's model, occupants' work performance decreases when the value of STI increases in the range of 0.20 and 0.50, while beyond this range the STI value has little effect (Kang & Ou, 2019). The key acoustic parameters used in the open-plan office standards (ISO 3382-3) are also developed based on this relationship (Kang & Ou, 2019). The STI of speech also relies in reality on the current sound level, the height of the panels, acoustic material absorption, furniture, width between a speaker and a listener (Haapakangas et al., 2014). Secondly, the quality of open office background intelligibility of background speech is an initial factor (Hongisto, 2005; Kitapcı, 2008; Haapakangas et al., 201). Unattended background speech has significant effects on well-known cognitive functions, such as short-term memory arithmetics, reading ability, proofreading and efficiency in writing (Haapakangas et al., 2014). The background noise levels in the open-plan offices should be sufficiently high to ensure good speech privacy by disrupting social interaction (Egan, 1988). High ambient noise levels will therefore improve speech privacy; too much noise does not contribute to maximum acoustic comfort (Kitapcı, 2008; Kitapçı, Yilmazer, and Erkip, 2007). Background noise should be regulated and made homogeneous and should not exceed a average of 55 dB in order to eliminate harmful effects on the occupants (Kitapcı, 2008; Kitapçı, Yilmazer and Erkip, 2007). If there is a requirement of additional background noise electronic sound masking system can be designed in an open office environment. Many scholars have documented the impact of complex masking methods on speech intelligibility. Even though many researchers study the psychoacoustic effects of speech masking, only a few static masking methods are implemented in office work environments (Krasnov et al., 2018). Among these masking techniques, white noise (WN) is the most widely utilized. Although most of the researches claim that WN is an effective masker it causes substantially frustration at the loudness rate enough to effectively mask speech (Krasnov et al., 2018). Another way of masking is using the sounds of nature, including rushing water, ocean waves, and rain though these sounds are inefficient to cover the conversations in the office environment (Krasnov et al., 2018).

A strong emphasis is put on the determination of human auditory experience in the soundscape design process (Hong et al., 2019). Auditory perception has been described as affecting how we act and navigate around places and how public spaces are used (Calleri, 2018). According to ISO/TS 12913-2:2018, soundscapes can be assessed in situ, recorded or virtually reproduced, or synthesized. This thesis focuses on the comparison of real and virtual open offices in terms of soundscape assessment. In this sense, this study analyzed the types of open-plan offices regarding the previously mentioned open-plan office acoustical problems.

2.3 Virtual environment soundscapes

Nowadays, with the advent of virtual reality (VR) technology virtual soundscape studies have been increased through VR technology having the potential of creating a more accurate audio-visual scene. VR technology allows designers to reconstruct virtual objects and spaces through their digital representation (Biocca, 1992). These recent approaches help designers and researchers to make educated decisions by investigating the positive and negative effects of sound on users' perception (Ruotolo et al.,2013).

Virtual Reality (VR) is a systematic approach that provides the user's immersion and presence in computer-generated virtual environments (Vorländer, 2008). Since the 1990s, VR has been widely used for environmental preference studies. Jiang et al., (2018) defines virtual reality (VR) is a 3D user-computer interface that creates an actual or modelled world and simulates the user's existence in this world using multiple sensor channels in real time. OoI et al., (2017) claims that virtual reality (VR) has been extensively examined and authenticated as a method of reproducing visual and auditory environments for subjective testing under laboratory conditions. The main benefit of VR technology is that it is capable of simulating different situations within a limited laboratory setting (Jeon & Jo, 2019).

Furthermore, virtual scenes are visually oriented experiences that are presented on a desktop or via a special head-mounted display (HMD) comprised of two display screens (Shahrbanian et al., 2012). Immersive VR provides users with a sense of presence which is the feeling of being in a VR environment as it was a real environment (Adi & Roberts, 2014). The head tracking system makes possible this sense of presence by tracking the user’s head movements (head-related transfer functions, HRTF). The non-immersive VR environment makes 2D interface devices such as keyboards and mice that are less interactive with less interaction (Shahrbanian et al., 2012).

VR simulations used during soundscape assessment, to ensure high ecological validity of the findings obtained. The combination of VR technology and audio rendering techniques enables researchers to conduct virtual soundscape studies and to evaluate several acoustical environments. To obtain high ecological validity of soundscape study conducted in the virtual acoustic environment, recording and reproducing techniques have a significant role (Hong et al., 2019). For this reason soundscape is described as human perception of the recreated acoustic environment and this interpretation is linked to the perceptual consistency of the recording and reproduction techniques (Hong et al., 2019).

2.3.1 Virtual environment soundscapes assessment

Binaural and ambisonics are basically two recording technologies used in soundscape studies. An extended form of stereo recording is binaural recording. Presumably, binaural recording encapsulates only the sound received at left and right ear positions in the same way as human hearing (Figure 4-5). Consequently, binaural audio is the medium that is similar to human ears as it is played by tuned headphones (Hong et al., 2017). Binaural recording consists of a calibrated artificial head and they are recorded with head-related transfer functions (HRTF) which requires a static position to record the environmental sound (Hong et al., 2019). That kind of audio technology can be further categorized into simulated sound field technology to increase the sense of presence and sound image externalization technology in headset reproduction conditions to transfer the sound picture beyond the ear. (Jeon & Jo, 2019).

Figure 4. Artificial head (from left to right): KEMAR, Brüel & Kjaer 4128HATS, Head Acoustics HMS III,and Neumann KU-100, (Hong et al., 2017)

Figure 5. Binaural microphones from 3Dio (Hong et al., 2017)

Most of the soundscape studies prefer to use binaural recording devices to obtain perfect timbre quality, realism, and immersiveness. ISO, 2018 suggests using headphone for the playback of the binaural sound recordings

The suggested recording technique for interactive and spatial studies based on audio reproduction is in other respects ambisonics, that require a sound field in full-sphere surrounding (Figure 6). The ambisonic format can be replicated via headphones or multichannel speaker systems with the versatility of translating to specific audio formats (Hong et al., 2019).

Figure 6. Ambisonics microphones (from left to right) Sennheiser AMBEO, Core Sound TetraMic, and SoundField SPS200 (Hong et al., 2017)

The significant issue is selecting the most appropriate method among the mentioned recording methods for soundscape applications (Hong et al., 2017). The researcher should consider firstly the existing soundscape environment and secondly designing better soundscape recordings. Finally, all audio recordings should verify the design soundscape after its implementation (Hong et al., 2017). The most important requirement for soundscape recording in all of these stages is that it must adequately represent the characteristics of the acoustic environment and all perceptual accuracy, it depends on the aim of the study (Hong et al., 2017).

Hong et al., (2017) explained the soundscape design process into three stages (Figure 7). Stage 1 aims to define and analyze existing soundscapes. Stage 2 proposes soundscape planning and design scenarios depend on an analysis of the current soundscapes. In stage 3, the final soundscape design will be implemented in situ.

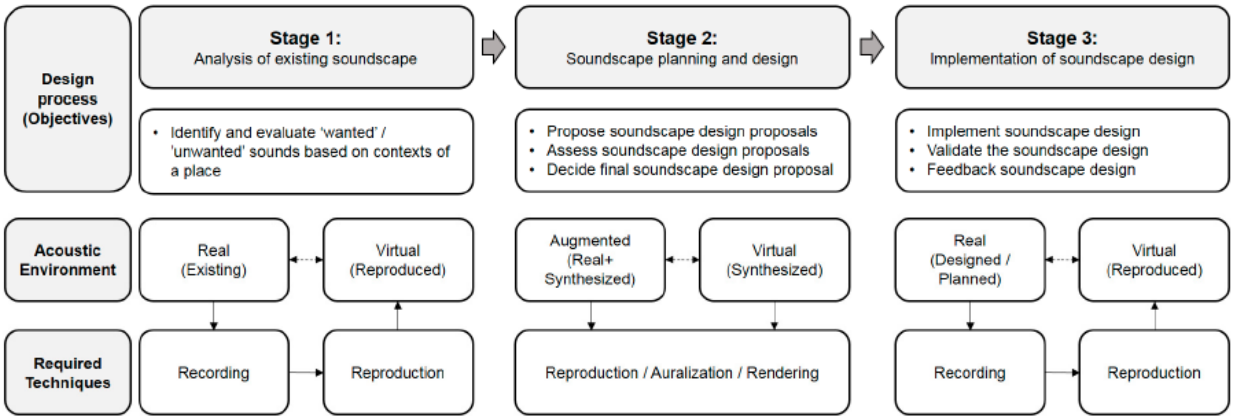


Figure 7: Schematic illustration of soundscape design process, types of acoustic environment and required techniques (Hong et al., 2017).

For this thesis, we select statically recorded binaural audio recording and non-immersive VR technique that requires 2D interaction devices to compare real ,recorded and virtual open office environments.

2.3.2 Previous studies on virtual environment soundscapes

According to ISO/TS 12913-2:2018, an acoustic environment can be real, recorded, or virtual. In light of this information, there are various soundscape studies conducted in real, recorded virtual and virtual acoustic environments. Many experiments have been carried out on how sound is used in real and virtual settings for determining soundscape. From an architectural and urban design context, Chandrasekera et al., (2015) explores the role of architectural soundscapes in virtual environments. In this way, they examined the idea of soundscapes as landmarks to guide the wayfinding method in virtual environments and to investigate the connection between sense of immersion in virtual environments and spatial visualization. In the experiment, the participants were divided into three groups: first group with soundscape and visual landmarks, the second group with only visual landmarks, and the third group with only soundscape landmarks. After exploring through the environment, the subjects filled out a questionnaire that analyzed the level of immersion they observed. As a result, the present study claims that auditory immersion may be more important than visual immersion. The findings illustrate the significance of spatial abilities regarding immersiveness (Chandrasekera et al., 2015).

In another study, Chung and his colleagues claimed that sound quality is a subjective issue and depends on human perceptions in different contexts (Chung et al., 2016). In this experiment, a virtual soundwalk application software was developed to auralize different sounds and link them to a 3D virtual, photorealistic environment. This app provided users the ability to immerse themselves in this virtual space to experience different changes (Chung et al., 2016).

Moreover, Maffei et al., (2016) built a test to investigate if the acoustic and visual effects of a virtual environment in immersive virtual reality (IVR) is reasonably compatible with their associated elements in a real sense.

After experimenting in real and laboratory settings, two groups of participants were requested to fill out questionnaires on international qualitative assessments, coherence and familiarity with acoustic and visual impulses. (Maffei et al., 2016). The results showed that IVR systems are smart and innovative methods for developing interactive planning and forecasting the effect on the society (Maffei et al., 2016).

Chung and his coworkers have experimented with 'soundcape design application software that allows the user to try out different sound environments prior to the design is being finalized' (Chung et al., 2017). This paper analyzed some of the noise issues caused by concerts at the Hong Kong Stadium and Cantonese operas at other public spaces. The research suggested that VR technology would be used to determine how the possible soundscape and noisescape at various times of a music occurrence would be used by audiences during the public participation process. (Chung et al., 2017).

In 2017, Puyana et al. conducted an experiment that aimed to explain the improvement and testing of an online participatory tool that uses interactive maps and Immersive Virtual Reality (IVR) for the multisensory evaluation or urban soundscapes. The method will measure and track the spatial improvements in the ambient noise measurements of many city sites for future planning processes (Puyana et al., 2017). This tool also provides a higher number of participants the opportunity to compare the noise with laboratory experiments (Puyana et al., 2017). In this sense, researchers created a web platform that allows having a VR experience with three hardware reproduction systems of virtual scenarios: Oculus Rift DK2 (IVR), mobile-based head-mounted display (IVR), and a laptop or desktop (DVR). For the playback of spatial audio recordings, the Ambisonic technique is used on-site. The statistical analysis showed that there is no statistically significant differences between the outcomes of the three modalities of multisensorial experience (Puyana et al., 2017).

Additionally, Hong and his colleagues have conducted an experiment about the assessment of three spatial audio reproduction methods in VR (Hong et al., 2019). The aim of this analysis was to examine whether there is a discrepancy in perceived soundcape quality between the three FOA replication methods. (Hong et al., 2019). To compare these soundscape reproduction methods, soundscape evaluations were conducted both in situ and in a virtual environment under laboratory conditions (Hong et al., 2019). As shown by statistical analysis there was no substantial gap between in situ and all VR approaches in determining the sound-source superiority and overall soundscape quality (Hong et al., 2019). However, significant differences were found in the perceived spatial qualities between three reproduction methods and in-situ (Hong et al., 2019).

Ahrens, Marschall, and Dau (2019) developed a simulated sound system experiment focused on the loudspeaker that offers a powerful resource for testing speech perception. This research aimed to correlate speech intelligibility to virtual models of the room as calculated in a reverberant reference area.

For room acoustic simulations, two reproduction methods have been selected, they are presented either using mixed-order ambisonics or the nearest playback mapping of loudspeakers. The third test used impulse reactions measured with a spherical microphone system and ambisonic mixed-order (Ahrens, Marschall & Dau, 2019). Three factors influencing speech intelligibility were reverberation, spatial structure and the form of disturbance. The findings revealed that the variations between the reference room and the simulation-based and the microphone array were more close to reference room in terms of calculated speech intelligibility (Ahrens, Marschall & Dau, 2019).

One more previous research focuses on the measurement of the impact of soundscape and lightscape changes on perceived safety and perceived social interaction in a pedestrian area by laboratory studies. Thirty-one participants engaged in the experiment with nine separate virtual scenarios, in which the same underpass was repeated under various sound and light-scape conditions. (Calleri et al., 2019). Participants were required to evaluate each situation by evaluating 10 items associated with perceived safety and social presence. The findings found that the soundscape had a large effect on perceived safety and perceived social presence (Calleri et al., 2019).

Rychtáriková et al. (2014) conducted an experiment that aimed to predict statistical noise levels on an urban public square. Additionally they conducted a second experiment in virtual laboratory settings that was based on binaural sound recordings from in situ environment to assess the disturbance perceived by people of the traffic noise. Scientists have developed auralization approaches using two algorithms based on two conditions (Rychtáriková et al., 2014). Site recordings were compared with auralized soundscapes and the results showed that there are significant differences in perceived traffic noise depending on the location of the participants (in-situ or virtual environment) (Rychtáriková et al., 2014).

The required office conditions are changing rapidly because of the global health problems and their economical concequences. As mentioned before, various studies have examined the soundscape assessments in different acoustic environments. While some of the studies are evaluating indoor soundscapes, some of them analyzing outdoor soundscapes. However, there is not any previous study about soundscape quality assessment in virtual open-plan office.To provide similar work satisfaction, well being and productivity in virtual open office environments, virtual acoustic environments should be analyzed by considering the soundscape. In this regard, to contribute a new approach for the real and virtual soundscape evaluation, this study aims to examine virtual open-plan offices regarding the soundscape quality assessment by analyzing the effect of sound source identification, perceived affective quality, assessment of surrounding sound environment and appropriateness on participants' subjective responses.

CHAPTER III

EXPERIMENTAL STUDY

3.1 Design of the Study

This research suggests a soundwalk experiment to test the soundscapes indoors and it investigates the occupants' auditory perception in terms of acoustical conditions of the office environment in an architectural office firm which is Demay Architecture in Ankara. The research aims to equate auditory perception in an open office environment that is real and virtual. Recently, the International Organization for Standardization (ISO) published technical guidelines on the minimum reporting standards in soundscape studies and data collection methods (ISO / TS 12913-2:2018). The paper includes an insightful appendix with three alternate approaches: two are based on soundwalks and questionnaires, while the third applies to the narrative interview (ISO/TS 12913-2:2018).

The research is conducted in a medium-scale open-plan office as a real open-plan office environment. Demay Architects' open-plan office was selected because it has sufficient number of workers to obtain required office sounds for the experiments and audio recording. In addition, Demay Architects has appropriate architectural features for this study. As a ceiling type, there is flat slab ceiling. There are various types of sound sources (elevator, air-conditioning etc.) to examine their perceived effect on participants' perception. Besides architectural features, the location (city centered and both residential and commercial) of the open-plan office is very suitable for this experiment.

Moreover, for recorded and virtual office environments design, video recordings with binaural audio technique, and for simulated virtual office environment 3D modelled animation video are used. Thereby, there are three groups of participants to examine these three environments.

3.1.1 Research Questions

This research is conducted in compliance with these standardizations to compare real and virtual environments by carrying out Method A which is based on soundwalk and questionnaires. This study examines the role of soundscapes assessment in virtual and real environments from an architectural design perspective and seeks to answer the following questions:

1) Does the soundscape quality can be measured in virtual open-plan office environments?
2) Does the sound source identification differ within the RE, VE_Rec, and VE soundscape assessment?
3) What is the direction of perceived affective quality assessment (positive or negative) in terms of eight perceptual attributes in RE, VE_Rec, and VE?
4) Is there any difference between RE, VE_Rec, and VE regarding the assessment of the surrounding sound environment and appropriateness?

Hypothesis

HP: Overall soundscape quality shall be described more appropriately in real an office environment than virtual recorded and virtual office environments.

3.2 Method

3.2.1 Participants

All the participants were selected from the Bilkent University Campus and our immediate surroundings who want to attend the experiment and all the participants are voluntary visitors of the office. In total, 90 participants (25 males and 65 females) were selected for the scientific research. Among 90 participants 12 of them had architectural acoustical expertise (Table 1). The 90 participants were divided into three groups with 30 people in any group to experience RE, VE_Rec, and VE. The age distribution of the participants ranged from 20 to 40 yrs (µage = 28,4, σ*age* = 5.7). The first group (23 females and 7 males) evaluate the real (in situ) environment about indoor soundscape (µage = 28.5, σ*age* = 5.98). Group 2 (21 females and 9 males) evaluate VE_Rec by watching the video and listening to the office sounds recorded from RE (µage = 28.6, σ*age* = 5.0). Group 3 (21 females and 9 males) evaluate the modeled/reproduced virtual environment (µage = 28.1, σ*age* = 6.2). ISO/TS 12913-2:2018 recommends to minimize the number of participant groups during in-situ soundscape evaluations to avoid the large groups' potential detrimental effects on soundscape evaluation and acoustic recording (Hong et al., 2019). Therefore, the 30 participants were divided into 6 groups with, at most 5 people in any group during the in-situ experiment. Before the experiment, an Online Hearing Test (Widex Online Test) was conducted for all the participants and all of them had the normal hearing ability.

Table 1: Demographic charecteristics of all participants

Demographics		**Frequency(n)**	**Percentage(%)**
Gender	Male	25	27,8
	Female	65	72,2
Age Range	20- 24	28	31,1
	25- 29	31	34,4
	30- 34	14	15,6
	35- 40	17	18,9
	Total	90	100
Expertness	Expert	12	13,3
	Non-expert	78	86,7

3.2.2 Materials

The ISO / TS 12913-2:2018 Method A questionnaire used in soundscape analysis aligns with the study objectives. ISO/TS 12913-2:2018 offers Method B for soundwalk experiment however, Aletta states that these 'two technical specification approaches culminated in identical soundscape evaluation findings with a statistically relevant correlation point' (Aletta et al.,2019). The first part of the questionnaire (sound source identification) provided data for the first research questions which examine the difference of sound source identification between three different acoustical environments. The second part of the questionnaire focused on the perceived affective quality of the soundscape. With the second research question, this study aimed to examine the eight perceptual attributes of the participants to compare directions (positive and negative) of the soundscapes in three environments. Finally, the third and fourth parts of the questionnaire based on the overall assessment and appropriateness of the surrounding sound environment. This part provides an examination for this study to compare the overall assessment and appropriateness within three environments.

3.2.3 Questionnaire

At the first part of the questionnaire, the identification of perceived overall dominant sound sources was assessed by “Method A” of ISO/TS 12913-2:2018 As sound sources play a significant role in soundscape evaluation, planning and application, the superiority of a pre-determined set of sound sources at each location was measured on a 5-point scale (1: do not hear at all; 2: hear a little; 3: hear moderately; 4: hear a lot; 5: dominates completely) (Hong et al., 2019). The types of sound sources were classified into four categories such as technological sounds, other sounds, sounds from human beings, and natural sounds (ISO/TS 12913-2:2018).

The perceived affective quality model in Method A was seen to have the most detailed soundscape knowledge for assessing soundscape based on the rating of eight (Pleasant-annoying, chaotic-calm, eventful-uneventful, vibrant-monotonous) personal attributes at the second part of the questionnaire. The perceived affective quality model uses two orthogonal descriptors in the shape of the following four grouped adjectives (Hong et al., 2019). The second part consists of a question (to what extent do you agree or disagree that the present surround sound environment) and additional instructions in a five-point ordinary scale (5: strongly agree; 4: agree; 3: neither agree/disagree 2: disagree; 1: strongly disagree (ISO/TS 12913-2:2018).

To explore the overall surrounding soundscape environment, the third and fourth parts of the questionnaire were used. While third part explains the assessment of surrounding sound environment and represents a five-point ordinary scale (5: very good; 4: good; 3: neither good/nor bad 2: bad; 1: very bad) the fourth part examines the assessment of appropriateness represented by five-point ordinary scale (1: not at all; 2: slightly; 3: moderately 4: very; 5: perfectly)' (ISO/TS 12913-2:2018).

3.2.4 Soundwalk

As a qualitative approach, soundwalk, and questionnaire (Method A) survey were conducted in RE. According to ISO/TS 12913-2:2018, soundwalk is a participatory sound team which navigates around the area. During the soundwalk procedure, there should be characterizations of some acoustical requirements such as weather conditions, time of the year and time of the day, sound source combinations of the environment, and acoustical measurement points (ISO/TS 12913-2:2018). In this study, a specific walking route was designed by considering the sound sources of the office. In light of these considerations, there were 10 locations to walk and listen to real office sounds. These locations were determined in parallel with the location of office sound sources (Figure 9-10). They were located from the entrance of the office to the last working area. Five participants for each group walked and listened to the office sounds for two minutes for each location and answer the questionnaires prepared for each location (Figure). All the soundwalk experiments and response time took almost 40 minutes. For the in-situ experiment, questionnaires have been collected in the same location across multiple days to obtain 30 questionnaires for each location from 30 participants to fix the changing of environmental conditions. The influence of temperature, wind, and brightness actively affect the soundscape (ISO/TS 12913-2:2018).

3.2.5 Site

The study will be carried out in an architectural office firm which is Demay Architects in Ankara. It is located in NEP Office building in Söğütözü. This locality is known as both residential and commercial part of the Ankara. The company has more than thirty employees, but some workers work out of the office. The office has 180m² area and ceiling height is 2.80 m (Figure 8-9).

Figure 8: Floor plan of the Demay Architects' Office and 10 Locations are displayed with red signs on the plan (not to scale)

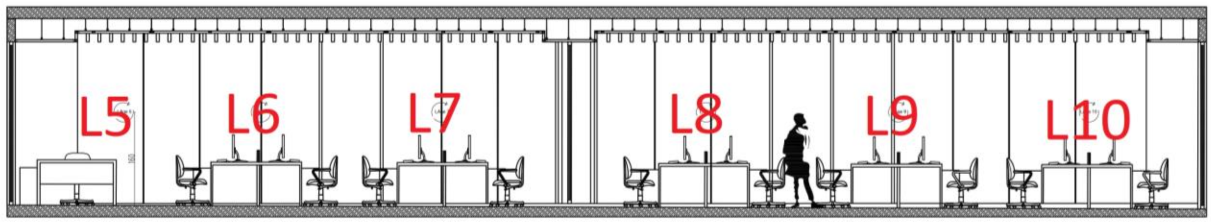
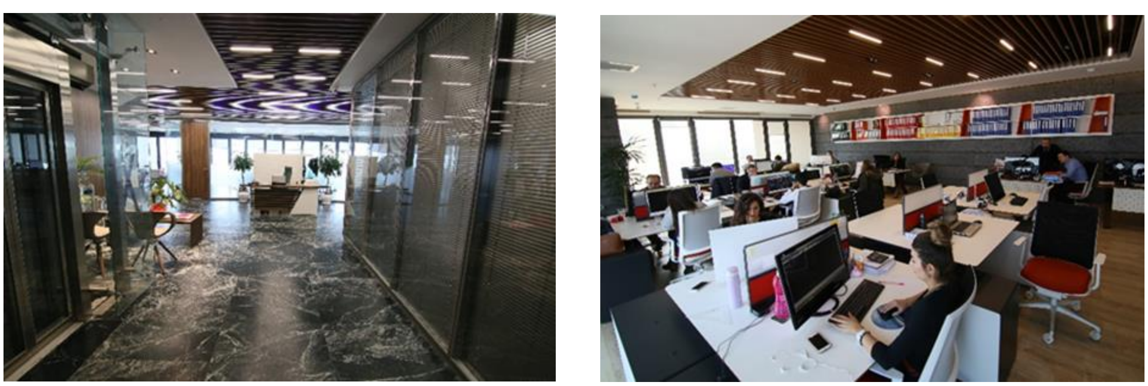


Figure 9: Section of the Demay Architects' Office 10 Locations are displayed with red signs on the plan and (not to scale)

For wall covering material, natural stone is preferred for most of the office walls. Only meeting rooms have glass walls. Open-office parts' ceiling is covered with wooden like linear ceiling panels with acoustical properties and for other parts of the ceiling, plaster panels are preferred. Floor materials are marble and laminated parquets (Figure 10).



(a) (b)

Figure 10: Interior views of the (a) entrance of the office and (b) working area

3.2.6 Experimental Design

To equate and verify the three distinct acoustic settings, soundscape measurements were performed under laboratory conditions, both in a real environment (RE) and in a virtual recording environment (VE Rec) and virtual reality (VE). A between-groups design was conducted with repeated measures. The independent variables were three different types of acoustic environments (RE, VE_Rec, and VE) including the real/in-situ environment, the audio-video recording, and reproduction methods. The different groups of participants get involved in both the physical in situ soundscape evaluation and the corresponding recorded and virtualized versions in the laboratory to avoid memorization of the acoustic environments during the comparison.

3.2.7 Sound Stimuli

3.2.7.1 RE: Audio-video Recording

The main focus is placed throughout the soundscape design process on the assessment of human auditory perception over a physical acoustic environment. An in-situ soundscape analysis should be carried out as an on-site survey, interview or soundwalk, maintaining strong ecological validity as it represents the real-world scenario. Hong et al. reported that recording and reproducing technologies have a major role to play in obtaining strong ecological validity of the soundscape research performed in the virtual acoustic environment. Thus, soundscape is described as the human perception of the reproduced acoustic environment and this perception is linked to the perceptual accuracy of the recording and reproduction technologies (Hong et al., 2019). According to ISO/TS 12913-2:2018, there are two recording techniques, binaural and ambisonics. A virtual acoustic environment can be comprised of recorded sound sources or synthesized sources that would be mixed into an acoustic environment. Calibrated biaural measurement systems (artificial head) shall be used to record an acoustic environment (Hong et al., 2019). Binaural recording technique with a calibrated artificial head is the most popular selection for soundscape studies. Ambisonics, the process of capturing and reproducing a sound field in a full-sphere setting, is the leading recording technique for immersive spatial audio reproduction (ISO/TS 12913-2:2018). International standardization supports the binaural recording technique since calibrated condenser microphones provide excellent timbre quality to attain realism and immersiveness (ISO/TS 12913-2:2018). These binaural tracks should be recorded and rendered in a static position (Hong et al., 2019). In this study, the binaural audio technique (artificial head) is selected to reflect the spatial audio effect. Canon 100D DSLR camera and an additional binaural microphone provide Full-HD (1080p) quality video recording for designing both audio-visual office environment.

3.2.7.1 VE_Rec: Reproduction

For the second part of the experiment, the previously recorded audio-video recording from RE was designed with reproduction techniques to examine VE_rec soundscapes. During the recording process, all 10 soundwalk locations and measurement points were captured for the VE_rec soundscape evaluations. To achieve this, the soundwalk moderator behaved and moved similarly to the participants. Additionally, video recording was edited by Adobe Premier Pro 2016. The volume level of the recorded audio was adjusted on 0.00 dB that can be defined as a medium level in Adobe Premier Pro 2016. All the locations, soundwalk routes were indicated on the video by editing. Participants listened to the audio from JBL T500BT headphones to feel the 3D effect and watching on MSI laptop with Nvidia Geforce GTX 1650 video card.

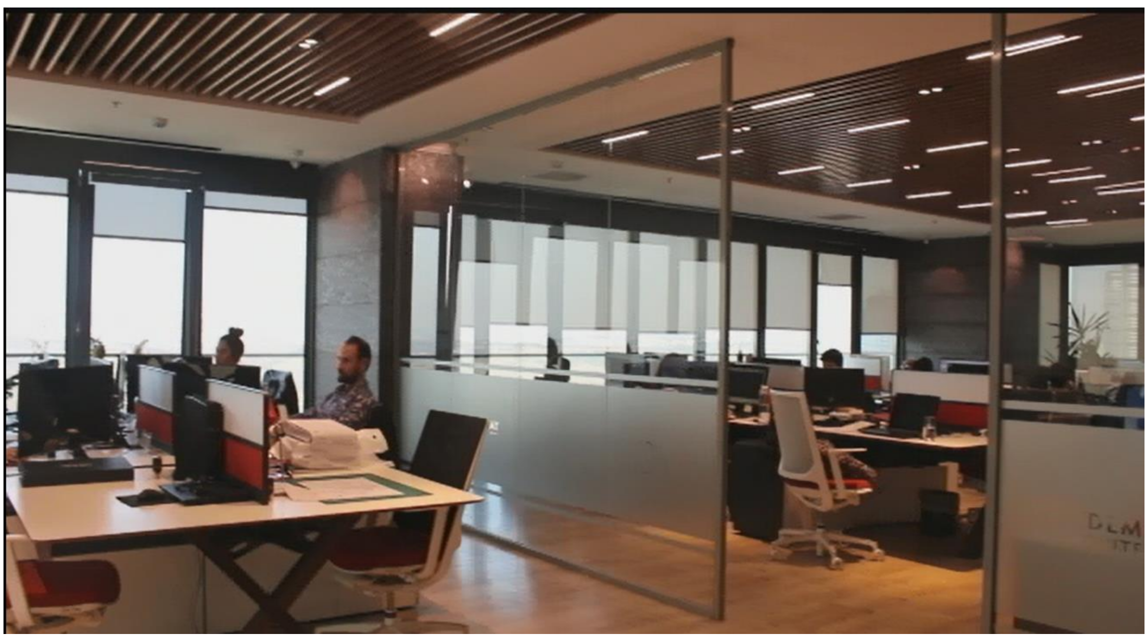


Figure 11: A view from the binaurally recorded video for VE_Rec

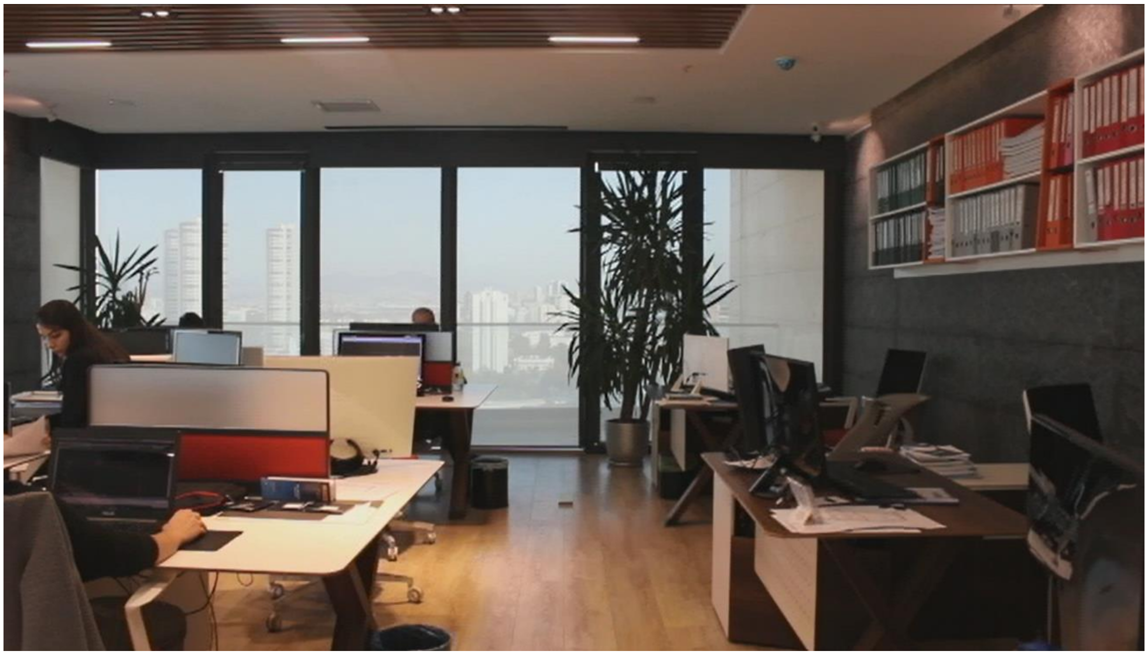


Figure 12: A view from the binaurally recorded video for VE_Rec

3.2.7.1 VE: Modeling &Reproduction

For the final part of the experiment, a 3D modeled animation video was designed with the same audio recording that was recorded binaurally from RE. The office was modeled with Sketchup Pro 2016 software and animated with Lumion Pro 2016 software (Figure 15-16). The recorded audio (0.00 dB) was post-processed into the animation video and edited with Adobe Premiere Pro 2016 software the same as the video recording. There are 10 locations and the same walking route in the animation video to experience a virtual soundwalk. Participants of VE used the same types of equipment with the VE_Rec for to provide the same conditions for all acoustic environments.

Figure 13: A view from the 3D modelled, animated and audio reproduced video for VE

Figure 14: A view from the 3D modelled, animated and audio reproduced video for VE

3.2.8 Procedure

As the first session of the experiment, the first group of participants evaluated RE walked in silence throughout a predefined route, observing the soundscape and the office environment. Throughout the RE experiment, LAeq levels were measured for all 10 locations. They were measured during the occupied hours with Bruel & Kjaer 2230 Sound Level Meter which was placed at the height of 160 cm and kept a minimum one meter away from the reflected surfaces. (Location LAeq levels 1-10 : 53.9 dB; 52.5 dB; 52.3 dB; 51.6 dB; 51.8 dB; 51.7 dB; 51.5 dB; 51.4 dB; 51.0 dB; 50.7 dB).

The second group experienced VE_rec by watching a recorded video from RE as a virtual soundwalk (Figure 11-12). The study was carried out in the Bilkent University department of interior architecture and environmental designs' VR laboratory (Figure 15-16).

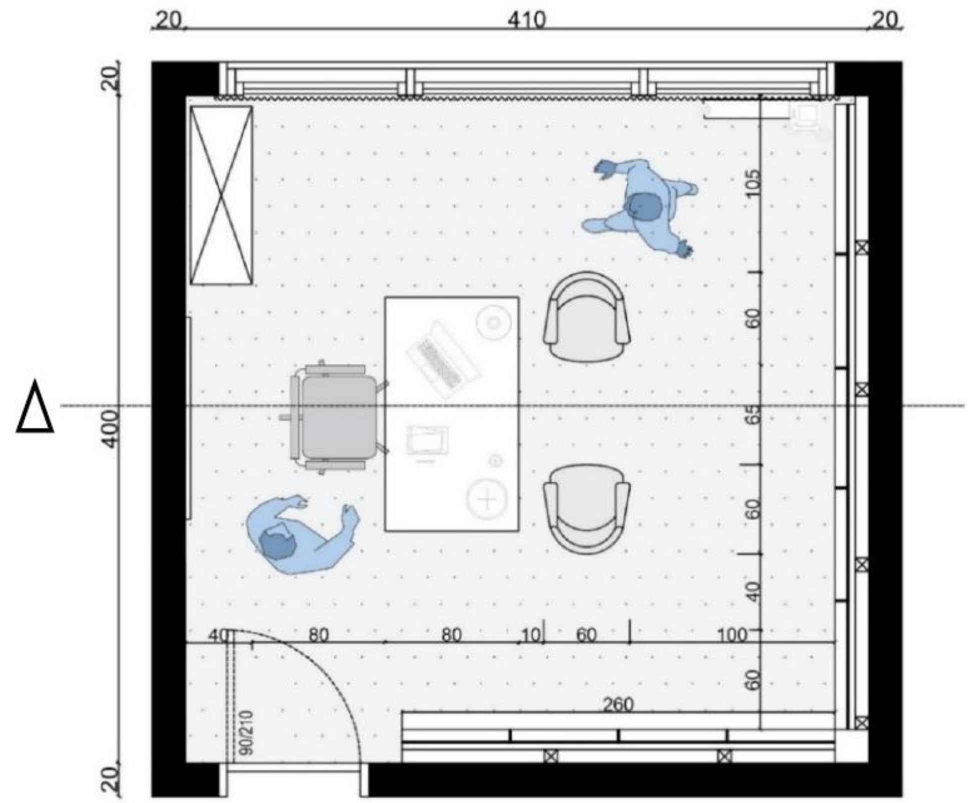


Figure 15: Bilkent VR laboratory plan (not to scale) (Kuş,2019)

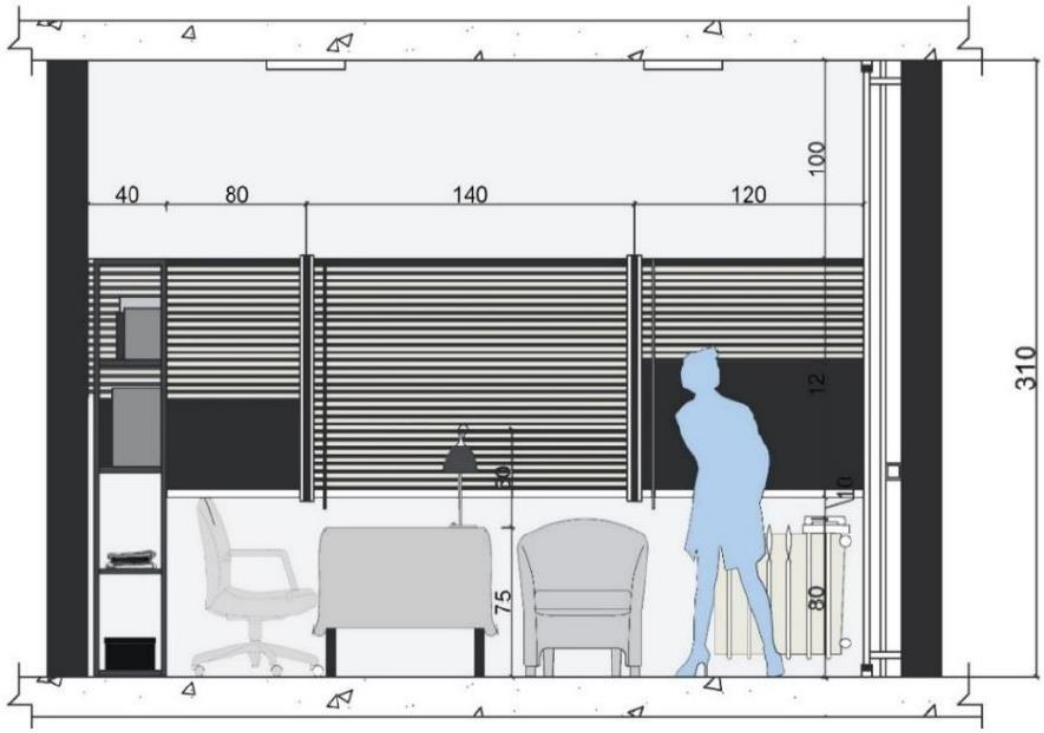


Figure 16: Bilkent VR laboratory section (not to scale) (Kuş,2019)

The binaural audio-video recording technique was applied for this video. 30 participants evaluated VE_rec by watching the video and listening to the office sounds that recorded from RE. We can explain this experiment as a “Virtual Soundwalk” by watching and listening to recorded audio-visual data from RE. In this video recording, there are 10 locations to walk virtually and participants listened to the sounds for 2 minutes for each location. (Figure 17).

Figure 17: A general interior view from RE

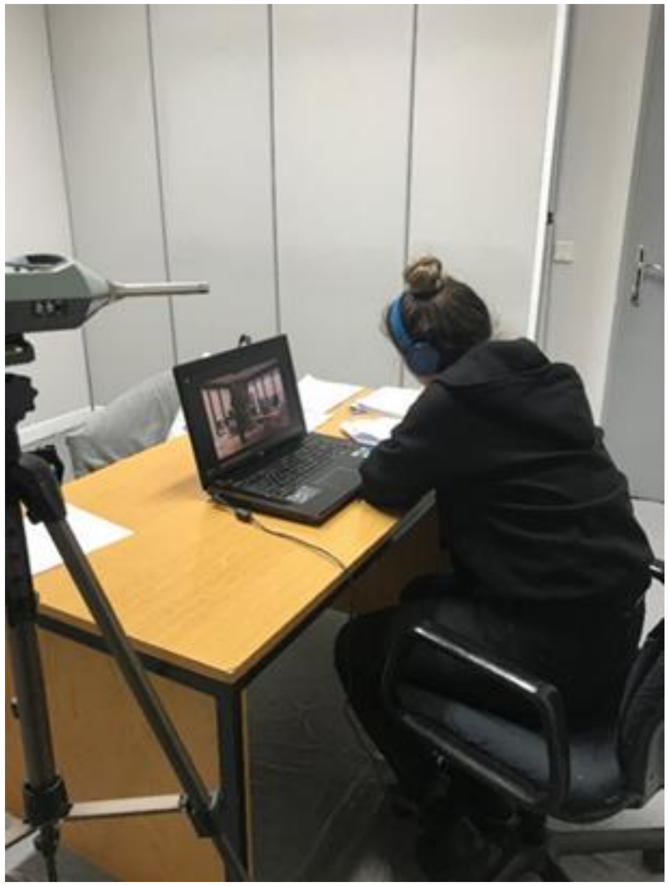


Figure 18: A general interior view from VE_Rec and VE experiments

Finally, the third group experienced VE by watching a virtually modeled animation video (Figure 13-14). After listening, there was an expectation to fill the questionnaire Method A (ISO/TS 12913-2:2018) for each location. The same questionnaire procedure was implemented for all groups and time durations (40 minutes) of the experiments were the same for all environments (Figure 18).

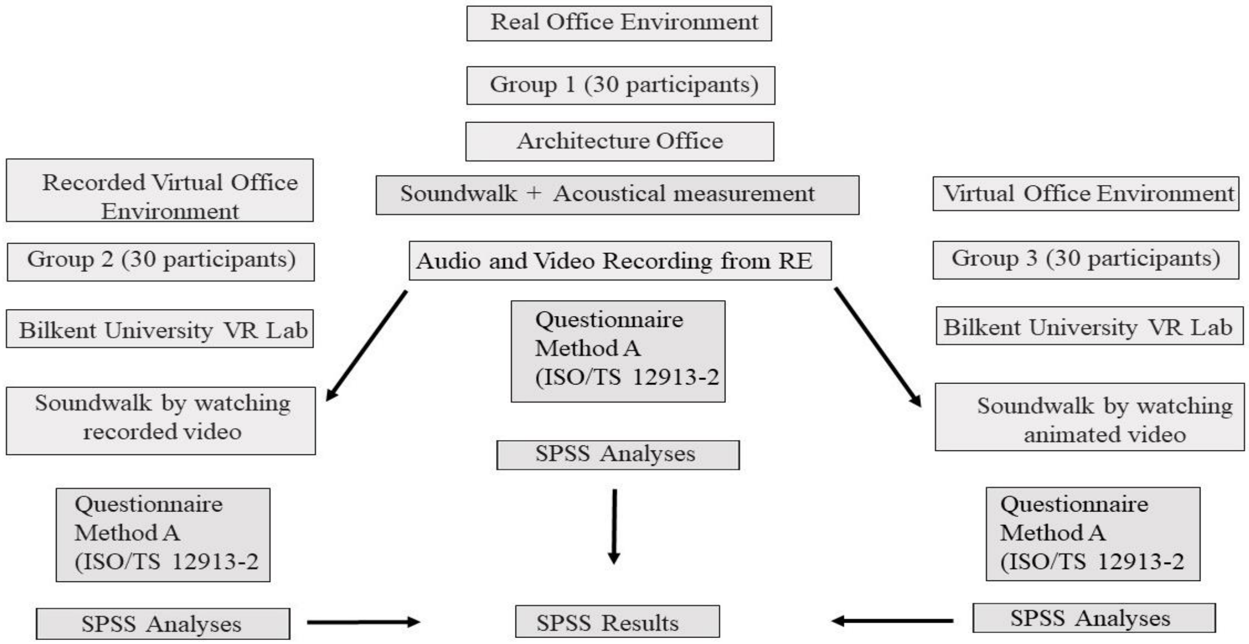


Figure 19: Flow Chart of the Study

3.2.9 Data Analysis

Recently ISO/TS 12913-3:2019 was released to guide researchers on how to analyze data collected in agreement with ISO/TS 12913-2. According to this specification, Method A should be accepted as a quantitative method, even so rating data collected via questionnaires should be linked to the results of the acoustic data analyses to identify potential relationships. These relationships may be investigated using statistical analyses, such as correlation analyses, linear regression, or ANOVA (ISO/TS 12913-3:2019). In this study, the final step is data analysis to compare these three environments statistically, which are consist of RE, VE-Rec, and VE. All quantitative data was listed using the SPSS of Windows 20.0 software for statistical analysis. One-way ANOVA test was conducted to investigate the between-groups effects in the subjective responses between these three office environments for soundscape analyses. Pearson's correlation was run for all items to compare the relationship between eight perceptual attributes. The two-dimensional circumplex model proposed by Axelson et al. (2010) was used to analyze the effect of "perceived affective quality". Additionally, bar charts and graphs were conducted to show sound source differences between 10 locations and three environments in terms of auditory perception.

CHAPTER IV

RESULTS

The ISO / TS 12913-2:2018 measured the recognition of perceived dominant sound sources and perceived affective quality in soundscapes. Soundscape descriptors were used to distinguish the difference between these three acoustic environments by subjective measurements of how participants perceive the acoustic environment. As mentioned in Section 2.2.1, the soundscape quality was evaluated based on the identified dominant sound sources, the perceived affective quality, and the overall surrounding soundscape environment of each location. The sound source identification perceived affective quality of soundscapes and overall soundscape quality were analyzed statistically with the One-Way ANOVA tests. Formulation of the hypothesis is;

$H0$: μ1 =μ2 =μ3 ("RE, VE_Rec and VE means are equal")

$H1$: At least one mean is different from the others ("RE, VE_Rec and VE means are not equal")

Reject $H0$ if $p < 0,05$ at (95% Confidence level)

4.1 Dominance of Sound Source Identification

The mean rating scores of the three acoustic settings were measured to recognize differences in the perceived dominant sources of sound at each location. The qualitative responses of the dominance of sound sources were divided into four separate types of sound sources. The ANOVA One-way test was conducted to analyze the statistical significance of the interpretation of dominant sound sources in the soundscape evaluation sessions (RE, VE_Rec, and VE). The sound source identification results show that technological sounds, other sounds, human sounds, and natural sounds have equal mean scores. All acoustic environments perceived identified sound sources equally ($p < 0,05$) (Table 2) (Figure 22-23). According to Anova results and mean scores, while technological sound and human sounds were mostly perceived in VE_Rec , other sound sources and natural sounds were mostly perceived in RE. (Table 2)

Technological and human-related sounds consider the difference with regard to mean scores among the four sound sources. Technological sound from machines and caused by human sounds governed across the atmosphere of the open-plan workplace. Natural sounds and other sounds were heard less. In light of this information, the cluster bar charts were designed for these two sound sources. The clustered bar chart shown in figure 20, shows that technological sound was mostly perceived in location 8 by VE_Rec participants. Other clustered bar chart shown in figure 21, shows that human sound was mostly perceived in location 4 by VE_Rec participants.

Table 2: Summary of the ANOVA for the four sound sources with the mean scores of three environments

Sounds	df	F	p	Environment	Means
Technological	2	1,026	0,372	RE	3,60
				VE_Rec	3,79
				VE	3,68
Other	2	1,306	0, 287	RE	1,63
				VE_Rec	1,50
				VE	1,44
Human	2	2,642	0,090	RE	3,93
				VE_Rec	4,34
				VE	4,10
Natural	2	0,636	0,537	RE	1,14
				VE_Rec	1,12
				VE	1,10

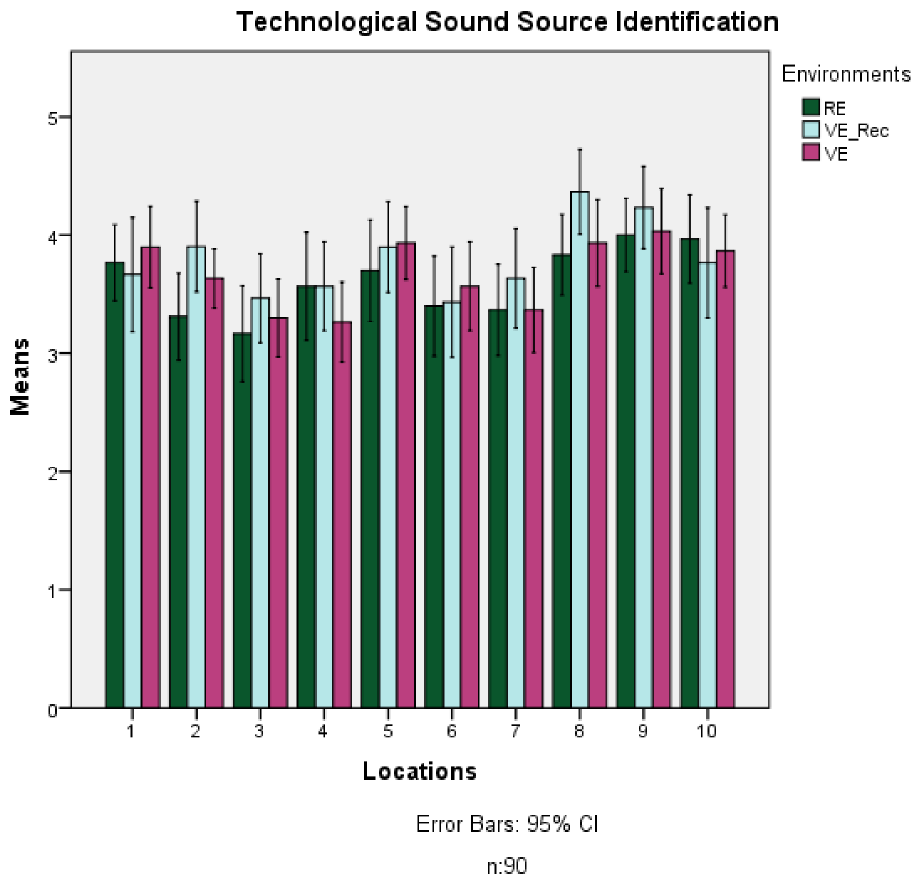


Figure 20: Mean scores of technological sound source identification of three environments

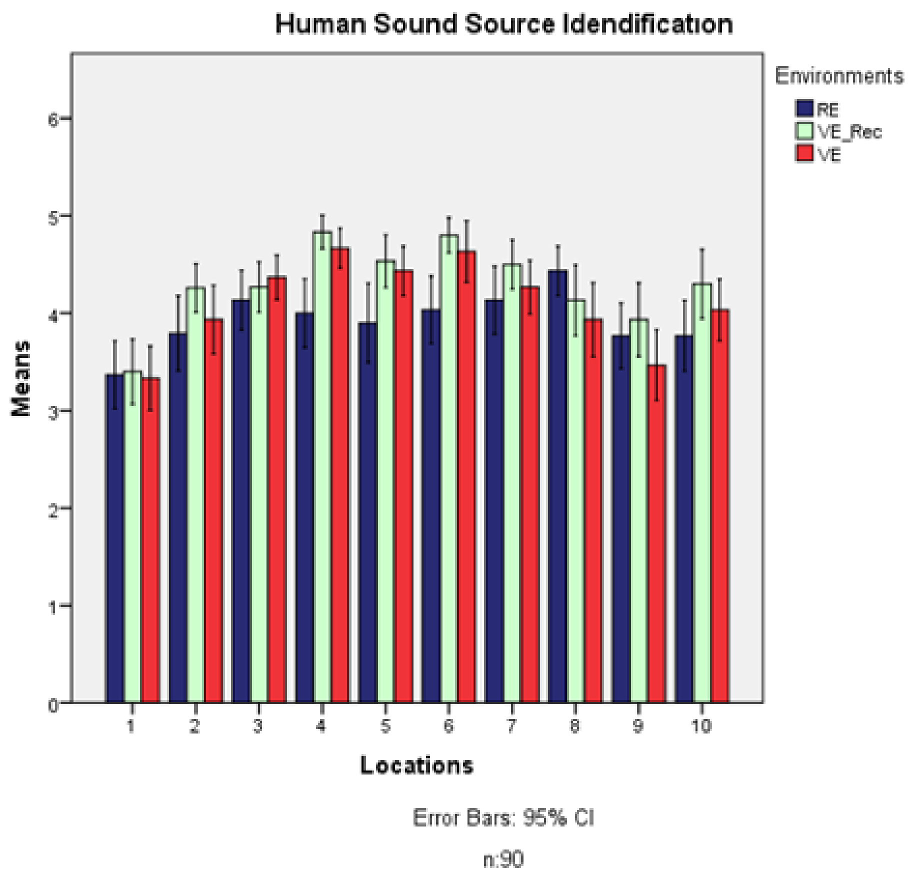


Figure 21: Mean scores of human sound source identification of three environments

4.2 Perceived Affective Quality of Soundscape

To investigate the perceived affective quality of soundscape between the three acoustic environments, mean rating scores of the eight personal attributes, (Pleasant-annoying, chaotic-calm, eventful-uneventful, vibrant-monotonous) One-Way ANOVA test was conducted to investigate the effects of the different acoustic environments. Regarding the main effects of acoustic environments, significant differences were found in “Pleasant, annoying, calm, chaotic and vibrant”, whereas there were not any significant differences in “eventful, uneventful and monotonous” between three acoustic environments (Table 3).

The post hoc tests were conducted to examine the mean differences in the perceived affective quality of soundscape among the 10 locations across all eight perceptual attributes. The post hoc test results showed that RE was perceived more “pleasant” than others while VE_Rec and VE were perceived more “annoying” than RE. RE was significantly different from VE_Rec and VE regarding pleasantness. Although VE_Rec was perceived as more “chaotic” than RE and VE, RE was perceived more “calm” than others and again RE was significantly different from VE_Rec and VE regarding calmness. VE_Rec was found more “vibrant” than others and all three acoustic environments were perceived “monotonous” equally. Finally, all these environments were perceived as the items “eventful and uneventful” equally

Table 3: Summary of the ANOVA for the eight perceptual attributes of three acoustic environments

Perceptual Attributes	df	F	p
Pleasant	2	24,923	0,0005
Annoying	2	36,504	0,0005
Calm	2	12,755	0,0005
Chaotic	2	25,083	0,0005
Vibrant	2	24,747	0,0005
Monotonous	2	0,677	0,517
Eventful	2	2,217	0,128
Uneventful	2	0,610	0,551

Eight personal attributes were plotted on a two-dimensional circumplex model to facilitate the interpretation under this model for soundscape assessment proposed by Axelsson et al. (2010). This thesis provides a two-dimensional circumplex model to compare the eight personal attributes of RE, VE_Rec, and VE. This model shows the mean scores of the perceived affective quality items (second question category in Table 2 in the questionnaire) at the 10 locations of the soundwalk, plotted under the circumplex model (Axelson et al., 2010). Higher scores signify a higher level of agreement with the specific attribute. ANOVA test results and the circumplex model show the same results for eight personal attributes. RE was perceived more positively than VE_Rec and VE regard to the direction of the model. While RE goes toward to pleasant and calm, VE_Rec and VE are close to annoying and chaotic (Figure 22).

Table 4: Summary of the ANOVA for the eight perceptual attributes' mean scores of three acoustic environments

	Eventful	**Vibrant**	**Pleasant**	**Calm**	**Uneventful**	**Monotonous**	**Annoying**	**Chaotic**
RE	3,34	2,12	2,82	2,72	2,41	2,83	2,65	2,48
VE_Rec	3,63	2,56	2,22	1,90	2,28	2,67	3,58	3,45
VE	3,50	2,14	2,12	2,11	2,33	2,71	3,36	3,01

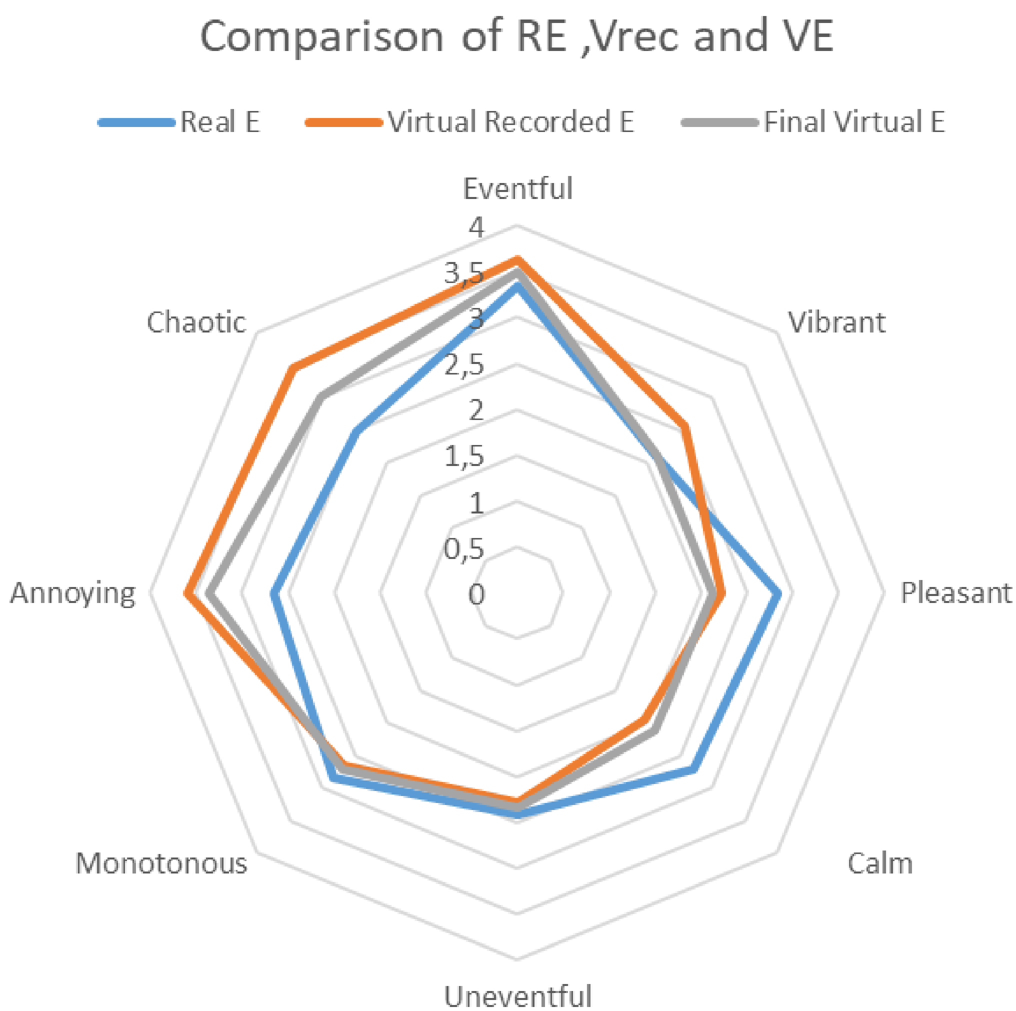


Figure 22: Mean scores of the perceived affective quality items at the 10 locations of the soundwalk, plotted in accordance with the circumplex model proposed by (Axelsson, Nilsson, & Berglund, 2010)

As mentioned before ANOVA test results showed that, “pleasant, annoying, calm, chaotic and vibrant” were perceived differently amongst three acoustic environments. Figure 23 shows the fluctuation of five perceptual attributes which have a significant difference between RE, VE_Rec, and VE’s mean scores. In

Figure 24 clustered bar charts show the mean score difference of the eight perceptual attributes within three acoustic environments. The mean score of “Pleasant” was the highest in RE (location 5) while the mean score of “annoying” was the higher in VE_Rec (location 6). “Calm” was perceived mostly in RE (location 2) and “chaotic” was perceived in VE_Rec (location 3). The mean score of “vibrant” was the highest in VE_Rec (location 5) and monotonous. “Eventful” and “uneventful” were perceived mostly in RE (location 8) (Figure 24).

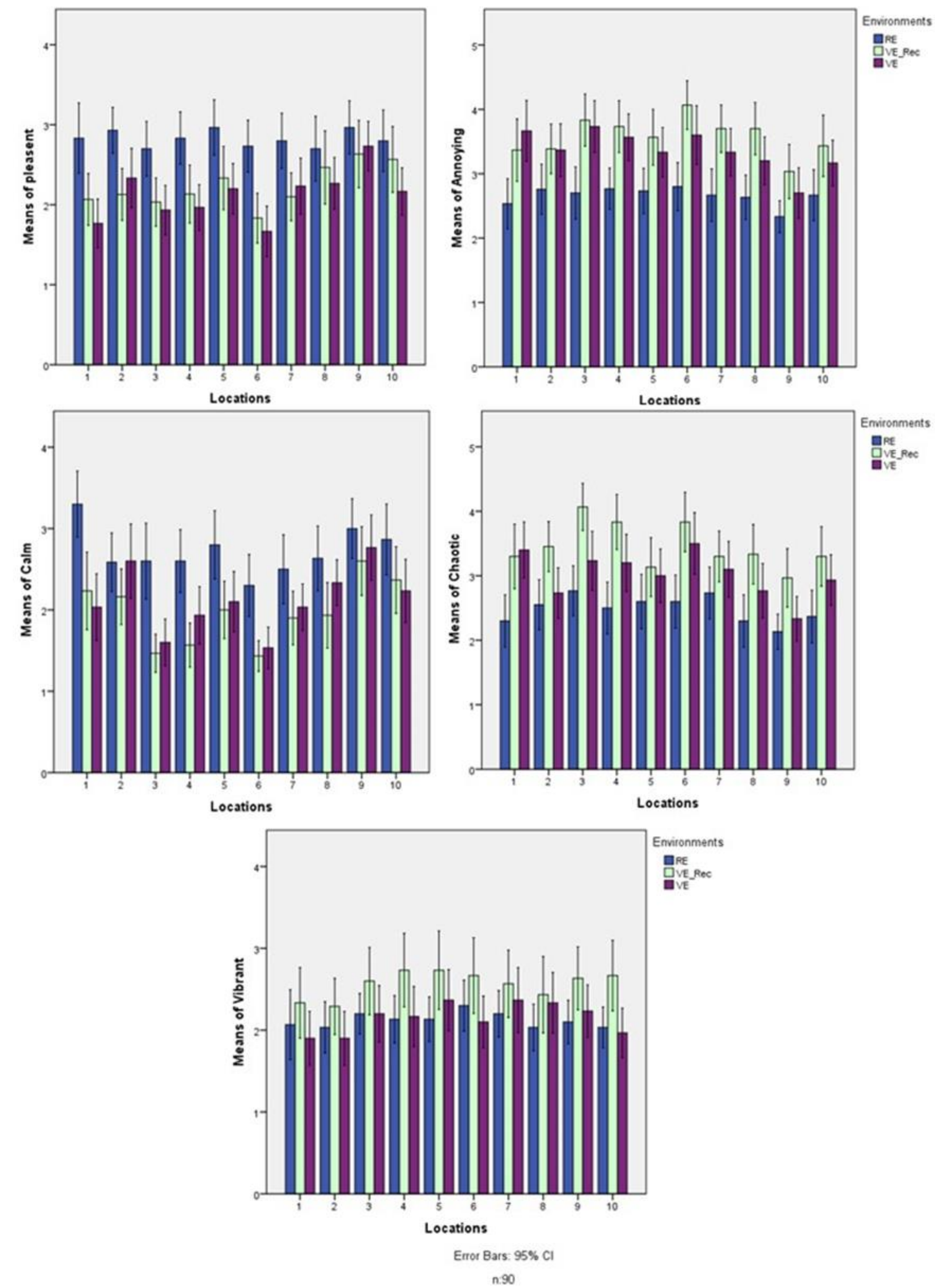


Figure 23 : Mean scores and 95% confidence intervals of the perceived affective quality of five perceptual attributes

RE **VE_Rec** **VE**

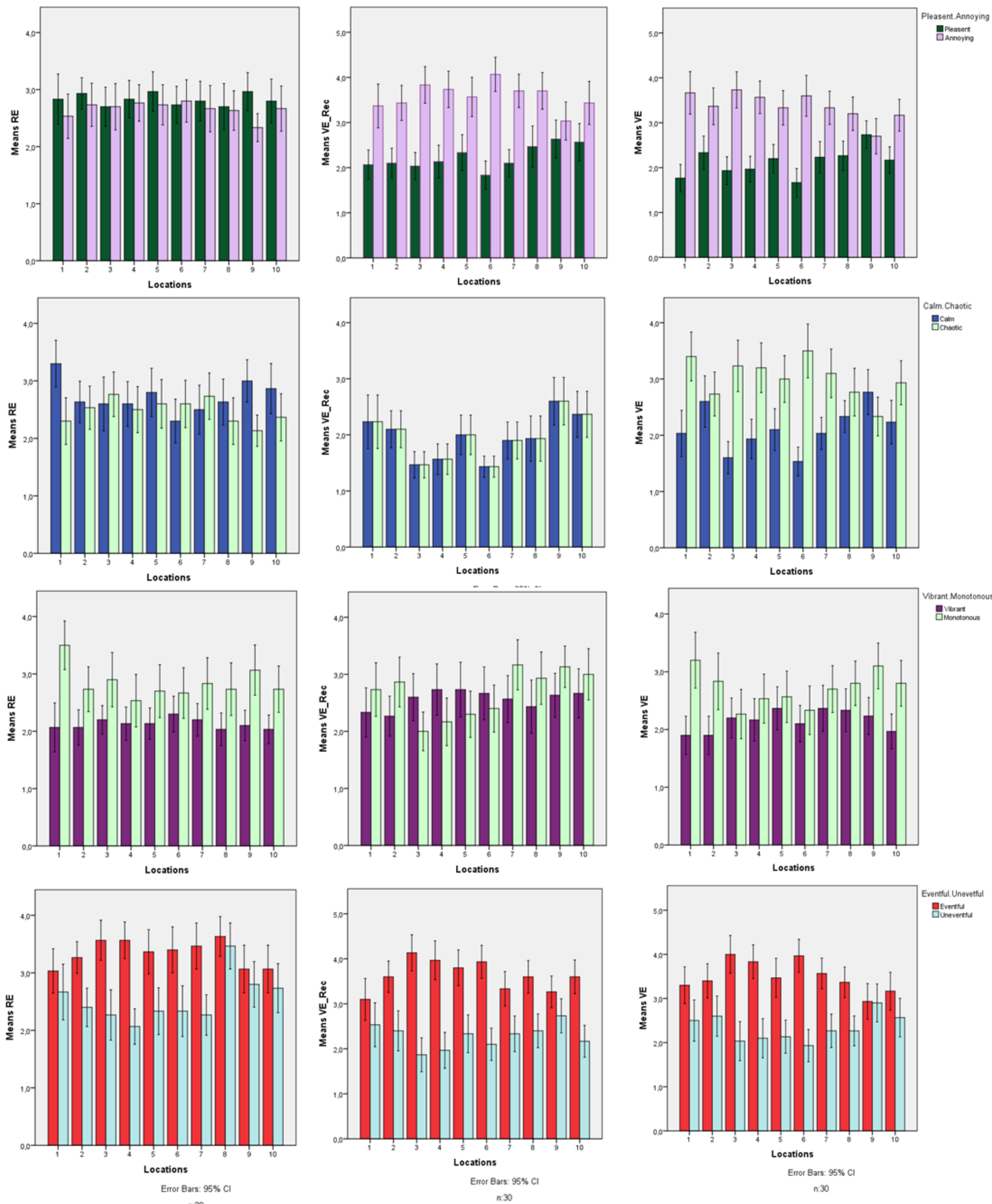
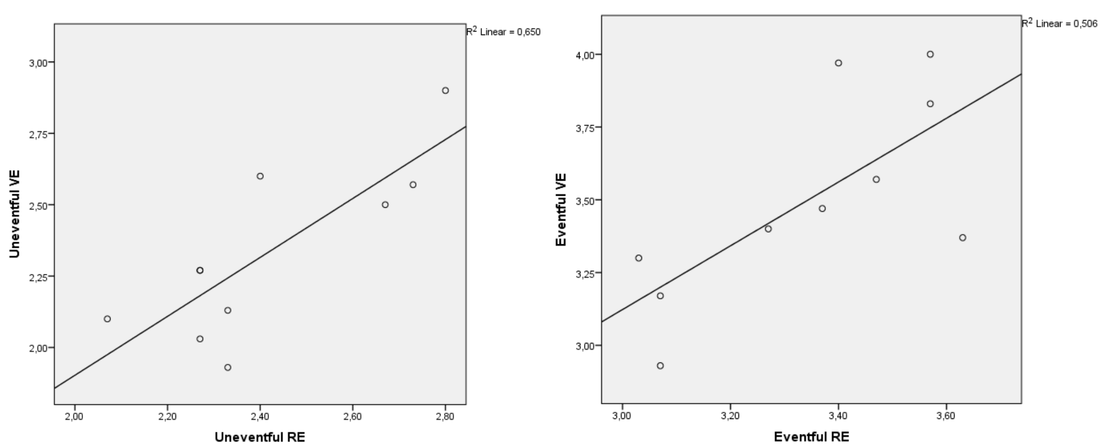

Means RE
Means VE_Rec
Means VE
Locations
Pleasent.Annoying
Pleasent
Annoying
Calm.Chaotic
Calm
Chaotic
Vibrant.Monotonous
Vibrant
Monotonous
Eventful.Unevetful
Eventful
Uneventful
Error Bars: 95% CI
n:30

Figure 24: Mean scores and 95% confidence intervals of the perceived affective quality of eight perceptual attributes of all environments

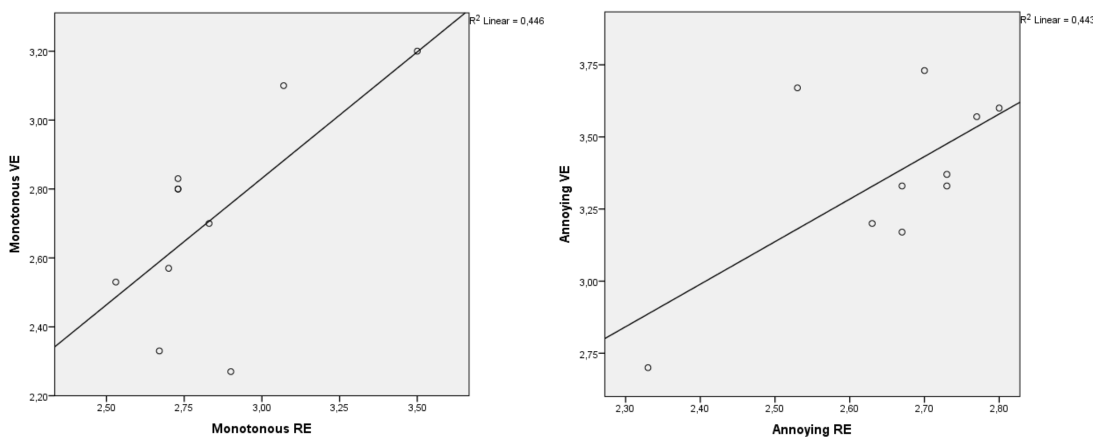
A Pearson's product-moment correlation was run to assess the relationship mean scores of the items for RE and VE. These two environments were chosen because they are closer in the two-dimensional circumplex model. For the item "uneventful" there was a statistically significant, strong positive correlation between two environments, *r(6) = .806, p = .005,* with an explained variance of 65% as shown in Figure 25(a) and for the item "eventful" there was a statistically significant, strong positive correlation between two environments, *r(6) = .711, p = .021,* with an explained variance of 51% as shown in Figure 25(b).



(a) (b)

Figure 25: Scatter plots and linear trend of the mean scores of the item (a) "uneventful" and (b) "eventful" for RE and VE

Likewise, another Pearson's correlation was run for the item "monotonous" there was a statistically significant, moderate positive correlation between the two environments, *r(6) = .668, p = .035*, with an explained variance of 45% as shown in Figure 26 (a). For the item "annoying" there was a statistically significant, moderate positive correlation between the two environments, *r(6) = . 666 , p = .036* with an explained variance of 44% (Figure 26b).



(a) (b)

Figure 26: Scatter plots and linear trend of the mean scores of the item (a) "monotonous" and (b) "annoying" for RE and VE

These four scatter plot and linear trends show the items which have strong and moderate positive correlations**.** Other four items' Pearson's correlation results are *("pleasant" r(6) = .578, p = .048), ("chaotic" r(6) = . 551, p = .099), ("calm" r(6) = .449, p = . 204), ("vibrant" r(6) = .283, p = .428).* There were statistically moderate positive correlation for "pleasant, calm and chaotic between two environments. For "vibrant" there was a weak positive correlation between RE and VE.

4.3 Assessment of surrounding sound environment soundscape and appropriateness

Part three and Part four of the questionnaire were used to evaluate the assessment of the surrounding sound environment and appropriateness. To identify the ratings in the assessment of the surrounding sound environment and appropriateness in each location, the mean rating scores of the three acoustic environments were compared. The One-way ANOVA test was conducted to examine the statistical significance amongst the soundscape assessment sessions (RE, VE_Rec, and VE). The results show that the assessment of the surrounding sound environment and assessment of appropriateness have significant differences and they do not have equal mean scores.

The post hoc tests were conducted to examine the mean differences of these variables among the 10 locations across all acoustic environments. The post hoc test results showed that the assessment of the surrounding sound environment was perceived mostly in RE, VE_Rec and VE had equal results. RE has significant differences between other environments. The assessment of appropriateness differed for all environments while RE has higher mean scores. RE can be defined as more appropriate among all environments (Table 5).

Table 5: Summary of the ANOVA for the assessment of surrounding sound environment and appropriateness mean scores of three acoustic environments

	df	F	p	Environment	Means
Surrounding sound environment	2	35,515	0,0005	RE	3,21
				VE_Rec	2,39
				VE	2,48
Appropriateness	2	35,539	0, 0005	RE	3,54
				VE_Rec	2,70
				VE	3,13

Regarding difference mean scores of RE, VE_Rec, and VE, clustered bar charts were designed to explore and show fluctuation between these assessments within the 10 locations (Figure 27-28). These charts show that the surrounding sound environment was mostly perceived in location 5 by VE participants and the assessment of appropriateness was mostly perceived in location 9 by RE participants.

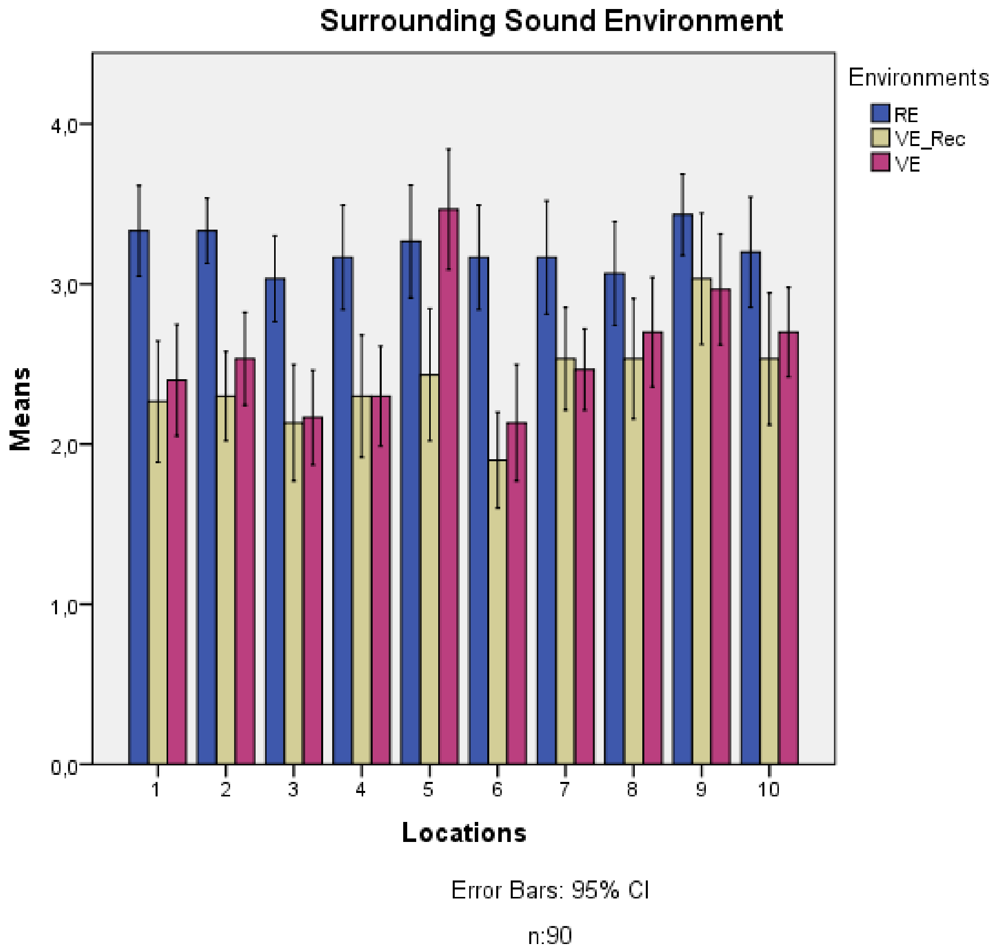


Figure 27: Mean scores and 95% confidence intervals of the assessment of surrounding sound environment

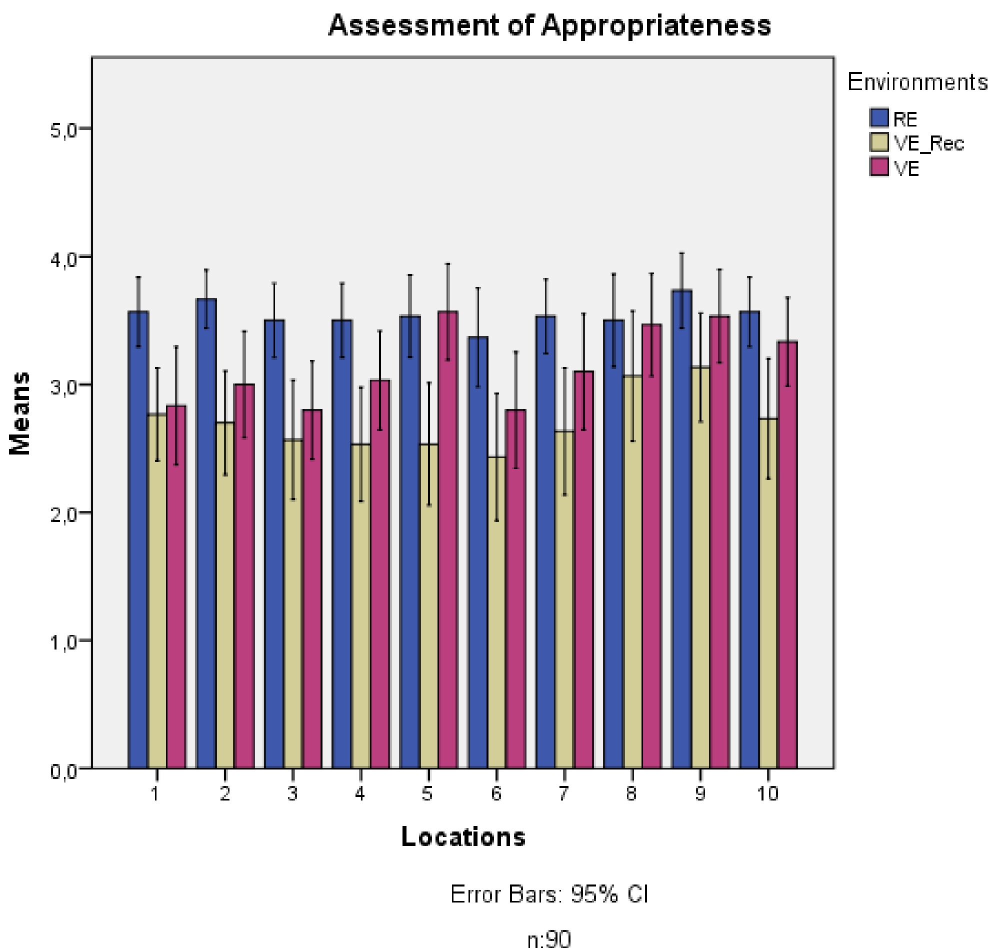


Figure 28: Mean scores and 95% confidence intervals of the assessment of appropriatenes

CHAPTER V

DISCUSSION

5.1 Differences in perceived sound source identification

The subjective assessment results across the three acoustic environments are summarized in Table 2. Regarding the perceived sound sources (Section 4.1) and source-related spatial attributes, this study focused on the comparisons based on the statistical analyses (ANOVAs and post hoc tests) between three acoustic environments (RE, VE_Rec, and VE). Overall, there was no significant difference in perceived dominant sound sources between them. According to these findings, this study reaches an agreement with previous studies showing that binaural audio-video recording techniques and non-immerse VR would be accepted as reliable tools for soundscape assessment as an alternative to on-site surveys. As previously mentioned study, Hong et al. (2019) conducted a comparative experiment about three FOA reproduction methods. Their result supports this study's result that there is not a significant difference in the perceived sound source between in-situ and virtual environments (Hong et al., 2019).

As a suggestion for future studies, all (VE_Rec, VE) virtual methods would be the alternative methods to examine the sound sources of real acoustic environments without any in-situ experiment.

5.2 Differences in perceived affective quality of the soundscape

Unlike the SPSS results of the perceived sound source identification analyses, significant differences were found in the perceived affective quality among these three acoustic environments. Statistical analyses based on subjective responses show that among the eight perceptual attributes “pleasant, annoying, calm, chaotic and vibrant” had a significant difference in the affective quality of soundscape, whereas “eventful, uneventful and monotonous” had similar affective qualities between three acoustic environments. During the assessment of the acoustic environment based on the affective quality, binaural audio recording technique and reproduction methods were used for designing VE_Rec and VE. However, statistical results demonstrated that there is a difference between VE_Rec and VE regarding the direction of the auditory perception as shown in the two-dimensional circumplex model (Figure 24). This model points out the perceptual role of eight perceptual attributes in three acoustic environments. According to this model, RE is perceived as more positive in terms of auditory perception. While the area of RE can be defined as the closest area to the pleasant and calm, VE_Recs’ defined area on the model is closer to the annoying and chaotic more than VEs’ area. We can conclude that VE and VE_Rec need some improvements to reflect a real acoustic environment regarding the perceived affective quality of soundscape.

5.3 Differences in assessment of the surrounding sound environment and appropriateness

Regarding the assessment of the surrounding sound environment, participants describe RE more preferable and positive than VE_Rec and VE (Table 4) except location 5 for VE (Figure 28-29). Statistical analyses demonstrate that the assessment of appropriateness was perceived more positively in RE. According to the Post Hoc test, all environments were perceived differently in terms of mean scores (RE>VE>VE_Rec).

Besides these results, this study provides a different approach to compare real and virtual environment soundscape assessments. In situ a particular acoustic condition is measured based on short-term knowledge. The simulated acoustic environment, by comparison, is tested under laboratory conditions. Hong et al., (2017) argues that real environment evaluating methods are advantageous as they provide realistic real-life setups. These approaches have unregulated variables such as temperature, humidity, daylight and wind speed. Virtual environments have the advantage of getting the ability to monitor the behavioral factors and explore various social interactions or associations. A laboratory-based experiment will reduce the impacts of certain environmental disturbing variables (Hong et al., 2017).

The present study has some inherent limitations. As an in-situ environment (RE), only one open-plan office (Demay Architecture Office) was selected. Therefore, this study suggests that there should be additional office environments to analyze the difference in auditory perception comparatively and obtain more general results. Additionally, a non-immersive virtual (desktop) system was used for designing a virtual office environment (VE). The assessment of the immersive VR technique may cause the different perception results thus the impressiveness can affect the visual space perception. For designing the VE_Rec environment, this present study provides 2D camera recording techniques however a 3D camera shall be used to record audio-video recordings from the in-situ environment. So, participants would experience a 3D environment by using a virtual reality headset (HMD).

As mentioned above, RE participants experience a soundwalk in groups consisting of five people. However, VE Rec and VE participants experienced the environment individually. Even though group experience may seem to be a limitation, the participants were informed to keep quiet during the soundwalk experiment. Despite the limitations, this study has significance to provide perspective about the usability of different acoustic environments and their application in the indoor soundscape research area. As a suggestion for future studies, the effect of architectural components of the open-plan office on soundscape assessment is the incontrovertible topic. Researchers shall examine these components to demonstrate different soundscape results for differently designed open-plan offices.

5.4 Discussion of Results with Previous Studies

As mentioned before there are many virtual reality studies examined the virtual environments regarding soundscapes or applications whether virtual environment soundscapes compensate real environment soundscapes. However, there is no previous study about virtual open-plan office soundscapes so we need to compare with other virtual soundscape studies to discuss our results. After statistical analysis of this thesis, the result shows similarities between previously conducted studies about binaural audio-video recording techniques and non-immerse VR. As previously mentioned, Hong et al. (2019) conducted a comparative experiment about three FOA reproduction methods. The result of this previous study testified our results that there is not a significant difference in the perceived sound source between in-situ and virtual environments (Hong et al., 2019). Although there is not any significant difference in sound source identification, there are significant differences in perceived affective quality between three acoustic environments. Hong et al. (2019) claims that there were significant differences in the perceived spatial qualities between three reproduction methods. In the assessment of the surrounding sound environment and assessment of appropriateness, this thesis found significant differences between three acoustic environments. Hong et al. (2019) concluded that there was not significant difference between reproduction methods' overall quality.

For another case study which conducted by Rychtáriková et al. (2014) to compare the site recordings with auralized soundscapes. Similar to the results concluded in this study, they found there are significant differences in perceived traffic noise, depending on participants' location (In-situ or virtual environment) (Rychtáriková et al., 2014).

CHAPTER VI

CONCLUSION

Studies in soundscapes typically concentrate on urban and rural environments, rather than enclosed spaces. Studies of indoor soundscapes have been found mainly during the last decade. In the context of soundscape studies, this study aims to compare whether the participants have equal auditory perception between three environments (RE, VE_Rec, and VE) by collecting individual responses with ISO 12913-2:2018. An architectural open-plan office Demay architects was involved in the study because it is located in both residential and commercial location in Ankara. The office is also crowded and an active office to obtain reliable data from the experimentally, in-situ acoustic experiments were carried out in the Demay Office for the calculation of physical parameters. To get the perceptual data, a questionnaire was conducted with a totally 90 visitors. ISO 12913-2:2018 Method A, soundwalk technique was used to assess the interviews and the SPSS statistical software was used to analyze the outcomes of the questionnaires. Build an interactive soundscape solution to variations of an open-plan office environment gathered data were evaluated and compared with each version of the office. Overall, these three environments resulted in different soundscape assessment outcomes with a statistically significant level of associations in terms of eight personal attributes (except monotonous, eventful, and uneventful) showing that the three methods would not be evaluated similarly “positive” and “negative” soundscapes as the same level. Generally, RE soundscape properties were perceived as more positive than VE_Rec and VE. On the other hand, regarding four sound source identification results, there is not a significant difference in perceived dominant sound sources between RE VE_Rec, and VE. Sound source identification can be measured in VE. Any additional research will be carried out to measure perceived affective content with eight perceptual attributes, assessment of the surrounding sound environment and appropriateness in VE. This thesis will lead to a particular viewpoint in the literature and include new case study descriptions of soundscape approaches.

As a recommendation for future studies, immersive VR technologies may affect the perception of the participants. To close the gap between the perceived soundscape qualities of the real and the virtual environments, a variety of related methods can be analyzed. The architectural characteristics of the environments may be addressed or the sound spectrums may be adjusted to the creation of virtual acoustic environments of comparable soundscape content in real environments.

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APPENDICES

APPENDIX A

Research on Sound Environment Perception in Open-Plan Offices

This survey is conducted within the scope of perceived sound environment research by Bilkent University Interior Architecture and Environmental Design Department. The survey does not ask for your identity. Data obtained from all participants will be kept strictly confidential and used for scientific purposes only. Participation is entirely voluntary.

For more information: zekiye.sahin@bilkent.edu.tr

A. Personal Info	**RE**	**VE_Rec**	**VE**
1- Age:	☐	☐	☐

2- Gender:

- Female
- Male

3- **What is your job?**

4- **Are you an expert about architectural acoustics?**

- Yes
- No

B. Questionnaire parts (Location 1-10)

Questionnaire part 1: Sound source identification

To what extend do you presently hear the following four types of sounds?

Please tick off one reponse alternative per type of sound

	Not at all	A little	Moderately	A lot	Dominates completely
Noise from technological devices (eg.computer, air condition, ventilation, typing)	☐	☐	☐	☐	☐
Other sounds (e.g. sirens, construction, industry)	☐	☐	☐	☐	☐
Sounds from human beings (eg.conversation, laughter, footsteps)	☐	☐	☐	☐	☐
Natural sounds (e.g. singingbirds, wind, rain)	☐	☐	☐	☐	☐

Questionnaire part 2: Perceived affective quality

For each of the 8 scales below, to what extend do you agree or disagree that the present surrounding sound environment is…

Please tick off one reponse alternative per scale

	Strongly agree	Agree	Neither agree, nor disagree	Disagree	Strongly disagree
- **pleasant**	☐	☐	☐	☐	☐
- **chaotic**	☐	☐	☐	☐	☐
- **vibrant**	☐	☐	☐	☐	☐
- **uneventful**	☐	☐	☐	☐	☐
- **calm**	☐	☐	☐	☐	☐
- **annoying**	☐	☐	☐	☐	☐
- **eventful**	☐	☐	☐	☐	☐
- **monotonous**	☐	☐	☐	☐	☐

Ouestionnaire part 3: Assessment of the surrounding sound environment

Overall, how would you describe the present surrounding sound environment				
Very good	Good	Neither good, nor bad	Bad	Very bad
☐	☐	☐	☐	☐

Ouestionnaire part 4: Appropriateness of the surrounding sound environment

Overall, to what extent is the present surrounding sound environment appropriate to the present place				
Not at all	Slightly	Moderately	Very	Perfectly
☐	☐	☐	☐	☐

Figure 29. Questionnaire in English

APPENDIX B

Açık Ofislerde Ses Ortamı Algısı Araştırması

Bu anket çalışması, Bilkent Üniversitesi İç Mimarlık ve Çevre Tasarımı Bölümü'nde hazırlanan, algılanan ses ortamı araştırması kapsamında yapılmaktadır. Ankette kimliğiniz sorulmamaktadır. Tüm katılımcılardan elde edilen veriler kesinlikle gizli tutulup, sadece bilimsel amaçla kullanılacaktır. Katılım tamamen isteğe bağlıdır.

Araştırmayla ilgili bilgi almak için: zekiye.sahin@bilkent.edu.tr

A. Kişisel Bilgiler	**Gerçek O**	**Kaydedilmiş sanal O**	**Sanal O**
1- Yaş:	☐	☐	☐

2- Cinsiyet:

- Kadın
- Erkek

3- **Mesleğiniz:**

4- **Mimari akustik alanında uzmanlığınız var mı?**

- Evet
- Hayır

B. Anket Bölümü (Lokasyon 1-10)

Anket 1. Bölüm: Ses kaynağı tanılama

Şu anda dinlediğiniz dört çeşit sesi hangi ölçüde değerlendirirsiniz? Lütfen her ses çeşidi için bir yanıt seçin	**Hiç**	**Biraz**	**Kısmen**	**Çok fazla**	**Tamamen hâkim**
Teknolojik cihaz sesleri (Bilgisayar, klima, havalandırma, klavye, vb.)					
Diğer sesler (Siren, inşaat, endüstriyel, vb.)					
İnsan sesleri (Diyalog, kahkaha, ayak sesi, vb.)					
Doğa sesleri (Kuş sesleri, rüzgâr, yağmur, vb.) vb.)					

Anket 2. bölüm: Algılanan etkin nitelik

Aşağıdaki her 8 ölçek için, dinlediğiniz ortam sesinin tanımlanmasına ne ölçüde katılırsınız ya da katılmazsınız? Lütfen her tanım için bir yanıt seçin	**Kesinlikle katılıyorum**	**Katılıyorum**	**Ne katılıyorum, ne katılmıyorum**	**Katılmıyorum**	**Kesinlikle katılmıyorum**
- **Memnuniyet verici**					
- **Kaotik**					
- **Heyecanlandırıcı**					
- **Hareketsiz**					
- **Sakin**					
- **Rahatsız edici**					
- **Hareketli**					
- **Monoton**					

Anket 3. Bölüm: Çevredeki ses ortamının değerlendirilmesi

Dinlediğiniz çevredeki ses ortamını genel olarak nasıl tanımlarsınız?

Çok iyi	İyi	Ne iyi, ne kötü	Kötü	Çok kötü
☐	☐	☐	☐	☐

Anket 4. Bölüm: Çevredeki ses ortamının uygunluğu

Genelinde, dinlediğiniz var olan ses ortamı bulunduğunuz mekâna ne ölçüde uygun?

Hiç değil	Çok az	Kısmen	Çok fazla	Mükemmel olarak
☐	☐	☐	☐	☐

Figure 30. Questionnaire in Turkish

APPENDIX C

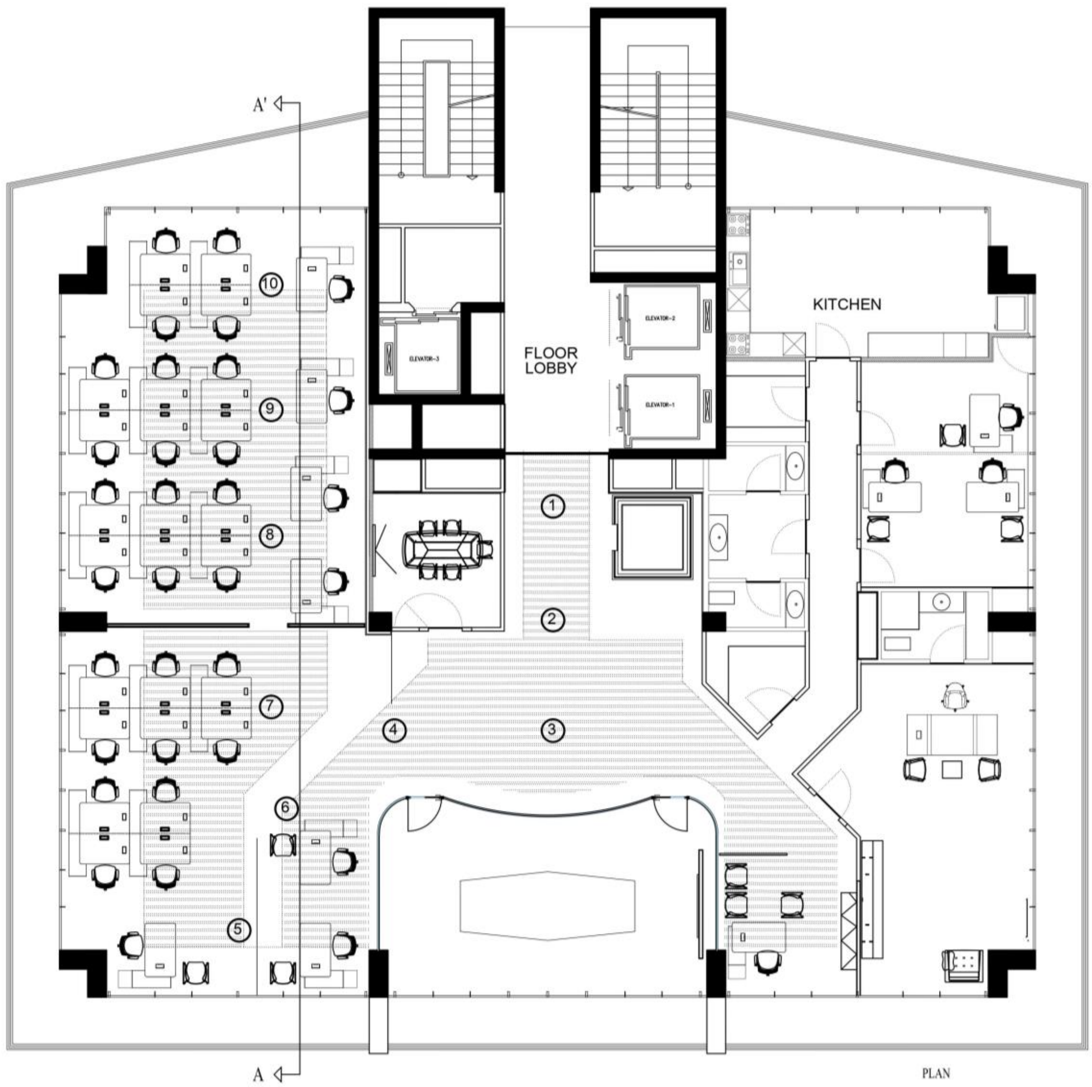
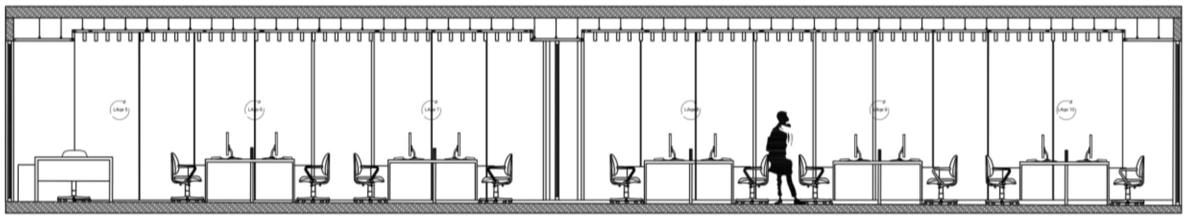


Figure 31. The floor plan of the Demay Architects' open-plan office (not to scale)



SECTION A-A'

Figure 32. The section of the open-plan office (not to scale)