THE EFFECT OF THE SOUND ENVIRONMENT ON SPATIAL KNOWLEDGE ACQUISITION IN A VIRTUAL OUTPATIENT POLYCLINIC

A Ph.D. Dissertation

by

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DONYA DALIRNAGHADEH THE EFFECT OF THE SOUND ENVIRONMENT ON SPATIAL KNOWLEDGE Bilkent University 2022

To my parents,

Bahram and Naghme

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The Graduate School of Economics and Social Sciences

of

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DONYA DALIRNAGHADEH

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By Donya Dalirnaghadeh

I certify that I have read this thesis and have found that it is fully adequate, in scope and in quality, as a thesis for the degree of Doctor of Philosophy in Interior Architecture and Environmental Design.

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ABSTRACT

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This study examines the impact of the sound environment on spatial knowledge acquisition in a virtual outpatient polyclinic. Outpatient polyclinics have a critical role in determining early outpatient treatments to prevent hospitalization or death and reduce hospital burden. However, they have not been widely investigated in the literature. The studies on spatial knowledge have identified environmental elements mainly related to vision with no focus on sound. Currently, there is limited research on the effect of the sound environment on spatial knowledge acquisition in virtual outpatient polyclinics. In this study, a virtually simulated outpatient polyclinic has been created to analyze the effect of varying levels of visual and audio cues. Eighty participants were randomly assigned to one of the four groups: a control (no visual signage and no sound), a visual (visual signage), an only audio (no landmarks and no visual signage), and an audio-visual group (visual signage, landmarks and sound). The virtual environment was presented as a video walkthrough with passive exploration to test spatial knowledge acquisition with tasks based on the landmark-route-survey model. The results showed that a combination of visual signage, landmarks, and the sound environment resulted in higher spatial knowledge acquisition. No significant difference was found between the performance of the visual group and the control group, which shows that signage alone cannot aid spatial knowledge in virtual outpatient polyclinics. Data from the only audio group suggests that landmarks associated with sound can compensate for the lack of visual landmarks that may help design a wayfinding system for users with visual disabilities.

Keywords: Landmark-route-survey model; Outpatient Polyclinics; Sound Environment; Spatial Knowledge, Virtual Environments

ÖZET

SANAL POLİKLİNİKTE SES ORTAMININ MEKANSAL BİLGİ EDİNİMİNE ETKİSİ

Dalirnaghadeh, Donya

Doktora, İç Mimarlık ve Çevre Tasarımı Bölümü,

Tez Danışmanı: Doç. Dr. Semiha Yılmazer

Mayıs 2022

Bu çalışma, sanal bir poliklinikte ses ortamının mekansal bilgi edinimi üzerindeki etkisini incelemektedir. Poliklinikler, hastaneye yatış veya hasta kaybını önlemek ve hastaneler üzerindeki yükü azaltmak için önemli bir role sahiptir. Fakat bu konular literatürde geniş bir şekilde araştırılmamıştır. Mekansal bilgi üzerine yapılan çalışmalar, sese odaklanmadan, esas olarak görme ile ilgili çevresel unsurları tanımlamaktadır. Günümüzde sanal polikliniklerde ses ortamının mekansal bilgi edinimi üzerindeki etkisi üzerine sınırlı araştırma bulunmaktadır. Bu çalışmada, farklı düzeylerde görsel ve işitsel ipuçları ile sanal simülasyonlu bir poliklinik oluşturulmuştur. Seksen katılımcı dört gruptan birine atanmıştır: kontrol (görsel işaret yok), görsel (görsel işaret), sadece (yer ve görsel işaret yok) ve görsel-işitsel grup. Sanal ortam, yer işareti-rota-anket modeline dayalı görevlerle mekansal bilgi edinimini test etmek için pasif keşifli bir video incelemesi olarak sunulmuştur. Sonuçlar, görsel tabela ve ses ortamının bir kombinasyonunun daha yüksek mekansal bilgi edinimi ile sonuçlandığını göstermiştir. Sanal polikliniklerde tabelaların tek başına mekansal bilgiye yardımcı olamayacağını gösteren görsel grubun performansı ile kontrol grubu arasında anlamlı bir fark bulunmamıştır. Sadece ses grubundan elde edilen veriler, sesle ilişkili yer işaretlerinin, görme engelli kullanıcılar için bir yol bulma sistemi tasarlamaya yardımcı olabilecek görsel yer işaretlerinin eksikliğini telafi edebileceğini göstermektedir.

Anahtar kelimeler: Yer işareti-rota-anket Modeli; Poliklinikler; Ses Ortamı; Mekansal Bilgi, Sanal Ortamlar

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CHAPTER 1

INTRODUCTION

Spatial knowledge development is one of the four theories of wayfinding (Jamshidi & Pati, 2021). Human spatial knowledge is linked to and defined by finding and following routes from one destination to another (Kuipers, 1990). Hospitals are among the most complex environments that the public accesses (Zijlstra et al., 2016). Better acquisition of spatial knowledge in hospitals leads to better wayfinding performance (Gärling et al., 1981; Siegel & White, 1975) that benefits patients, institutions, and medical outcomes (Rodrigues et al., 2020). It reduces lost staff and patient time and users' dissatisfaction because of being disoriented, enhances staff concentration by not being interrupted to provide directions, and minimizes the costs of delayed or missed appointments. In hospitals and other healthcare units, wayfinding is generally emergency with patients or visitors aiming to find their destination as quickly as possible, either for an appointment or finding the emergency unit, or visiting a patient (Greenroyd et al., 2018). In this process, unfamiliarity with the setting and crowdedness puts the visitors in a stressful situation as they try to navigate and find their way within the space (Baskaya et al., 2004). In the case of outpatient polyclinics, complex floor layouts make wayfinding daunting for familiar and unfamiliar users. Navigating between diagnosis and analysis units of an outpatient polyclinic can be difficult because of poor signage, poor layout design, and crowdedness (Baskaya et al., 2004). Being disoriented or uncertain of one's location can cause anxiety and distress in unfamiliar spaces (Gibson, 2009). This has gained even more importance with the outbreak of the COVID-19 virus and the increased anxiety and stress levels in healthcare units (Hau et al., 2020).

Wayfinding is the real-world application of spatial knowledge that corresponds with spatial abilities such as spatial perception and mental rotation (Choi et al., 2006). Wayfinding relies on environmental cues such as landmarks and signage (spatial cues such as arrows, color coding, and directional texts) (Morag & Pintelon, 2021; Rodrigues et al., 2020). However, this system can be confusing because of the hospitals' complex layouts and the overwhelming number of signs (Passini, 1984). Landmarks, plan configuration, spatial differentiation, signage, and room numbers are cited as the factors that aid wayfinding (Weisman, 1981). Although these environmental cues ease wayfinding, there are also difficulties related to their use, such as highly reflective decorative elements, misleading lighting, and signage size and placement (Rousek & Hallbeck, 2011). Studies conducted on signage as wayfinding aids suggest that signage alone cannot overcome architectural failures (Arthur & Passini, 1992); furthermore, increasing the number of signage has been found to decrease wayfinding performance (Carpman, 1984). Even well-designed signs may not provide enough cues for efficient wayfinding (Lee et al., 2014; Rousek & Hallbeck, 2011). The problems associated with the use of visual environmental cues exacerbate by visual impairment and cognitive decline associated with aging (Bosch & Gharaveis, 2017). Although in recent years there has been a growing emphasis on the use of alternative methods such as digital wayfinding systems (Morag & Pintelon, 2021) and the use of auditory and haptic cues for all users, especially in spaces with a proliferation of visual signage (Devlin, 2014), research on these is still limited.

The importance of memory and attention in the development of spatial knowledge at both route and survey levels is widely known (Albert et al., 1999; Allen et al., 1996; Gärling et al., 1981). Various environmental cues have been studied regarding their role in spatial knowledge acquisition with an interest in distinguishing between different features such as colored walls or geometric shapes; however, little is known about the role of other sensory modalities on spatial knowledge formation. "Visiocentrism" is a term that highlights how navigation and spatial knowledge studies have focused on vision and encourages research on other modalities (Hohol et al., 2017). Furthermore, one critical step towards understanding attention is researching multiple senses; however, most studies only consider visual modality. Researching in more than one modality has various benefits, such as understanding the difference between sensory modalities and their impact on attention and memory. Additionally, considering the frequency of human interaction with multisensory stimuli, practical applications of attention and memory research entail understanding attention in multiple modalities. In that sense, the following section discusses the importance of sound and the problem statement.

1.1.Importance of Sound and Problem Statement

Memory and attention cannot operate without one another (Chun & Turk-Browne, 2007). Since memory has a limited capacity, attention determines what will be attended to and later recalled. Attention helps to improve memory. Attending to a stimulus signifies that processing resources are allocated to a task. Additionally, attention selects which stimuli deserve these resources and what should be ignored (Chun & Turk-Browne, 2007).

Furthermore, the availability of attentional resources does not necessarily lead to memory encoding. For instance, when visual scenes are combined to make complex stimuli, subjects can only remember what they attend to. Generally, selective attention is critical when there is competition between different stimuli in the environment. Sound is one of the stimuli that has been studied regarding its role in visual attention (Coutrot et al., 2012; Liu et al., 2020; Van der Burg et al., 2008; Vilaró et al., 2012; Ye et al., 2020). Yet surprisingly, the literature on the effect of auditory cues on navigation is minimal. Audition is one of the external senses that can provide spatial information. It can be used to localize noise-producing entities (Yost, 2001) and perceive the scale of the environment (Sandvad, 1999). Spatial language, verbal directions, environmental descriptions, and spatialized sounds emitted from specific decision points or landmarks are among auditory information that have been mentioned as aids that can provide accurate knowledge of the environment in the previous studies (Bosch & Gharaveis, 2017; Couclelis, 1996; Giudice et al., 2007; Loomis et al., 2007; Waller & Hodgson, 2013).

Auditory cues have other benefits, such as giving access to objects in distance. Unlike haptic cues, auditory cues do not require direct physical contact; in contrast to visual cues, they can be perceived even when the user is not facing the stimuli. Finally, sound signals can travel through the environment regardless of visual barriers (Long & Hill, 1997). The sounds of a bell tower or slants of the sidewalk in a neighborhood with hills are examples of cues that help us know where we are (Nardi et al., 2020). Although positive impacts of auditory stimuli have been discussed in a few studies, they have used signal, object, or animal sounds as auditory stimuli, with only a few studies focusing on ambient sound. Complex indoor spaces such as hospitals, shopping malls, and airports are dominated by a variety of sound sources that are associated with specific landmarks; considering the importance of navigation in these spaces, it is vital to see whether sound can be used as a tool to aid spatial knowledge acquisition. With this in mind, this study aims to explore whether the addition of the sound environment that includes sound sources associated with architectural landmarks in a virtual outpatient polyclinic can aid spatial knowledge acquisition.

1.2.Aim of the Research

The main aim of the study is to explore the effect of the sound environment on spatial knowledge for two main reasons. From a practical point of view, nonvisual cues are intuitively and routinely used, especially in cases with low visibility or visual impairment (Giudice, 2018). However, differences and similarities among visual, auditory, and haptic cues are still unclear. This knowledge would have many applications for sighted and blind people as it can aid navigation by optimizing the guidance of spatial behavior. It can also be integrated into new strategies and tools for navigation for the visually impaired (Weisberg et al., 2018). Secondly, from a theoretical point of view, it addresses whether characterizing navigation applies only to a visually accessed environment or it can be extended across different sensory modalities. Furthermore, it can shift the emphasis from perceiving navigation as a purely visually-driven task to a complex multimodal one. In that sense, the study aims to: (i) determine the effect of the sound environment in isolation and combination with landmarks and signage on spatial knowledge; (ii) determine if the sound environment used in isolation can provide sufficient spatial information for performing spatial knowledge tasks; (iii) determine whether characteristics of the sound environment have any role in the memorability of the landmarks; (iv) to propose a new approach for studies in spatial knowledge.

1.3.The General Structure of the Thesis

This thesis includes seven chapters. After the introduction section, the following chapter discusses the relevant theoretical background for the study. It includes two sub-sections on definitions and concepts in navigation, and cross-modal correspondence. In the first sub-section, components of navigation that are spatial knowledge and wayfinding are introduced and discussed in detail. Spatial knowledge and the effect of environmental factors such as landmarks, the effect of sound, and the association with attention would be discussed. In the following sub-section, wayfinding in familiar and unfamiliar environments, virtual and real environments with focus on active and passive explorations, and individual factors that affect wayfinding are discussed. Literature on cross-modal correspondence would also be analyzed in the context of the thesis.

In the third chapter, the theoretical framework of the study would be introduced. The methodology of the study is described in the fourth chapter. The research questions and hypotheses are discussed at the beginning of the methodology chapter. The simulated virtual environment, information on the participants, experimental stimuli, procedure, and performance tasks are also explained.

In the fifth chapter, the analysis of the results regarding spatial knowledge tasks, perceptual analysis of the sound environment, and physical properties of the sound environment are discussed. The sixth chapter is a general discussion of the results. The seventh chapter includes the conclusion and the contribution of the study to the literature with suggestions for further research. The limitations of the study are also discussed.

CHAPTER 2.

THEORETICAL BACKGROUND

2.1.Definitions and Concepts in Navigation

Spatial knowledge and components of navigation would be discussed as the definitions and concepts in navigation. Navigation is the ability to move through real and virtual environments, and it consists of locomotion and wayfinding (Darken & Peterson, 2014). Locomotion is the physical element of navigation that involves getting from one place to another, while wayfinding is the cognitive feature that concerns planning efficient routes, finding locations, and discerning destinations when reached (Montello & Sas, 2006). By moving around the environment, humans perceive and gather information from their surroundings, store it in their minds, alter the information that has been acquired, and apply it when demanded, either consciously or unconsciously. Spatial knowledge that is stored in the brain, is used to help people find their way, plan their routes, and give navigational directions. Thus, in the next section, literature on spatial knowledge acquisition, the effect of different environmental factors, effect of sound and effect of attention on spatial knowledge would be discussed. Later on, components of navigation would be explored with ta focus on wayfinding.

2.1.1. Spatial Knowledge Acquisition

Spatial knowledge and wayfinding are the two main aspects of spatial cognition studies; however, these two interrelated domains are generally discussed separately (Jansen-Osmann & Fuchs, 2006). Wayfinding refers to the performance of finding a way in addition to orientation behavior in unfamiliar spaces. During wayfinding, one acquires spatial knowledge of the environment, stores it, forms a "cognitive map" of the environment, and finds ways based on it (Qiu et al., 2020). During a typical wayfinding task, there are some steps that people follow consciously or unconsciously, such as orienting themselves, finding some clues, relating these clues to places, etc. During navigation, a mental or a cognitive map is formed and is later recalled to help humans find their ways (Tolman, 1949). Spatial knowledge and cognitive mapping explain the processes involved in wayfinding. Within the context of the current study, this section discusses spatial knowledge in detail.

Spatial knowledge is a hypothetical multidimensional construct of the built environment (Golledge, 1999), and it refers to the representation of large-scale spaces (real or virtual) in which spatial relations are not all visible from a single location (Montello, 1993).

Different sources of information and cues from cognitive and perceptual processes that provide an intrinsic reference system are combined to create spatial knowledge (Gallistel, 1990; Hegarty et al., 2006; Mou & McNamara, 2002). Landmarks, the structure of the environment, distinctiveness and visibility of landmarks, and different types of salient environmental information such as edges and neighborhoods are among the cues that aid spatial knowledge acquisition (Lynch, 1960; Mou & McNamara, 2002; Shelton & McNamara, 2001; Steck & Mallot, 2000).

Spatial knowledge gives humans the ability to find their way to unobservable destinations without navigation aids. Successful navigation within a space depends on the acquisition of spatial knowledge and the cognitive processes involved in organizing, storing, and retrieving spatial information from the cognitive maps. Spatial knowledge acquisition involves locating targets, estimating distance and directional associations, and perceiving objects' orientation and position (Lawton, 2010) and is gained as people move within an environment. It can be acquired directly by experiencing environments; or viewing maps, images or 3D models (Montello, 2001; Richardson et al., 1999); or by watching a presentation; or by using virtual environments. When building a representation of environments, people rely on the basic senses of vision, acoustics, touch, and sensory motor to identify, encode and store environmental knowledge (Golledge et al., 2000). Therefore, environmental knowledge is gained during movement through space (MacEachren, 1992).

Siegel and White (1975) were one of the first who developed theories on how cognitive maps are developed. They argue that learning the layout of a plan involves acquiring three types of knowledge: landmark, route, and survey, also known as the LRS theory. Landmark knowledge refers to the identity of places (landmarks) and objects based on their salience, appearances, and subjective importance without knowing their relative spatial relationship (Iachini et al., 2009). It requires the acquisition of sensory and semantic information, storage of the representation in long-term memory, and the retrieval of the memory when prompted (Parong et al., 2020). Route knowledge connects the landmarks that are necessary to reach one point from another (Siegel & White, 1975). It links and chains landmarks and associates them with particular actions such as "turn left at landmark x" (Montello, 1998). Survey knowledge (or configurational knowledge) is knowledge of the spatial layout and spatial relationships between objects and places. It is the most complex type of spatial knowledge to be acquired and allows the navigator to plan alternative routes while finding places outside of the visual field (Bosco et al., 2004; Montello, 1998). Survey knowledge demands the acquisition, storage, and retrieval of landmarks and routes and their orientations from long-term and working memory, and it is interchangeable with the term "cognitive map" (Thorndyke & Hayes-Roth, 1982). Successful navigation requires all three types of spatial knowledge.

Measurement of Spatial Knowledge

Performance in wayfinding and navigation tasks is related to measures of visual memory ability (Allen et al., 1996; Thorndyke & Hayes-Roth, 1982). In that sense, a variety of tasks have been used to measure spatial knowledge, such as cue recognition, object recall, pointing task, scene recognition task (Carassa et al., 2002), route drawing (Iaria et al., 2009), chronological scene classification, and sketch-mapping tasks (Gaunet et al., 2001; Lapeyre et al., 2011). However, the validity of these measures has not been examined closely, and as a result, making comparisons between the available navigation studies may be problematic because of the application of different measures (Kitchin & Blades, 2002).

2.1.1.1. Effect of Environmental Factors on Spatial Knowledge Acquisition

Visual elements are essential in the formation of cognitive maps and affecting spatial knowledge acquisition. A good level of spatial knowledge would lead to a successful wayfinding that affects “the traveler’s ability to achieve a specific destination within the confines of pertinent spatial or temporal constraints and despite the uncertainty that exists” (Allen &Golledge, 1999, p. 47). Inadequate spatial knowledge leads to poor wayfinding that raises problems both for the way finder and the organization (Arthur & Passini, 1992; Dogu & Erkip, 2000; Zimring, 1990); stress related problems such as headaches, raised blood pressure, and fatigue are all related to wayfinding in complex spaces (Arthur & Passini, 1992; Zimring, 1990). Furthermore, reduced staff concentration due to providing directions for the users, lost staff time, missed appointments, additional security staff, lost business, and dissatisfaction and frustration of users are among the complications induced by inadequate spatial knowledge and poor wayfinding. Difficulties associated with a lack of spatial knowledge indicate a poor design, a lack of a wayfinding system, or inadequacy of the users (Arthur & Passini, 1992; Baskaya et al., 2004; Haq et al., 2005; Haq & Zimring, 2003). Users with communication impairments and hearing losses may find it difficult to follow verbal instructions, whereas those with visual impairments cannot rely on visual information (Coleman et al., 2003). As Arthur and Passini (1992) proposed, if a wayfinding task is unsuccessful, there are two components to blame: people or the environment. In their book Wayfinding: people, signs, and architecture, they claimed that people may pay no attention to the objects they see. Alternatively, even if they pay attention, they might still forget the objects leading to the wayfinding task being unsuccessful. Alternatively, the environment can be blamed if it is poorly designed. Both of these components can be the reason for people to lose their way or become disoriented. Thus, in this section, the factors related to people (their observations and behaviors) and the environment will be discussed to examine how they affect the process.

Literature on cognitive science, spatial knowledge, and wayfinding has introduced some key terms. Accordingly, for acquiring spatial knowledge, environments should embody relatively high legibility (Arthur & Passini, 1992; Golledge, 2003; Lynch, 1960), readability (Arthur & Passini, 1992), and imageability (Arthur & Passini, 1992;

Lynch, 1960). Weisman (1981) focused on simplicity (the complexity of the environment), describability (the ease with which the environment can be described), memorability (the ease with which one could remember the environment), and legibility (the judged ease of wayfinding) of environments. He discovered that there is a clear relationship between environmental legibility and the acquisition of spatial knowledge. He also discovered that people's simplicity judgments were an essential predictor of wayfinding behavior. Gärling et al. (1986) stated that the degree of differentiation, degree of visual access, and complexity of spatial layouts are vital factors for wayfinding and the acquisition of spatial knowledge. In their definition, differentiation refers to the degree in which various parts of an environment look the same or different in respect to their shape, size, color, and architectural style. A higher degree of differentiation in the space supports the acquisition of spatial knowledge because of the distinctiveness and memorability of the differentiated parts. Visual access refers to the degree to which parts of an environment can be seen from different viewpoints. For instance, visual access is about whether the travelers can see the starting point, the destination, and the landmarks along the route. Greater visual access aids orientation. Finally, layout complexity has been found to lessen spatial knowledge acquisition and make wayfinding difficult. Spaces that are articulated and broken into different parts are considered more complex, though the organization of the parts is also critical. The size of the environment and the number of possible destinations and routes are also related to layout complexity.

Signage can be considered as another environmental factor that affects the acquisition of spatial knowledge and wayfinding. The design and placement of the signs affect orientation (Arthur & Passini, 1992). To avoid disorientation caused by signs, they must be eligible from a distance, be simple and clear in design, be placed where the users need the information and include enough but not too much information. Even an ideally designed signage may be confusing if placed in a background with visual clutter. It should also be mentioned that perfectly designed, and placed signs cannot overcome the poor characteristics of the other environmental factors. In addition to the mentioned environmental factors, landmarks are one of the other factors that affect wayfinding which will be discussed in more detail in the next section.

Apart from the environmental factors that affect the acquisition of spatial knowledge, navigation aids also assist environmental learning, reduce the likelihood of getting lost, and help travel towards the correct destination. Improving spatial representations requires aids that draw attention to different elements in an environment. Traditional aids, landmarks, and audio aids are among the mediums that aid the acquisition of spatial knowledge. Traditional aids such as maps and compasses help make navigational decisions such as directional heading and planning a route and are used during active and free-exploration navigation and provide minimal advantages for spatial knowledge, but they can be more effective when used in combination with other forms of aids (Ruddle et al., 1998). Besides traditional aids, paths, edges, nodes, districts, and landmarks have been stated as spatial elements, among which landmarks tend to be most commonly associated with spatial knowledge (Lynch, 1960). Landmarks that are persistent, perceptually salient, and informative are considered as reliable aids during navigation (Waller & Lippa, 2007). Audio aids are the other type of aids that are primarily used in virtual environments. Audio aids will be explained in section 2.1.1.3, with respect to the role sound plays in the acquisition of spatial knowledge.

2.1.1.2. Landmarks and Spatial Knowledge Acquisition

Researchers have investigated how one might acquire and utilize various spatial information. Landmarks are one of the five elements of the built environment identified by Lynch (1960). They are considered as spatial aids used for spatial information and are among the most prominent environmental features used during wayfinding (Darken & Sibert, 1996; Elvins et al., 2001; Parush & Berman, 2004; Siegel & White, 1975; Tversky et al., 1994). Although landmarks' importance has been widely discussed, only a small portion of the literature have analyzed specific features of landmarks and their attribution to the acquisition of spatial knowledge (Steck & Mallot, 2000; Yesiltepe et al., 2021). Thus, in this section, particular aspects of landmarks that are critical for efficient acquisition of spatial knowledge will be discussed.

The anchor-point hypothesis, a theory of spatial knowledge, emphasizes the landmark's importance (Couclelis et al., 1987). Based on this hypothesis, landmarks serve as a foundation for acquiring spatial knowledge. This hypothesis suggests that specific landmarks may be acquired first based on the information they convey. Landmarks effectively support orientation and navigation in real and virtual environments (Darken et al., 2001; Lynch, 1960; Parush & Berman, 2004). Landmarks can be used for different purposes, including finding one's way to a particular location (Klippel & Winter, 2005), and orienting oneself to understand whether the selected path is correct (Philbeck & O'Leary, 2005), or identifying specific locations (Downs & Stea, 1973). Therefore, they help people organize their spatial knowledge and locate themselves to specific destinations (Couclelis et al., 1987). Most commonly, landmarks provide information for people to better understand when they should change their orientation along a route (Michon & Denis, 2001). Hence, they affect decision-making (Golledge, 1999) and route learning (Waller & Lippa, 2007). Thus, they can be used for various purposes at different stages of wayfinding.

Landmark characters are categorized by different visual or other sensory characteristics such as color, texture, sound, or smell (Gunther et al., 2004; Helvacıog & Olguntürk, 2011; Hidayetoglu et al., 2012; Yesiltepe et al., 2021). Among these sense-based characteristics visual distinction such as shape, size, and spatial footprint have been widely discussed. Lynch (1960) was one of the first researchers to identify the differences between large, prominent landmarks and smaller ones. Lynch (1960) stated landmarks as easily identifiable objects that are more likely to be selected as a significant point of reference. In addition to the features of the objects, Lynch also discussed their relationship to their surroundings. According to him, landmarks should have a contrast with their background or have a unique shape or other specific characteristics that makes them prominent.

Landmarks are defined in different ways across various research fields such as geography, psychology, and urban planning (Golledge, 1999; Lynch, 1960). Landmarks are defined as objects that are attended to and aid users in navigating, understanding, and recalling spaces (Lynch, 1960). According to Arthur and Passini (1992) people should be able to remember the objects or the key points that affect their wayfinding process. If people are able to remember the objects they see during wayfinding, then they can find their way easily and orient themselves in the environment. However, which features make objects attract users' attention as landmarks? Any object in the environment can act as a landmark; however, not all objects are landmarks. It is stated that a part of the brain called the retro splenial cortex discriminates between permanent objects and transitory ones (Bond, 2020), so that rather than remembering objects that might disappear soon, like rainbows or vehicles, we tend to remember fixed objects, such as buildings and trees. This idea provides insights, but still, it is not clear how we select objects in an environment where we are surrounded by fixed objects. There can be various objects in an environment, but to be a landmark, they must be attended to and help the user in some way.

The definition given by Lynch (1960) is still valid today as it provides information and guidance about the properties of landmarks. Additional characteristics have also been discussed in the literature. Richter and Winter (2014) argued that landmarks serve as anchor points and points of reference. The significance of the location of landmarks (Lovelace et al., 1999; Siegel & White, 1975; Sorrows & Hirtle, 1999), their visual characteristics (Golledge, 1999; Raubal & Winter, 2002), and their relationships with their environments as prominent objects (Caduff & Timpf, 2008), have been previously discussed. It was also stated that the political, cultural, or social impact of landmarks on users might make them more distinguishable (Caduff & Timpf, 2008; Couclelis et al., 1987; Sorrows & Hirtle, 1999). As an example, Couclelis et al. (1987) identified landmarks as having distinctive or outstanding features or being objects with symbolic meanings. These features assist landmarks to be discerned and remembered (Presson & Montello, 1988). Based on the literature, it can be claimed that four characteristics of objects can be remembered:

1. Form: do they have a particular shape, size, or distinctive physical characteristics?
2. Visibility and accessibility: can they be moved or seen clearly?
3. Use: what function do they have? Is the function also distinctive?
4. Symbolic importance: do they have cultural or historical meaning for citizens?

Overall, landmarks are used for a variety of purposes such as finding one's way to a specific location (Klippel & Winter, 2005), identifying certain locations (Downs & Stea, 2011), and orienting oneself to determine whether the chosen path is correct (Philbeck & O'Leary, 2005). Landmarks make it easier for people to organize their spatial knowledge and find themselves in relation to a specific destination (Couclelis et al., 1987). The most common use of landmarks is to help individuals recognize when they should alter their orientation along a path (Michon & Denis, 2001). They are also effective in route learning and decision making (Golledge, 1999; Waller & Lippa, 2007). Literature on the effect of landmarks on spatial knowledge and wayfinding can be divided into two headings: visibility and saliency. Although these two concepts are closely intertwined, they are often discussed separately in the literature. Thus, the following section reviews the literature on landmark visibility and saliency.

2.1.2.1.1 Visibility and the Location of Landmarks

The visibility and the location of landmarks are the two prominent features of landmarks that also define the distinction between local and global landmarks. Distant objects such as towers that can be observed from many vantage points are accepted as global landmarks (Steck & Mallot, 2000). Lynch (1960) described global landmarks as elements seen from different angles and distances that act as reference points during orientation (Ruddle & Péruch, 2004; Steck & Mallot, 2000). In contrast, local landmarks are only visible from close up (Steck & Mallot, 2000), from a limited area, or specific approach directions (Lynch, 1960). Local landmarks can be trees or signs (Lynch, 1960), or they might be more personal (Dalton & Bafna, 2003). In terms of location, a number of studies have emphasized that landmarks located at decision points are better remembered (Janzen, 2006) and more effective in wayfinding tasks (Lynch, 1960). Aginsky et al. (1997) indicated that landmarks that were placed at intersections or points where the direction changes are recalled easier. Furthermore, they propose that landmarks that are small and are located along the route are not very helpful with survey knowledge but rather aid the acquisition of route knowledge.

Numerous studies have claimed that the role of local landmarks in wayfinding is more critical. Ruddle et al. (2011) hypothesized that adding both types of landmarks to an environment would reduce the number of navigational errors. They designed four virtual marketplaces in a grid layout and asked people to navigate under four different conditions: no landmarks, only local landmarks, only global landmarks, and both local and global landmarks. All landmarks consisted of pictures, and the positions of landmarks were automatically generated by a computer program. Researchers observed that local landmarks did reduce participants' errors; however, global landmarks did not influence the overall number of errors. Moreover, local and global landmarks interfered with each other and participants who were provided with both kinds of landmarks made more errors. Meilinger et al. (2014) aimed to explain how the locations within different spaces are represented in memory through global reference frames, multiple local reference frames, and orientation-free representations. They conducted two experiments in which participants were asked to walk through an immersive VE, a labyrinth, and point to seven learned targets. As seen in previous research, this study showed that participants relied on local reference frames rather than global reference frames. Other studies conducted in VEs also found no advantages of using global landmarks (Credé et al., 2019).

Evans et al. (1984) analyzed the effect of internal and external landmarks on route knowledge. Internal landmarks (local) were small and were located in immediate surroundings along the route whilst external landmarks (global) were tall and visible from a distance. They found no significant difference between external and internal landmarks. Local landmarks are mostly associated with route knowledge acquisition; for instance, Parush and Berman (2004) found that in an unfamiliar VE, finding the goal took longer in the presence of local landmarks; however, in familiar settings, there was no difference in navigation with and without landmarks. The authors suggest that this may be because participants spent more time learning the landmarks and their placements at the start of the task or that they gradually ignored them later on. Although local landmarks may aid wayfinding tasks, they are not very helpful in tasks related to survey knowledge and orientation. Jansen-Osmann and Fuchs (2006) indicated that local landmarks aid in close location wayfinding tasks but are not necessarily beneficial in survey knowledge tasks. Janzen (2006) organized three experiments using recognition tasks in a VE with landmarks located at decision and non-decision points. Results indicated that objects at decision points were recognized more quickly. Miller and Carlson (2011) also devised two experiments in which 96 subjects learned a route through a virtual museum. They discovered that objects at decision points both with a turn and without a turn were recognized. It is also stated that the primary role of landmarks at decision points is to confirm one's orientation or heading (Schwering et al., 2013), so that it can be understood if a change in trajectory is needed to find the goal (Michon & Denis, 2001). This shows the significance of landmarks at decision points.

Not only landmarks at decision points but also on-route landmarks have been discussed in different studies. Klippel and Winter (2005) created a taxonomy of landmarks based on several criteria. Accordingly, landmarks can be located at some distance from the route or somewhere along the route. If they are along the route, they can be located between decision points or at decision points. Moreover, for landmarks at decision points with direction changes, they identified three different categories: landmarks passed before reorientation, landmarks passed after reorientation (landmarks that can be observed immediately after a turn) and landmarks not passed (reorientation without passing the landmark). The different locations of objects were then used for calculating an overall value for landmarks. Landmarks on routes and at decision points got higher scores.

In contrast to local landmarks, global landmarks aid in survey knowledge tasks. Ruddle and Péruch (2004) investigated the effect of global landmarks in a virtual maze by using tall posts but did not find any significant difference between the perimeter and global landmark condition. Global landmarks are in some way similar to structural landmarks such as hallways or T-junctions. Similarities between global and structural landmarks is that they both provide an organization to the space; however, they do not necessarily have the visual saliency of global landmarks (Ruddle & Péruch, 2004). Structural landmarks are learned and recalled better in comparison to object landmarks because the structure of a building is more persistent and does not change much over time. Furthermore, structural landmarks are more informative in providing users with navigational decisions (Stankiewicz & Kalia, 2007).

Overall, despite the unlimited studies on the effect of global and local landmarks on spatial knowledge, the findings vary. There are studies that suggest local landmarks are more effective in acquiring spatial knowledge; there are studies that confirm global landmarks are more advantageous, while there are ones that suggest using a combination of both landmarks to aid spatial knowledge. Different results may be due to the different settings of the studies (real vs. virtual), in addition to the variety of the tasks that have been used.

As a summary, researchers agree that spatial knowledge acquisition is exceptionally challenging without landmarks. Thus, visual features of the landmarks have been widely studied. Research suggests that one distinction between local and global landmarks is based on size and visibility. Global landmarks are large and visible from a distance while local landmarks are small and localized along a path. In that sense, global landmarks that are associated with survey knowledge serve as reference points that provide information that aids in structuring the space. Local landmarks are generally associated with route knowledge and aid wayfinding decisions. A general interest of this dissertation is whether it is the sound sources, visual landmarks, or a combination of both features that aid wayfinding and spatial knowledge acquisition. This dissertation aims to expand the knowledge of the roles sound sources available in the sound environment and visual landmarks play. In addition, it attempts to explore their role in spatial knowledge acquisition in isolation.

2.1.2.1.2. Saliency of Landmarks

Another critical issue raised by researchers is the saliency of landmarks. Caduff and Timpf (2008) specified the concept of saliency as the property of distinctness or prominence of an object compared to its surroundings. They discussed that a landmark should be perceptually salient and contrasting with its surroundings. Röser et al. (2012) stated that landmark salience refers to those properties of an object that make it stand out from its surroundings. Götze and Boye (2016) also argued that people choose salient landmarks since they are easily noticeable and memorable.

Sorrows and Hirtle (1999) presented one of the key contributions on landmark saliency. They defined three different landmark types in both real and virtual spaces: visual, cognitive and structural. According to their definitions, a visual landmark is an object that is physically prominent due to its color or size. Visual landmarks attract attention because of their appearance, with features such as their location, contrast with the background, and visual characteristics. A cognitive or semantic landmark is an object with meaning, such as one with historical or cultural associations or one that is well known. Finally, structural landmarks are significant due to the importance of the object's location. The memorability of visual landmarks is because of their contrast with their surroundings. A building with a different color, a high-rise building, or one with a unique shape may be visually salient. Cognitive landmarks might be historically or culturally prominent and thus be significant. Cognitive landmarks may also be more personal, and people may miss them if they are not familiar with the environment. Lastly, structural landmarks are generally in notable locations in an environment and thus are accessible (Sorrows & Hirtle, 1999). They can be situated in locations that are frequently visited or simply placed in an intersection that is well-known (Yesiltepe et al., 2020). A good landmark should include all three properties (Sorrows & Hirtle, 1999). According to Stankiewicz and Kalia (2007), a good landmark needs to be informative, salient, and persistent. Being informative includes providing information about the location, saliency is about how the landmark is detectable and easy to recognize, and persistency refers to existing in the same place over time. In that sense, the more informative, salient, and permanent a landmark is, the more likely it is to be noticed, encoded, and remembered.

In addition to the qualities stated by Sorrows and Hirtle, Caduff and Timpf (2008) introduced location-based (intensity, color, texture orientation), object-based (shape, size, and object orientation), and scene-context (metric refinements and topology) as additional characteristics describing perceptual salience. In their study, Miller and Carlson (2011) also intended to determine the factors that make landmarks salient. They used Caduff and Timpf (2008) definition and focused on contextual and perceptual characteristics of landmarks in a virtual museum. For perceptual characteristics, they focused on size and color, while for contextual characteristics, they analyzed objects at decision points with a turn and without a turn, and at non-decision points. Participants were asked to learn a route and memorize the objects. Then they were asked to give route directions, draw a map with instructions and answer whether an object was in the museum or not. The findings suggested that both perceptual and contextual salience are important characteristics of objects that are considered salient. In another study, Hamburger and Röser (2014) aimed to understand the impact of famous landmarks and to determine the changes in wayfinding performance with visual, verbal, and acoustic cues. In the first experiment, 25 university students were randomly assigned to one of the three conditions. In the recognition task, they indicated whether they saw a word (of an animal) or saw an image, or heard animal sounds. They were re-shown the environment and were asked which way to move at each intersection. The researchers discovered that verbal and sound instructions were better remembered. In the wayfinding task, however, they did not find any significant differences in results. In the second experiment, 20 students were asked to view visually salient but unfamiliar buildings as well as visually salient and familiar buildings. The results indicated that famous buildings were better recognized by people. This study showed that both visual and cognitive characteristics of landmarks affected people's preferences.

As mentioned earlier, visibility and color are among the key characteristics that make landmarks visually salient. Color as a design element has been widely discussed in terms of its impact on memorability and spatial knowledge. Findings suggest that warm colors are more attractive and memorable than others. Furthermore, cool colors and high brightness levels can help people be oriented in the space (Hidayetoglu et al., 2012). Increased brightness and saturation levels have also been found to increase attractiveness, which is one element that aids spatial knowledge acquisition (Camgöz et al., 2004). There are also studies that suggest that while color has a significant effect on wayfinding, there are no differences between different colors regarding their remembrance in school children (Helvacıog & Olguntürk, 2011). A higher level of contrast in terms of color hue and luminance (brightness) influences memory retention as they attract more attention and better visibility (Dzulkifli & Mustafar, 2013). Considering the cross-modal correspondence between sound and color that would be discussed in section 2.3. and the positive effects of color on spatial knowledge acquisition, the following section would go over the literature on the effect of sound on spatial knowledge.

2.1.1.3. Effect of Sound on Spatial Knowledge Acquisition

The attention devoted to spatial learning is among the factors that determine the successful acquisition of spatial knowledge (Albert et al., 1999). In the last 30 years, there has been a great deal of research on the automatic capture of spatial attention following the presentation of spatially nonpredictive cues (Spence & Santangelo, 2009). While the majority of the work has focused on the capture of spatial attention by visual cues (Wright & Ward, 1994, 2008), an increasing number of studies have started to investigate the attention-capturing properties of auditory cues (Ho & Spence, 2005; Spence & Driver, 1994). Research on cross-modal links in spatial attention indicates that the presentation of a cue from different modalities (e.g., vision and hearing) from the same spatial location facilitates spatial attention (Spence et al., 2004). Perception of space relies on integrating information from different modalities (Driver & Spence, 1998). Based on cross-modal links between different modalities, sudden sounds attract not only auditory attention but also visual and tactile attention to their location; likewise, abrupt touches attract auditory and visual attention towards them (Driver & Spence, 1998). Furthermore, recent studies suggest that sound has a leading effect on visual elements' noticeability in a way that variations in sound level correspond with changes in visual attention (Liu et al., 2020).

Regarding the importance of visual elements in acquiring spatial knowledge, it should be noted that visual reference points (e.g., church) are characterized by sound signals (e.g., church bells) (Karimpur & Hamburger, 2016). Thus, pairing visual cues with audio cues may help spatial knowledge acquisition. Designers of virtual worlds utilize various visual and auditory cues to draw attention toward a point of interest or a spatial goal. Nonverbal audio and spatial placement of audio in virtual spaces have been used as navigational cues in prior studies (Burkins & Kopper, 2015; Dodiya & Alexandrov, 2008; Lokki & Grohn, 2005; McMullen & Wakefield, 2014). Spatial audio has been used as an aid for navigation with and without vision (Giudice & Tietz, 2008; Klatzky et al., 2006; Lokki & Grohn, 2005). In the presence of visual stimuli, the addition of stereo sounds enhanced navigation and estimation of target orientation and distance (Lokki & Grohn, 2005). In non-visual experiments, the effect of verbal descriptions of the layout in the virtual environment has been investigated, and results have shown that spatial knowledge is impaired relative to sighted navigation; however, this exacerbation could be reversed by using spatial audio instead of monaural verbal descriptions (Giudice et al., 2010; Giudice & Tietz, 2008).

Lokki and Grohn (2005) explored the use of audio and visual cues in a 3D virtual environment and found that audio cues were as helpful as visual cues. In another virtual environment, Burkins and Kopper (2015) investigated the effect of 3D sound as a wayfinding tool. They found that participants were faster in finding the correct target and had a higher performance in pointing tasks in the maze with audio cues. Hamburger and Röser (2014) compared recognition and wayfinding performance for verbal, visual, and acoustic landmarks (animal sounds) in a virtual environment and found a good recognition and wayfinding performance for acoustic landmarks. Another study found that an interactive exploration in a virtual environment with environmental sound provided sufficient spatial mental maps (Picinali et al., 2014). Marples et al. (2020) explored the effect of landmark, auditory, and illumination cues on player navigation in virtual mazes. The findings indicated that both lighting and audio cues reduced solve time when used in isolation; however, no reinforcement interaction was detected when they were used together. In another study, instead of using auditory cues, Chandrasekera et al. (2015) investigated the use of soundscape as auditory landmarks in wayfinding tasks. They found that soundscape provided navigation aids and enhanced immersion in virtual environments. In their study, a church, a market place, and a school soundscape were used in a virtual maze as auditory landmarks. Based on the studies mentioned above, it can be concluded that the addition of audio or ambient sound in a virtual environment would lead to better performance in spatial knowledge tasks. Since the current study focuses on the effect of sound environment on spatial knowledge acquisition, terms and definitions about sound would be explained in the following paragraphs.

Psychoacoustics of Sound

Sound waves are changes in pressure generated by vibrating molecules. Frequency, spectral, and intensity are physical qualities of sound that influence the three psychological features of pitch, timbre, and loudness, respectively (Houtsma, 1997). These psychological aspects are psychoacoustic parameters that determine how humans understand sounds (Howard & Angus, 2013). Pitch and timbre refer to subjective and perceptual attributes of sound and play an essential function in speech and music perception. Pitch is defined as "the attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from high to low," and timbre is defined as "the attribute of auditory sensation in terms of which a listener can judge that two sounds with similar loudness and pitch are different" (The American National Standards Institute, 1960). Timbre, therefore, is defined in a purely negative manner as "everything that is not loudness, pitch, or spatial perception."

Loudness depends on the amplitude (intensity) or height of sound waves and energy distribution in the frequency domain (Fastl & Zwicker, 2006). It is defined as the intensive attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from soft to loud (The American National Standards Institute, 1960). The greater the amplitude, the louder the sound perceived. Although the perceived loudness of an acoustic sound is related to its amplitude, there is not a simple one-to-one functional relationship. Amplitude is measured in decibels. The decibel scale and the intensity value are based on objective measures of sound. While intensities and decibels (dB) are measurable, the loudness of a sound is subjective and varies from person to person (Fastl & Zwicker, 2006). As a general rule, loudness doubles with every 10-decibel increase in amplitude (Houtsma, 1997).

The amplitude of a sound wave does not directly relate to its perceived loudness. A sound wave with a larger pressure amplitude can sound quieter than a sound wave with a lower pressure amplitude because of the differences in frequencies (Howard & Angus, 2013). As a function of frequency and sound pressure levels, the loudness of sine wave signals is given by the "phon" scale, based on listeners' judgments to match the loudness of tones to reference tones at 1 kHz. Sounds with equal intensities but different frequencies are perceived by the same person to have unequal loudness. For instance, a 60 dB sound with a frequency of 1 kHz sounds louder than a 60 dB sound with a frequency of 500 Hz.

In previous years, research in interior and urban spaces generally focused on noise level reduction levels associated with amplitude. However, recent studies show that reducing the noise level does not necessarily lead to less annoying or more positively perceived environments (Berglund & Nilsson, 2006; Cain et al., 2013; Dubois et al., 2006). On the other hand, loudness can even be desired (Torresin et al., 2020). Equally loud sounds can trigger very different perceptual responses depending on a multitude of factors, besides sound level (e.g., the meaning attributed to the sound source, spectral and temporal characteristics of sound stimuli, building user's traits, building and urban context, socioeconomic, situational and environmental factors) (Torresin et al., 2019). Considering the variety of loudness and frequency of different sound sources in the interior space of outpatient polyclinics, the current study explores whether changes in the loudness and frequency of sound sources associated with local landmarks has any impact on the memorability of the landmarks.

2.1.2.3. Attention and Spatial Knowledge Acquisition

As discussed earlier, navigation involves a variety of tasks such as estimating distance, recognizing a destination, determining the best route, and understanding the relationship between different places. The success rate in these tasks depends on many factors such as familiarity with the route, complexity of the environment, individual differences, and the amount of attention devoted to spatial learning (Albert et al., 1999). Thus, in this section, literature related to the way objects are attended to in the visual and auditory domain are discussed regarding attention and perception. The information that is attended to in the visual domain is well documented (Boynton, 2005; Dzulkifli & Mustafar, 2013; Luck & Ford, 1998; Tas et al., 2016). This body of literature indicates which features are visually attended to within virtual environments and the strategies involved in acquiring and recalling information in visual scenes. Visual attention literature suggests different contextual factors, such as size and type of stimulus, duration of exposure, and provided instruction, as factors that affect attention and memory.

Attention is the cognitive process that involves selecting the available information in the environment. Paying attention to specific information means selecting and focusing on the amount of information to be processed in the cognitive system. An increased level of attention to a stimulus increases the probability of the information being stored in memory (Pan, 2010; Smilek et al., 2002). What we attend to depends on two distinct types of attentional mechanisms (Connor et al., 2004). Bottom-up mechanisms operate on raw sensory stimuli with shifting attention between salient visual features of potential importance, such as sudden changes in luminance. Top-down mechanisms enforce long-term cognitive strategies and are characterized by deliberate objectives to pay attention to specific spatial locations. In other words, while bottom-up attention allows monitoring environmental stimuli on an unconscious level, top-down attention supports goal-driven behavior (Carretié, 2014).

In the visual domain, cues at target locations facilitate the processing of stimuli at an attended location (Posner et al., 1980); however, in the auditory domain, auditory spatial attention is only effective when the location of the stimuli is displayed in regions that are related to the task and affected by attention. In an experiment with valid, invalid, and neutral audio cues, results indicated that reaction times were not significantly different and spatial attention in the advance of auditory cues does not necessarily facilitate response time (Posner, 1978). In another study analyzing the effect of visual and auditory cues on visual and auditory targets, results indicated that both types of cues increased responses on visual targets, but no effect was found on auditory targets (Buchtel & Butter, 1988). Van der Burg et al. (2008) investigated the effect of non-spatial sound on spatial visual searching and found that a visual scene is easier to discern in the presence of a synchronized non-spatial sound. Furthermore, there are studies that suggest eye movement differs in the presence and absence of soundtracks (Coutrot et al., 2012). Liu et al. (2020) investigated the effect of sound level and sound type on visual attention in railway stations and found that sound has a leading effect on visual items' noticeability.

Successful navigation through the environment requires some level of attention allocated to the spatial information provided. The spatial relevance hypothesis explains spatial orienting (Spence & Driver, 1996) that guides attention toward a specific stimulus. The human auditory system has the capacity for spatial orienting. However, the lack of a spatial code in the early stages of auditory analysis leads to a less consistent orienting than the visual modality. When moving through an environment, attention may be allocated to tasks other than the one at hand, which may detract from spatial learning; thus, it is critical to understand which design elements can attract attention throughout a route. Previous studies suggest that a shift in attention enhances spatial knowledge. Thus, regardless of how navigation has occurred in an environment, acquisition of spatial knowledge is directly linked to the amount of attention allocated to the elements along the route. In architectural spaces, a variety of auditory and visual information are in interaction (Abdalrahman & Galbrun, 2020); however, the effect of audio-visual interaction on spatial knowledge acquisition has seldom been studied. Regarding the importance of sound in space perception and the available studies on the effect of sound on visual attention, we aim to find out whether adding the soundscape of an outpatient polyclinic with different sound sources affects spatial knowledge acquisition.

2.1.1. Components of Navigation

Navigation is the coordinated and goal-directed movement of one's body through the environment. Successful navigation relies on organizing, storing, and retrieving information from the cognitive map. Locomotion and wayfinding are two components of navigation (Montello, 2005). Locomotion refers to physical movement that is coordinated with the immediate surroundings, whereas wayfinding refers to planning and decision-making that is coordinated with both distal and local surroundings. There are different forms of locomotion, such as unaided by machines and aided by machines. The modes of locomotion are significant because they influence how we obtain and interpret information while moving. Different modes vary in the degree to which they are active or passive. In that sense, spatial decision-making and control are the main aspects of navigation. Active navigation includes both components of decision-making and control, whereas passive navigation involves observation (Farrell et al., 2003).

In contrast to locomotion, wayfinding is the efficient goal-directed, and planned movement of one's body in the environment. A location goal that is not in the immediate vicinity and a destination are necessary for wayfinding. As a result, memory preserved internally (in the neurological system) and externally (artifacts such as maps) is critical in navigation. Another distinction between locomotion and wayfinding is whether movement is guided perceptually by sensory information or cognitively by previously acquired information (Pick & Palmer, 1986, p. 135). Locomotion and wayfinding vary in the degree to which they are associated with perception/action versus memory/planning systems (Montello, 2005).

Different sensory modalities provide information for navigation, and various cognitive systems are employed to process information from memory and the senses. Vision is known to be the most accurate channel for spatial information, such as recognizing landmarks, notably at a distance. However, recognition can be based on audition, olfaction, satellite signal, and so on (Montello, 2005). Depending on the type of navigation at hand (walking a short distance with blindfolds on or driving in an unfamiliar environment), the required attentional resources vary. In that sense, some tasks do not demand working memory capacity, whereas there are ones that require attention. Walking from the bedroom to the kitchen would be an example of a task that does not require working memory, while maintaining orientation in an unfamiliar environment or giving directions demands working memory capacity (Montello, 2005).

2.1.1.1 Wayfinding

Wayfinding is a component of navigation that explains human movement within the space. Navigation involves processing spatial information in response to position and rate of travel between origins and destinations (Golledge et al., 2000). On the other hand, wayfinding involves selecting routes and linking them as one travels along a specific path. In that sense, the future sections will explain the definition of wayfinding,

wayfinding in virtual environments, wayfinding in familiar and unfamiliar environments, and individual and environmental factors that impact wayfinding.

Wayfinding is the process that involves getting from one place to another in familiar and unfamiliar spaces by acquiring and applying environmental and spatial information. One of the earliest uses of the term wayfinding was made by Lynch (1960). He defined wayfinding and the factors that affect the wayfinding process, mentioning related components such as an environmental image or orientation and disorientation. According to Lynch, wayfinding is about using sensory cues from the external environment to survive from free-moving life. Wayfinding has multiple descriptions in the literature. Golledge (2003) stated wayfinding as the ability to learn a route and retrace it. He added that for successful wayfinding, environmental knowledge is vital, and it can be gained in two different ways: incidentally or intentionally. Gaining knowledge while exploring a space would lead to incidental spatial knowledge, whereas reading about the environment or taking classes leads to intentional spatial knowledge. Harniss et al. (2015) identified wayfinding as the ability of people to find their way. Similarly, Passini (1984) defined wayfinding as a cognitive and behavioral ability of people to find spatial destinations. Peponis et al. (1990) discussed that wayfinding is about finding a way to a specific destination without any delays. Golledge (1999) stated that following a path between a start point and a destination is called wayfinding.

According to Raubal (2008), “Wayfinding behavior is the purposeful, directed, and motivated movement from an origin to a specific distant destination that cannot be directly perceived by the traveler. It involves the interaction between the way finder and the environment" (2008 Page 1243). Thus, he stressed the significance of the interaction between the environment and the way finder, as well as taking into account the size of environments. Based on this definition, it can be said that wayfinding can only be done in large-scale environments where way finders are not able to see the target points (destinations). These definitions make some significant points about wayfinding: it is about finding our way to a specific point, where we cannot view this point from the origin and where we complete the task without delays –without getting lost– by using environmental cues.

2.1.1.1.1. Wayfinding in Familiar and Unfamiliar Environments

According to Allen (1999), there are three different wayfinding tasks: finding a destination in a familiar environment, finding a destination in a familiar environment by exploratory traveling, and finding a destination in an unfamiliar environment. Finding a destination in a familiar environment is common as people commute to work or return home every day. Similarly, when people travel to a new place, they often walk around and explore their surroundings through exploratory travel. Wayfinding in an unfamiliar environment, as Allen and Golledge (1999) and Gärling et al. (1986) proposed, relies more on spatial information. This information could be a map, verbal directions, or environmental cues. Unfamiliar environments have been used by researchers in VEs in order to better understand the factors that shape wayfinding performance (Darken & Sibert, 1996; Han et al., 2008; Miller & Carlson, 2011), since people pay more attention to the cues when they are in unfamiliar environments.

In familiar environments, people generally find their way with the spatial representations in their minds, in addition to employing environmental cues. However, in an unfamiliar environment, there are no previously formed spatial representations. In order to produce this information, people use verbal directions or environmental cues such as landmarks. Thus, with the use of these cues, wayfinding tasks can be completed successfully. But what is critical for a successful wayfinding in an unfamiliar environment? In the next section, all factors that shape wayfinding performance are examined.

2.1.1.2.2. Wayfinding in Virtual and Real Environments

There are different modes and mediums for learning an environment that may influence the acquisition of spatial knowledge regarding the distinct sources of information that each medium conveys (Thorndyke & Hayes-Roth, 1982). In this work, a passive first-person perspective in a virtual environment has been used but the other modes are also discussed in terms of their differences and similarities.

Navigation in virtual environments produces similar and equivalent spatial representations to the real-world (Ruddle et al., 1997; Williams et al., 2007). Thus, virtual environments are a valid tool in spatial knowledge and navigation studies. Acquiring survey knowledge in a complex virtual environment may be more complicated than real world (Richardson et al., 1999); hence the level of reality and the quality of the graphics of VEs should be carefully considered (van der Ham et al., 2015).

Witmer et al. (1996) described virtual environments (VEs) as computer-generated simulated spaces where people can interact. Wayfinding and related topics have been discussed in VEs and in real environments in different studies (Conroy, 2001; Jansen-Osmann & Fuchs, 2006; Yang & Diez-Roux, 2012). A significant number of studies on VEs have been designed to understand whether or not it is possible to use VEs to better understand real environments and develop solutions for the problems of the real environments.

Skorupka (2009) compared real and virtual environments by using a complex office building and asking participants to find a specific location. Half of the participants experienced the virtual office while the rest experienced the real office building. She first discovered that it took more time for participants in the virtual office to complete the task. In addition, she could not find any correlation between patterns of wayfinding used in the real and virtual environments. Kort et al. (2003) considered the comparability of real and virtual environments by asking 101 participants to explore either real or computer-simulated environments. The results, however, were mixed: behaviors in VEs had similarities to that within real environments, but there were also significant differences. The researchers argued that integrating spatial information with configurational knowledge was one of the problems of VEs. However, they also discovered that VEs were better for approximating perception and interaction with spatial and architectural features. An interesting study was performed by Wallet et al. (2011) to understand the effect of the visual fidelity of VEs on wayfinding. To do this, they used VEs that were undetailed (with no color or texture) and detailed (with color and texture), and compared the results with those attained from the real environment. Researchers found that detail within VEs had a significant effect. Better performance was observed while the participants were moving within the detailed VEs. These critical results demonstrate that VEs are helpful in understanding real environments as long as the VE includes many details that can be found in the real environment. As well as listing the differences between real and virtual environments in their research, Ruddle et al. (1997) compared real and virtual environments with experiments. They observed that people could develop route-finding abilities in VEs easily as they gained spatial knowledge, and these abilities were just as accurate as those achieved in real environments.

Moreover, Witmer et al. (1996) aimed to understand whether a virtual model of a building could be used to navigate actual buildings. They observed that through a virtual model of a building, one could learn a route to follow in the real one. Hence, they concluded that VEs that represent the real world could be effective for learning complex routes.

Recent cognitive studies have also expressed similar results for real and virtual environments, stating that the use of a VE provides a reliable assessment of people's navigation abilities (Claessen et al., 2016). Based on all of the studies discussed here, it is possible to say that even though virtual environments might have limitations compared to real ones, one can test real environments by using virtual ones. Moreover, the factors with the most significant effect on people's navigational abilities can be detected. These factors can form a basis for creating easily navigable environments.

Overall, virtual environments are widely used in answering questions about spatial cognitive processes (Memikoğlu & Demirkan, 2020; Tang et al., 2009). Virtual environments provide an accurate representation of real environments (Westerdahl et al., 2006) while allowing systematic environmental manipulations that cannot be easily implemented in real environments (Kuliga et al., 2015). To achieve environmental comparability, it is vital to simulate naturalistic experiences in virtual environments (Bell et al., 2001). Sketches, photographs, and slide shows are traditional approaches to provide a natural setting in virtual environments (Bateson & Hui, 1992). Desktops and laptops are among common presentation devices that produce comparable results with high immersive virtual systems (Kalff & Strube, 2011; Kuliga et al., 2015) because they provide sufficient visual realism in spatial knowledge tasks (Green & Jacob, 1991; Parong et al., 2020; Sayers, 2004). It has also been stated that more immersive systems may lead to less behavioral realism because of the difficulties with controls.

2.1.1.1.3. Wayfinding with Active and Passive Explorations

There are inconclusive findings on differences between passive and active navigation in real and virtual environments. Active navigation involves decision-making and control, whereas passive navigation involves observing a route, such as watching a video. There are studies that suggest active navigation leads to a more accurate spatial knowledge (Downs & Stea, 1973). However, the benefits of active navigation are generally limited to specific measures of spatial knowledge (Péruch & Wilson, 2004). There are also studies that have indicated comparable results between active and passive navigation (Chrastil & Warren, 2013; Gaunet et al., 2001; Waller & Hodgson, 2013), while there are ones that suggest a better spatial knowledge acquisition with passive exploration (Cao et al., 2019). Attention has been stated as the reason behind inconclusive findings between active and passive exploration (Wilson & Péruch, 2002). Based on this finding, if attention is high, the difference between the modes of learning would be insignificant (Farrell et al., 2003). Besides attention, the variety of spatial knowledge measures in the available studies may explain disparate findings (Wallet et al., 2011). Overall, a passive exploration model is recommended for indoor public spaces with predetermined routes (Cao et al., 2019).

2.1.1.1.4. Individual Differences that Affect Wayfinding

Gender has received the most attention among the factors that may affect wayfinding (Lawton, 2010). In a review on the effect of gender on spatial orientational tasks, Coluccia and Louse (2004) found that 61% of the experiments indicated that males have a higher performance in spatial knowledge tasks, whereas the rest do not indicate any gender difference. In another review on spatial knowledge in virtual environments, it was found that 85.71 % of men outperformed women in active wayfinding tasks, while in passive explorations, only 28.57% of men outperformed women (Coluccia & Louse, 2004). In both active and passive explorations, in the rest of the cases, performance between the genders was equal, with women never performing better than males.

Coluccia et al. (2007) found that males indicated superiority in map drawing and spatial orientation abilities. Munion et al. (2019) also found that males had a higher performance in wayfinding tasks. Moreover, men tend to outperform women in active wayfinding tasks when they have access to a map; however, gender differences shrink when landmarks are used as aids (Hund & Minarik, 2006).

One difference between the genders is that males rely on both geometric and object landmarks for acquiring spatial knowledge whilst females generally rely on object landmarks (Sandstrom et al., 1998). Studies show that women are more likely than men to rely on landmark-based route information while men tend to rely on cardinal directions and global reference points (Lawton et al., 1996). In tasks such as direction giving, women tend to refer to landmarks more frequently than men, whereas men rely on cardinal directions more frequently than women (Dabbs Jr et al., 1998; Harrell et al., 2000; Lawton & Kallai, 2002; Montello et al., 1999). Furthermore, women tend to perform better in remembering landmarks and their locations (Lawton & Kallai, 2002; Montello et al., 1999). Women also have an advantage in identifying the shapes whose locations have been changed.

There are also studies that have not found a significant difference between genders in wayfinding tasks (Lawton et al., 1996; Malinowski & Gillespie, 2001). Brown et al. (1998) looked at gender differences by investigating landmarks, cardinal cues, and relational cues using maps and found no significant difference in overall wayfinding performance.

Overall, there is no clear evidence to suggest that one gender has superior levels of wayfinding skills. Women generally perform better in tasks involving landmarks and estimating distances (Lawton et al., 1996). Men, on the other hand, outperform women in terms of knowledge gained from travel, survey knowledge tasks, recognizing the overall environment, directional cues, and objects that are out of sight (Kitchin & Freundschuh, 2000).

Age is the other individual factor that may affect wayfinding performance. Previous research comparing younger and older adults' wayfinding and cognitive abilities suggests that older adults have more difficulty than younger ones in tasks related to memorizing maps, navigation, route learning, place learning, and map learning because of cognitive declines such as changes in short-term memory, response times, and attention (Iaria et al., 2009; Jansen et al., 2009; Mahmood et al., 2009; Rodgers et al., 2012).

Moffat et al. (2001) investigated the effect of age differences on spatial memory in virtual environments. They found that older adults took a longer time to solve the trials, traveled longer routes, and made more errors than younger participants. Lee and Kline (2011) explored the effect of wayfinding aids on wayfinding performance in older and younger adults in a virtual healthcare facility and found that older adults had a harder time recalling from memory when aids were not present. Iaria et al. (2009) analyzed the difference in forming cognitive maps between younger and older adults in a virtual environment and found that older adults needed more time to create and form cognitive maps, made more wayfinding errors, and needed more time to travel the route.

In addition to gender and age, familiarity, visuospatial abilities, experience, and education level have been mentioned as factors that may affect the acquisition of spatial knowledge. Dogu and Erkip (2000) stated familiarity is a critical factor that affects wayfinding behavior in interior spaces. Furthermore, they also associated individual differences such as education, occupation, and past experiences with wayfinding behavior. The visuospatial ability, defined as the ability to process information about spatial relations, is another factor that affects spatial knowledge acquisition (Meneghetti et al., 2021). There are studies that suggest that people with better visuospatial abilities had a higher performance in navigation with blindfolds than people with lower visuospatial working memory (Weisberg & Newcombe, 2016). Visuospatial abilities have been linked to mathematics achievement in a sense that mathematics students have been found to outperform humanities students in visuospatial tasks (Hubber et al., 2019).

2.2. Cross-modal Correspondence

There is a long history of research on cross-modal correspondence between auditory stimuli and color (Cytowic, 2002; Menouti et al., 2015; Sun et al., 2018; Ward et al., 2006). People tend to make reliable associations between specific dimensions of vision and sounds, such as loudness, visual size, brightness, and hue. Based on cross-modal links between visual and auditory stimuli, brightness and loudness are matched crossmodally (Mondloch & Maurer, 2004). Light grey colors have been matched with louder sounds, and darker grey colors have been matched with quieter sounds. People also match high-pitched tones with brighter surfaces and lighter colors (Marks, 1974) and louder sounds with visual stimuli that have higher contrast. Loud sounds have also been matched with larger shapes in a study conducted with children (Bond & Stevens, 1969).

Marks (1974) is one of the key researchers who studied the correspondence between specific features of vision and hearing. His findings indicate the association of high-pitched and louder sounds with light colors. Hagtvedt and Brasel (2016) analyzed the correspondence between the frequency of music and the lightness of color and found that light-colored objects with high-frequency sounds guided participants' visual attention. In addition to color, there are studies that suggest a correspondence between sound and other visual stimuli such as visual shapes (Adeli et al., 2014), and size (Evans & Treisman, 2010).

The use of cues and landmarks is essential for successful navigation in real and virtual environments (Commins et al., 2019; Jansen-Osmann & Fuchs, 2006; Morris, 1981). There is evidence that cue salience and physical properties (in terms of size, brightness, and proximity to the goal) impact spatial performance (Allen & Golledge, 1999; Commins & Fey, 2019). Brightness is among the characteristics that facilitate the memory of spaces (Hidayetoglu et al., 2012). As an example, brighter colors are more attractive (Camgöz et al., 2004) and enhance people's perception (Read, 2003), thus, can lead users toward their destination (Hidayetoglu et al., 2012). Considering the association between sound and certain visual features such as brightness and size and the variety of sound sources in terms of loudness and frequency in outpatient polyclinics, we hypothesize that the sound sources that stand out against the background and are associated with specific landmarks will enhance spatial knowledge.

CHAPTER 3

THEORETICAL FRAMEWORK

Landmarks are among the most important and mostly studied elements in spatial knowledge acquisition; however, the majority of the studies focus on the visual aspects of landmarks, such as visibility and saliency. Other sensory cues can also impact spatial knowledge; however, there are scarce studies on the effect of other cues on spatial knowledge. With this gap in mind, this section discusses the theoretical framework of the study.

The sound environment contains different sounds simultaneously (Raimbault & Dubois, 2005). Some of these sounds may attract the listener's attention more than others based on the physical characteristic of the signals and the meanings they carry (Papadopoulos et al., 2012). The sound environment of hospitals is generally described as chaotic and noisy (Löf et al., 2006), with high levels that fluctuate over time (Johansson et al., 2012), populated by speech and a variety of mechanical noises such as paging systems, floor cleaners, beeping alarms and air-conditioning systems (Ryherd et al., 2008).

Through an exploratory study, the effect of the available sound sources (landmarks with unique sounds), in a virtual outpatient polyclinic, on spatial knowledge acquisition, when combined with visual landmark and signage and in isolation will be investigated. The results of the current study are published in Dalirnaghadeh and Yilmazer (2022). The logic behind this study is based on the findings on multisensory representation, characteristics of auditory attention, and auditory input processing. Multisensory representation suggests that a congruent appearance (in terms of time, location, and meaning) of sound stimuli with a visual target leads to better attention, perception, and memory because of providing more detail in comparison to unisensory presentations (Lehmann & Murray, 2005; Spence et al., 2004; Talsma et al., 2010; Werkhoven et al., 2014). Furthermore, the representation of sound objects in memory is more long-lasting than visual objects. Additionally, auditory input processing occurs earlier than visual input processing (Zimmermann et al., 2016).

The information from different modalities is stored and processed in the working memory before being sent to long-term memory (Baddeley, 1992). The working memory comprises a visuospatial sketch pad, a central executive, and a phonological loop. The phonological loop holds speech-based and acoustic information while the visuospatial sketch pad processes visual and spatial information. In that sense, audio information provided by the sound environment of the outpatient polyclinic would be processed in the phonological loop, while the visual information would be processed in the visuospatial sketchpad. Hence, if one of the modalities fails to encode or retrieve information, the second may still be successful (Butler et al., 2011).

Previous research has shown that visual and spatial components of working memory are involved in acquiring landmark, route, and survey knowledge (Wen et al., 2011). Here, the aim was to assess whether receiving information from two different modalities (visual and audio) would aid the acquisition of spatial knowledge. Although the literature has stated the benefits of multisensory presentations on attention and memory, there are limited studies that have focused on the effect of multisensory presentations on spatial knowledge. The available ones have only looked at the effect of multisensory presentations on wayfinding and not on spatial knowledge tasks. With this gap in mind, the theoretical framework of the study presented in figure 1 was prepared. Based on this framework, the context provides environmental stimuli that can be visual, auditory, or tactile. The information from these modalities results in auditory and visual memory representations that are assessed independently. The phonological loop processes auditory information while visuospatial information is processed by the visuospatial sketchpad (Baddeley, 1992). These components of working memory lead to landmark, route, and survey knowledge that induce spatial knowledge acquisition (Wen et al., 2011). Within this context, it was hypothesized that the sound sources (landmarks associated with sound) available in the acoustic environment of an outpatient polyclinic would lead to a better spatial knowledge acquisition when combined with visual signage.

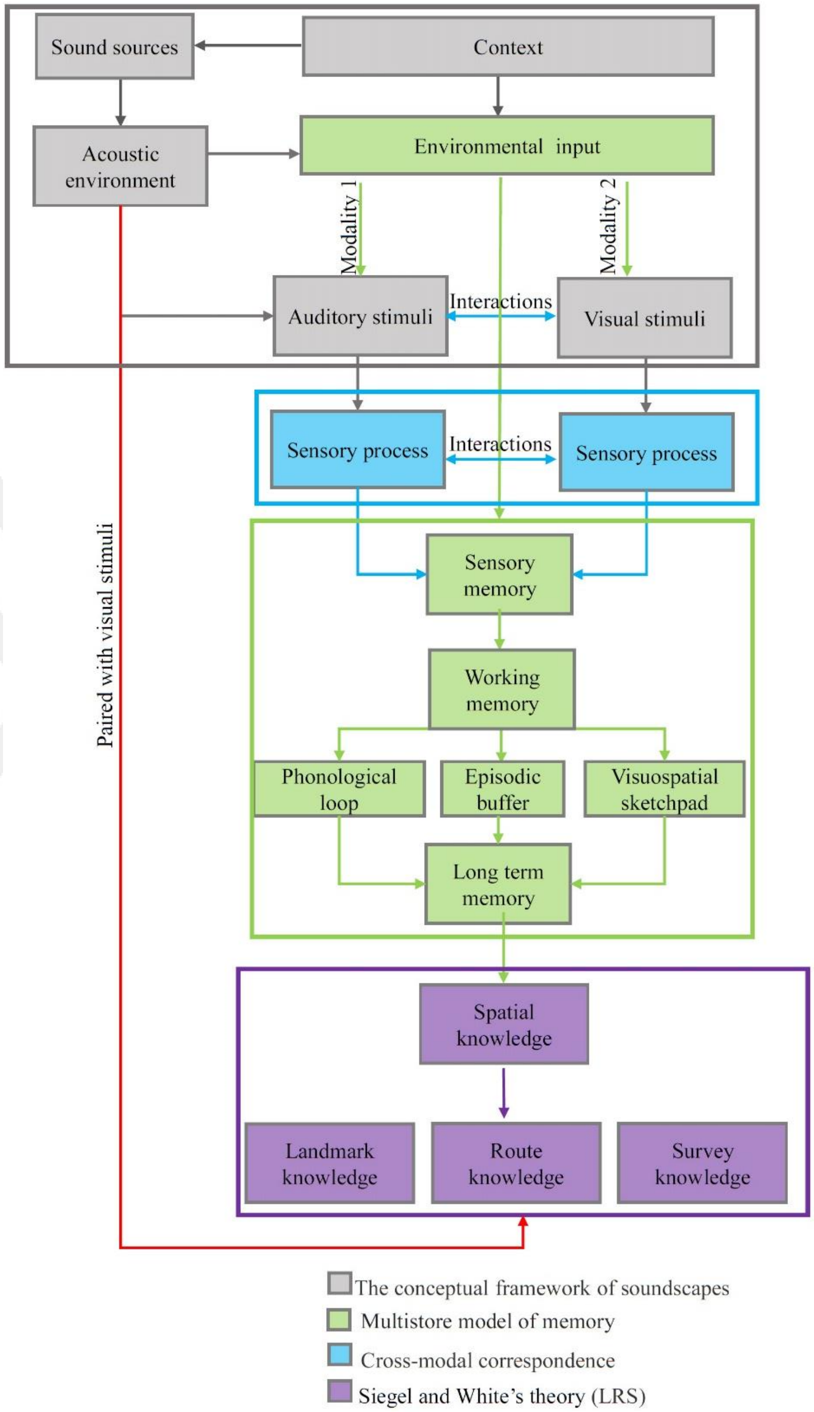


Figure 1. The theoretical framework of the study

This study has used audio and visual information derived from a real outpatient polyclinic in a simulated virtual environment. The motivation of this study is twofold. Firstly, it aims to contribute to the studies conducted on spatial knowledge by looking at the role of the sound environment. Secondly, it intends to provide grounds for using the sound environment as a design element to promote spatial knowledge by analyzing the physical and perceptual characteristics of the sound.

CHAPTER 4

METHODOLOGY

4.1. Design of the Research

This study was designed to address the gaps mentioned earlier and to provide a foundation for developing a new model for designing efficient wayfinding systems. In order to be able to employ sound as a resource for conveying spatial knowledge, first, the effect of sound needs to be investigated. The research can be summarized into the following steps:

1. Choosing an outpatient polyclinic with identical architectural features that makes wayfinding daunting,
2. Preparing audio and visual recordings of the environment,
3. Producing the virtual environment with varying details of visual and audio data,
4. Conducting the spatial knowledge tasks to determine the differences and similarities between the groups,

5. Analyzing the sound signal to explore the association between audio and visual contents in the environment,

4.2. Research Questions and Hypotheses

The study has two main questions, each with two sub-questions. These questions are:

RQ1: Is there any difference in spatial knowledge performance between different groups (control group, visual only, audio-only, audio-visual-only)?

a. Do sound, visual signage, and visual landmarks have an equivalent impact on spatial knowledge performance?

b. Are sound, visual signage, and visual landmarks essential for the acquisition of spatial knowledge?

c. Are there any differences between the performance of different genders in the spatial knowledge tasks?

RQ2: How does the sound environment of a virtual outpatient polyclinic provide cues for users that affect spatial knowledge acquisition?

a. Would there be any differences between the remembered landmarks across the different groups (control group, visual only, audio-only, audio-visual-only)?

b. Does the soundscape (sound sources linked with landmarks) provide sufficient cues for acquiring spatial knowledge?

Accordingly, the hypotheses of the study are:

H1a: The audio-visual group would have the best performance in spatial knowledge tasks. The rationale is that visual signage combined with sound from the soundscape draws more attention to the reference points.

H1b: The visual-only and audio-only groups would have a similar performance in spatial knowledge tasks. The rationale is that hearing, similar to vision, is a distance sense and can provide information about objects that are near or far in the environment.

H1c: The control group would have the worst performance in spatial knowledge tasks.

H1d: Males and females would have a similar performance in spatial knowledge tasks.

H2: Landmarks associated with a sound that stands against the background would be more memorable.

H3: Properties of the sound environment (both physical and perceptual) enhance performance in spatial knowledge tasks.

H4: A shift in the sound environment in line with the visual events would make landmarks or places more memorable.

4.3. Virtual Environment

In this study, the outpatient polyclinic of Bilkent Integrated Health Campus in Ankara was simulated to create a desktop virtual environment with predetermined routes that did not involve active wayfinding tasks. This hospital is the largest city hospital in Turkey (Kerman et al., 2012; Özkan, 2018) and serves as one of the hospitals to treat COVID-19 patients. This outpatient polyclinic has a large area and complex layout that make it a suitable choice for study. Figure 2 presents the schematic plan of the outpatient polyclinic with the traveled route. A detailed description of the visual signage is provided in Appendix D. As can be seen in figure 2, the architectural landmarks available in the space are the escalators, staircases, two different admission desks, and visitors' elevators located at two different locations. All the architectural landmarks are local ones.

The real outpatient polyclinic was visited to capture visual and audio recordings of a route starting from the main entrance leading up to the neurology department. A Canon PowerShot G10 equipped with a binaural microphone was used to collect the real environment's visual and audio data. Figure 3 shows interior pictures of the space.

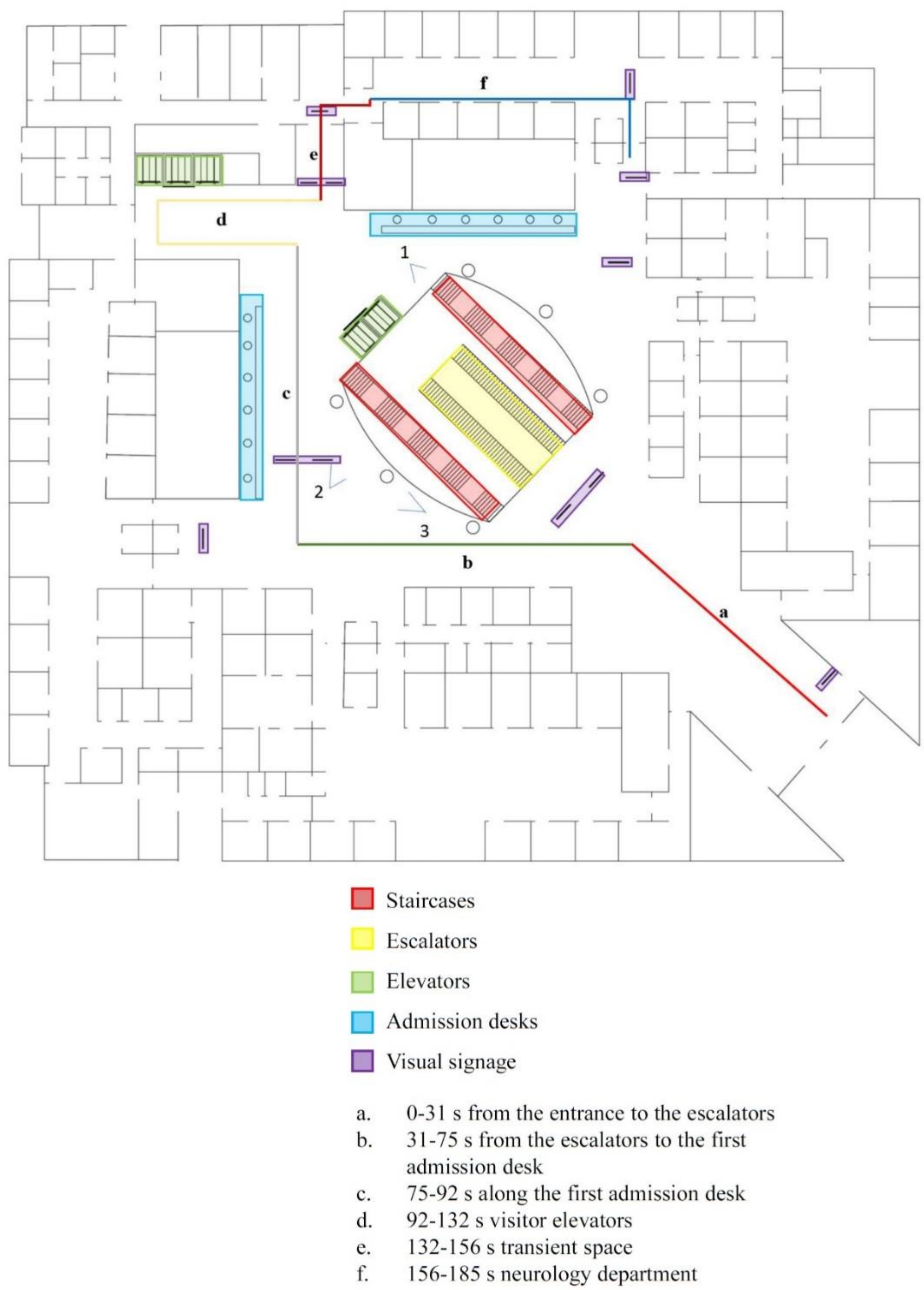


Figure 2. The outpatient polyclinic plan shows the entrance, the traveled route, the elevators, the escalators, and the patient administration desks. The interior pictures were taken from 1, 2, and 3. All the landmarks assessed (and omitted in group 3) are shown in the figure. The escalators and the elevators had distinct sounds.

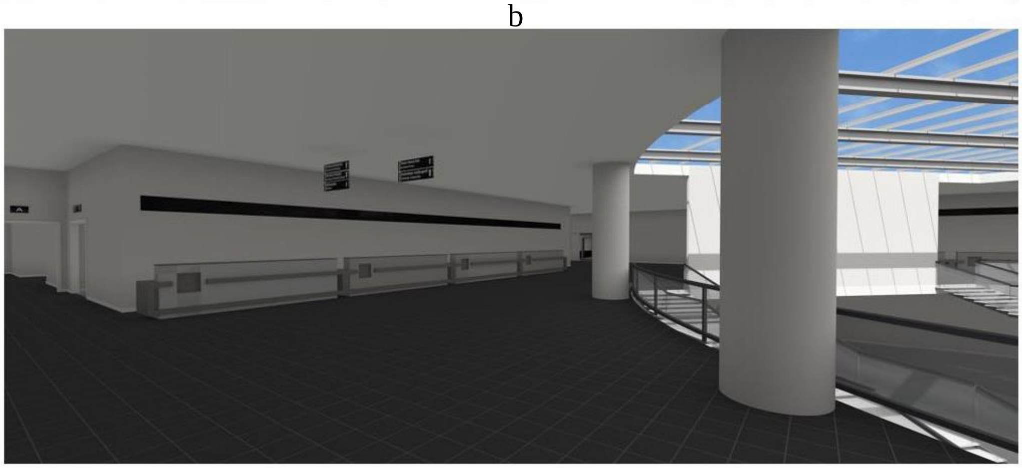
a b c

Figure 3. Interior pictures of the real environment; a) from the first admission desk towards the escalators b) from the second admission desk towards the escalators and the staircases, c) patient administration desks

Chief Architect Premier X11 was used to create a 3D simulation of the space. The scenes were rendered in real-time at a speed of 20 frames per second (Min & Ha, 2020). A video of the specified route was created by using the Walkthrough path tool for passive exploration. This route was similar to the one that was recorded in the real environment. Similar to previous virtual environments, the route was shown with a plain ceiling with sufficient contrast between the floor and the walls. No light sources were used to avoid directional cues from shadows (Sharma et al., 2017). The route was made of uniform and undistinguishable paths and neutral-colored walls so that the walls did not provide wayfinding cues (Lingwood et al., 2015). A simple model with grey-scale textures and little detail was preferred to assess users' performance in isolation from other factors as recommended by the literature (Kuliga et al., 2015; Natapov et al., 2015; Von Stulpnagel et al., 2014). Figure 4 presents renderings of the virtual environment.

a

b



c

Figure 4. Interior renders of the simulated virtual environment; a) renders showing the skylight and the escalators; b) renders from the exit of the neurology department; c) patient administration desks

4.4. Participants

In this study, a convenience sample of 80 students and employees from Bilkent University, Turkey was used. G*Power Software was used to calculate the total sample size for this study. This program can calculate sample size and power for a wide variety of statistical tests. For the ANOVA test, Cohen (1988) has suggested 0.25, and 0.4 for medium to large effect sizes respectively. For a medium effect size (0.25) at α=0.05, and 0.8 for power, a number of 68 participants was found sufficient. Sample Analysis of the data in all tasks showed a statistical power of higher than 0.80; thus, the sample size was sufficient to detect significant effects. Since familiarity with the setting could be a determining factor in task performance, the experiment was conducted with participants unfamiliar with the Bilkent Integrated Health Campus. The participants were randomly divided into four experimental groups that varied in the level of visual (signage) and audio (sound environment) stimuli, with 20 people (10 women and 10 men) in each group. Although the gender ratio is equal in all groups, participants' assignment to groups was random. All the participants were informed about the study protocol, voluntarily participated in the study, and filled a written consent form.

The participants' age distribution ranged from 19 to 40 years (mean=27.16 years, SD =4.527). Gender, age, education level, major, and nationality were collected as sample demographic information, shown in Table 1.

Table 1. Demographic characteristics of the participants in each experiment group (Group 1: Control group; Group 2: Visual-only; Group 3: Audio-only; Group 4: Audio-visual group)

	Gender		Education level		Age		Department				Nationality		
	F	M	University	Masters /PhD	M	SD	Engineer	Design	Science	Other	Turkish	Iranian	Other
Group 1	10	10	5 25.0%	15 75.0%	28.6	4.97	11 55.0 %	2 10.0%	5 25.0%	2 10.0 %	8 40.0%	9 45.0%	3 15.0 %
Group 2	10	10	2 10.0%	18 90.0%	27.2	3.82	13 65.0%	3 15.0%	0 0	4 20.0 %	7 35.0%	9 45.0%	4 20.0 %
Group 3	10	10	13 65.0%	7 35.0%	24.65	3.93	7 35.0%	5 25.0%	1 5.0%	7 35.0 %	15 75.0%	5 25.0%	0 0
Group 4	10	10	5 25.0%	15 75.0%	28.2	4.51	13 65.0%	5 25.0%	2 10.0%	0 0	9 45.0%	10 50.0%	1 5.0%
Total	40	40	25	55	27.16	4.52	44	15	8	13	39	33	8

4.5. Experimental Stimuli

Three different videos were created with the walkthrough path tool. One of the videos had the exact visual signage and landmarks from the real environment. The other one was wiped of all the available signage to create the control group's experiment setting, and the last video was wiped of all the visual signage and landmarks to create the setup for the audio-only group. The presented and omitted landmarks and signage are depicted in figure 2. The escalators, admission desks, elevators, and staircases were the landmarks. The escalators and visitor elevators had a distinct sound that stood out against the background sound. The justification for removing the signage and the landmarks was to assess the effect of sound environment on spatial memory when used in isolation versus when it was used in combination with visual signage and landmarks to see if the effect of audio and visual cues on spatial knowledge acquisition interacts with each other.

The videos with the visual signage and the one with no landmarks were reproduced by adding audio to them with Cyberlink PowerDirector editing software. Clapping was used to synchronize the video and sound information. Overall, four different experimental models were created that are:

- Group 1 (control group): No visual signage and no audio information was provided in the virtual environment. Only the landmarks were available.
- Group 2 (visual-only group): Visual signage and landmarks were provided in the virtual environment.
- Group 3 (audio-only group): All visual signage and landmarks were removed from the virtual environment. Only the sound environment was available.
- Group 4 (audio-visual group): Visual signage, landmarks and polyclinic sound environment were provided in the virtual environment.

The models were animated with a wide-angle lens following the route to provide a 65-degree field of view and a more immersive virtual environment (Lee & Kline, 2011). Figure 5 represents screenshots of each experiment group.

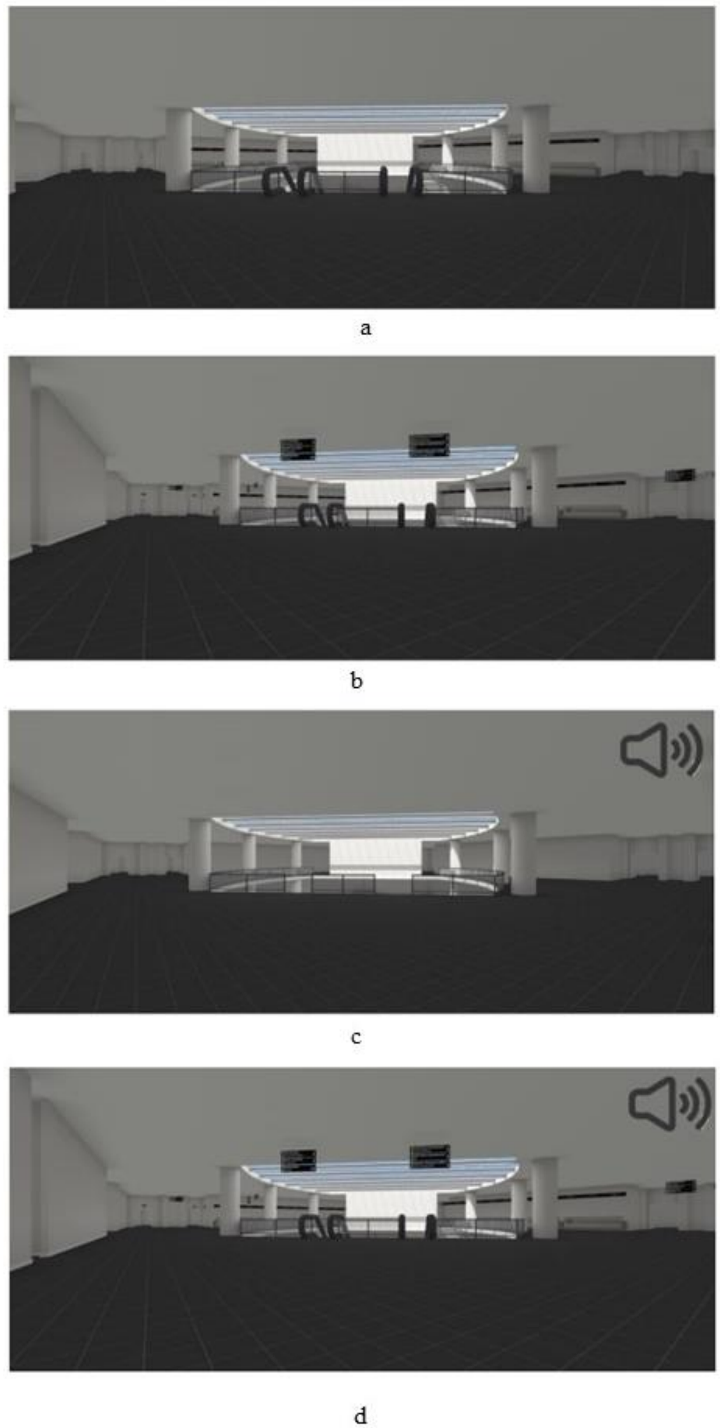


Figure 5. Created videos for each experiment group; a) Control group; b) Visual-only, c) audio-only; d) audio-visual group

The simulated eye height was set to 1.60 meters from the floor, and the walking speed was a constant of 1.1 m/s (Haq et al., 2005; Lee & Kline, 2011; North, 2002). The video duration was 185 seconds (including stops before the intersections). The route was identical for the different conditions, with a length of 154 meters and eight direction changes (three times left, five times right). A 17-inch Asus personal computer was used (2.59 GHz, 16 Gb RAM with an nVidia GeForce GTX 960) as an apparatus to provide visual information. The laptop was placed on a desk, and the participants sat in a chair approximately 50 cm from the screen. Each participant undertook the test individually and without interruption in the experimenter's office with closed doors and windows. Binaural signals of the soundscape were delivered by computer through headphones (ROG Strix Fusion 300 7.1) (Shu & Ma, 2018).

4.6. Procedure

The scenario of the test was introduced to the participants before the test. Participants were asked to watch a video of a route and recall details such as where to turn and certain architectural elements. No information was provided on which aspects of the route they should pay attention to. A questionnaire (See Appendix A and B) was handed out to each participant before viewing the video. Before watching the video, the participants were asked to answer demographic information about themselves. The participants' hearing was tested with the Widex online hearing test. All the participants had normal hearing. Although there were no sound stimuli in the control group (group 1) and visual-only (group 2), all the participants were asked to wear headphones for standardization and to create a feeling of presence (Liu et al., 2020; Marples et al., 2020). After the hearing test and filling in demographic information, the participants watched the video. The video started from the outpatient polyclinic entrance, traveled across the patient admission desks and elevators, and finally arrived at the destination, the neurology department. The plan of the space was not available to the participants during the learning phase. Figure 6 presents a schematic flowchart of the procedure.

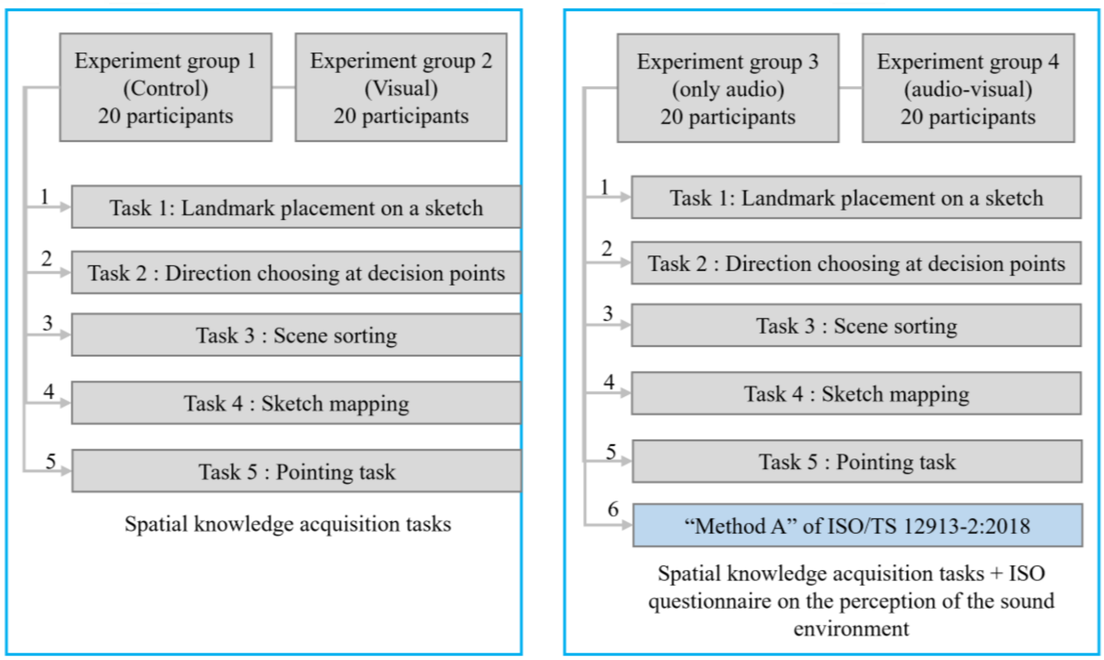


Figure 6. Schematic flowchart of the study

4.7. Performance Tasks

After watching the video, all groups were asked to do five different spatial memory tasks using the Landmark-Route-Survey model representation (Cogné et al., 2018). A landmark placement task was used to measure landmark knowledge. In this task, the participants were presented with a schematic plan of the outpatient polyclinic that showed the beginning of the route. They were asked to place the escalator, the staircases, the elevators, and the patient administration desks on the blank plan as accurately as possible similar to previous studies (Meneghetti et al., 2017; Muffato et al., 2017). For scoring purposes, the completed sketch maps were scanned and uploaded to Gardony Map Drawing Analyzer (GMDA version 1.2) (Gardony et al., 2016). This software is based on a bidimensional regression method (Friedman & Kohler, 2003) and compares the landmarks' location on the map and their Cartesian coordinates previously calculated on the target layout. The program generates several parameters. Like previous studies, the canonical organization's square root (SQRT-CO), ranging from 0 to 1, as a global index of accuracy was considered (Muffato et al., 2017). A higher score indicates a better performance. See the Appendix C for details of the tasks.

A direction choosing and scene sorting task were used to measure route knowledge. For the direction choosing at different decision points, the participants were asked to watch the video again, but this time the video would pause at each decision point, and the participants were asked to choose the correct direction (straight, right, and left) at each point (6 points to choose), on the questionnaire. Feedback was provided to the participants after answering each question, similar to previous studies (Muffato et al., 2020). Percentages of correctly taken directions were considered for scoring purposes (Wen et al., 2011). In the scene sorting task, the participants were presented with eight pictures taken along the route and were asked to sort them chronologically (Wallet et al., 2011). In this task, the sorting errors were counted. This score was then compared to the best possible score (i.e., 8) to obtain percentages.

A sketch-mapping and a pointing task were used to measure survey knowledge. In the sketch-mapping task, the participants were presented with the plan showing the escalators location, the staircases, and other architectural elements and were asked to draw the route they had watched on the video (Wallet et al., 2011). A pass or fail method was used to analyze the data (Cogné et al., 2018). If the route was drawn correctly, a passing score was considered, while a wrong turn at any of the decision points would lead to a failing score in the sketch-mapping task. In the pointing task, the participants were asked to imagine standing at a given landmark, facing another, and pointing to a third (Muffato et al., 2017). For scoring purposes, the circular mean of the minimum angles between each participant's response and the correct direction (0–180°) was considered (Borella et al., 2015; Muffato et al., 2017). The final pointing score consisted of the mean error score for the four pointing tasks.

Additionally, the participants in groups 3 and 4 filled in "Method A" of ISO/TS 12913-2:2018 questionnaire on the sound environment (Acun & Yilmazer, 2018, 2019; Orhan & Yilmazer, 2021) (ISO, 2018). The first part of the questionnaire classifies the sound sources into four categories: traffic noises, other sounds, sounds from human beings, and natural sounds on a scale from “1-not at all to 5-dominates completely”. The second part examines the sound environment's perceived affective quality based on eight perceptual attributes (pleasant, chaotic, vibrant, uneventful, calm, annoying, eventful, and monotonous) on a scale from “1-strongly disagree to 5-strongly agree”. The perceived affective quality is based on a two-dimensional model proposed by Axelsson et al. (2010). This modal is defined by four bipolar factors: the two orthogonal factors, Pleasantness and Eventfulness, which are located at a 45° (degrees) rotation from the second set of orthogonal factors, Calmness, and Excitement. According to this model, an exciting soundscape is pleasant and eventful, whereas a calm soundscape is pleasant and uneventful. In the same way, a chaotic soundscape is unpleasant and eventful, whereas a monotonous soundscape is unpleasant and uneventful. The data is generally presented on a radar graph to demonstrate the association between the attributes based on each attributes’ mean score. The third part of the questionnaire assesses the sound environment on a scale from 1-very bad to 5-very good, and the fourth part analyzes the appropriateness of the sound environment on a scale from 1-not at all to 5-perfectly.

4.8. Data Analysis

The Statistical Package for the Social Sciences (SPSS 25.0, IBM, USA) was used to analyze the data. All tasks showed good internal reliability (Cronbach’s α from 0.70 to 0.88). Leven’s test in all tasks indicated homogeneity of variance; thus, parametric tests were used to analyze the data. As discussed in section 2.1.1.1.5, gender is one of the individual factors that may affect spatial knowledge acquisition. Thus, gender and experiment group were considered as independent variables, and task performance was considered as the dependent variable. In that sense, A two-way ANOVA was used to analyze the data between the groups in all tasks except the sketch-mapping task. Tukey’s

Honestly-Significant-Difference (TukeyHSD) was used as a post-hoc test to make pairwise comparisons between the groups. In the sketch-mapping task, since the data was categorical (fail or pass), a chi-square test was used to make pairwise comparisons between the groups.

CHAPTER 5

RESULTS

5.1. Spatial Knowledge Performances in Each Task

Task 1 (Landmark placement on a sketch) analysis: Results of a two-way ANOVA indicated no significant effect of gender in the landmark placement task, $F(1,72) = 0.116$, $p=0.734$, $\eta^2 = 0.002$. Furthermore, no interaction was detected between gender and group; $F(3,72) = 0.364$, $p=0.779$, $\eta^2 = 0.015$. However, there was a significant difference between the experiment groups; $F(3,72) = 16.411$, $p < 0.001$, $\eta^2 = 0.406$ (observed power = 1.000). Tukey HSD was applied to compare performance in a pairwise fashion. There was a significant difference between group 1 and group 4, $p<0.001$, and between group 2 and group 4, $p<0.001$, and between group 3 and 4, $p<0.001$; however, there was no significant difference between group 1 and group 2 ($p=1.000$), group 1 and 3 ($p=0.099$), and 2 and 3 ($p=0.108$). The participant in group 4 scored higher (mean score=0.777) than group 2 (mean score=0.497), group 1 (mean score=0.499) and group 3 (mean score=0.355). See Figure 7 for the representation of the data analysis between the experiment groups in task 1 regardless of gender. Table 2 presents the mean scores in each group regarding gender differences. Crosstabs were also prepared on the association between the remembered landmarks and the experiment groups, as seen in table 3.

Table 2. Mean scores and p values in different group in task 1. Means with different letters indicate significant difference at P<0.05 between groups within each gender.

Gender	Groups	Mean	Std. Error	P Value		
				Gender	Group	Gender*Group
Female	Control	0.49a	0.06	0.734	<0.001	0.779
	Visual	0.50 a				
	Only-audio	0.31a				
	Audio-visual	0.79 b				
Male	Control	0.51a				
	Visual	0.49a				
	Only-audio	0.40a				
	Audio-visual	0.76b				

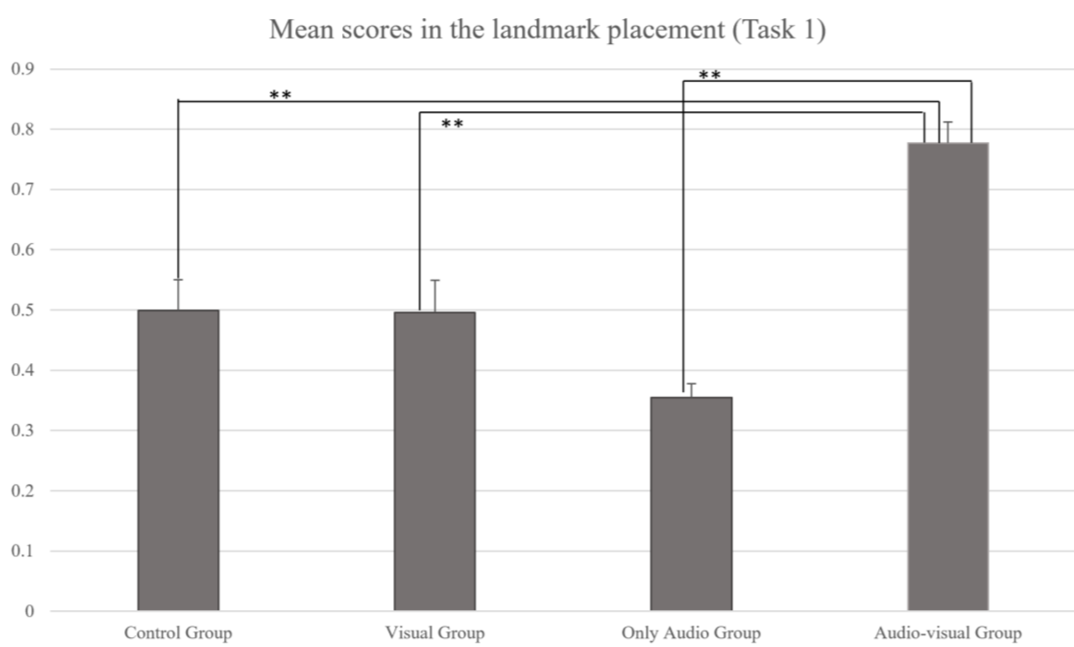


Figure 7. Mean scores in the landmark placement (Task 1) across the four experimental groups. Effects of gender (P= 0.734), groups (P < 0.001) and interaction between gender and group (P = 0.779) on landmark placement in task 1. Data represent the Mean ± standard error of the mean (error bars). Significant differences are indicated by asterisks that denote a significance level of $p < .05$. Landmark placement was influenced significantly by group but not by gender and gender × group interaction.

Table 3. Association between the remembered landmarks and the experiment groups.

	Escalator		Admission 1		Admission 2		Elevator 1		Elevator 2		Staircase	
	0	1	0	1	0	1	0	1	0	1	0	1
Group 1	2 10.0%	18 90.0 %	12 60.0 %	8 40.0%	12 60.0%	8 40.0%	13 65.0 %	7 35.0 %	18 90.0 %	2 10.0%	9 45.0%	11 55.0%
Group 2	4 20.0%	16 80.0 %	7 35.0 %	13 65.0 %	12 60.0%	8 40.0%	10 50.0%	10 50.0%	19 95.0%	1 5.0%	11 55.0%	9 45.0%
Group 3	5 25.0%	15 75.0%	14 70.0%	6 30.0 %	20 30.0 %	0 0.0%	14 70.0%	6 30.0 %	20 100.0%	0 0.0%	20 100.0 %	0 0.0%
Group 4	0 0.0 %	20 100.0%	3 15.0%	17 85.0%	7 35.0%	13 65.0%	2 10.0%	18 90.0 %	11 55.0%	9 45.0%	8 40.0%	12 60.0%
Total	11 13.8%	69 86.3%	36 45.0%	44 55.0%	51 63.7%	29 36.3%	39 48.8%	41 51.2%	68 85.0%	12 15.0%	48 60.0%	32 40.0%

In the landmark placement task, the escalators were correctly placed on the plan by at least 75% of the participants in all groups. The first admission desk was missed by at least 60% of the participants in the control and audio-only group, while more than 65% of the participants in the visual-only and audio-visual group placed it correctly on the plan. In the case of the visitor’s elevator (elevator 1), more than half of the participants in group 1 missed this landmark while 50% of the participants in the visual-only group placed it correctly. 70% of the participants in the audio-only group had misplaced the visitor's elevator while 90% of the audio-visual group placed the elevators correctly. The second elevators were missed by more than 90% of the participants in group 1, 2 and 3 while 55% of the participants in the audio-visual group remembered it correctly. The second admission desk was missed by 60% of the participants in groups 1 and 2 and all the participants in the audio-only group. 65% of the participants in the audio-visual had placed it correctly. The staircase was missed by 45% and 55% of the participants in groups 1 and 2, respectively. All the participants in the audio-only group had missed the staircase, while 60% of the participants in the audio-visual group had remembered it correctly.

Task 2 (Direction choosing at decision points) analysis: Comparison of the percentages of correct answers showed a significant effect of gender and group in this task. For gender the two-way ANOVA results were: $F(1,72) = 5.098$, $p = 0.027$, $\eta2 = 0.066$ (observed power=0.606). There was also a significant effect of group in this task; $F(3,72) = 4.199$, $p = 0.009$, $\eta2 = 0.149$ (observed power=0.838). Although both gender and group indicated a significant difference in this task, no interaction was detected between them: $F(3,72) = 1.983$, $p=0.124$, $\eta2 = 0.076$ (observed power=0.491). However, as the observed power in this test and the p-value suggests, if the sample size was bigger, an interaction between the variables would have been detected. The mean values and the differences between and within the groups have been presented in figure 8. Uppercase letters indicate a difference in each group between the genders (different letters present a significant difference). Lower case letters indicate a difference between the genders.

Tukey HSD was applied to compare performance in a pairwise fashion between and within the groups. There was a significant difference in the control (p=0.021) and audio-only group (p=0.035) between the genders in this task. In the control and audio-only groups males performed significantly better than females. Furthermore, there was a significant difference between the performance of females in the control (p=0.040), audio-visual (p=0.011), and a trend between audio-only and audio-visual (p=0.071). There was no significant difference between the performance of males in different experiment groups. The line graph in figure 9 depicts these differences more clearly. Table 4 presents the mean values between genders in different groups.

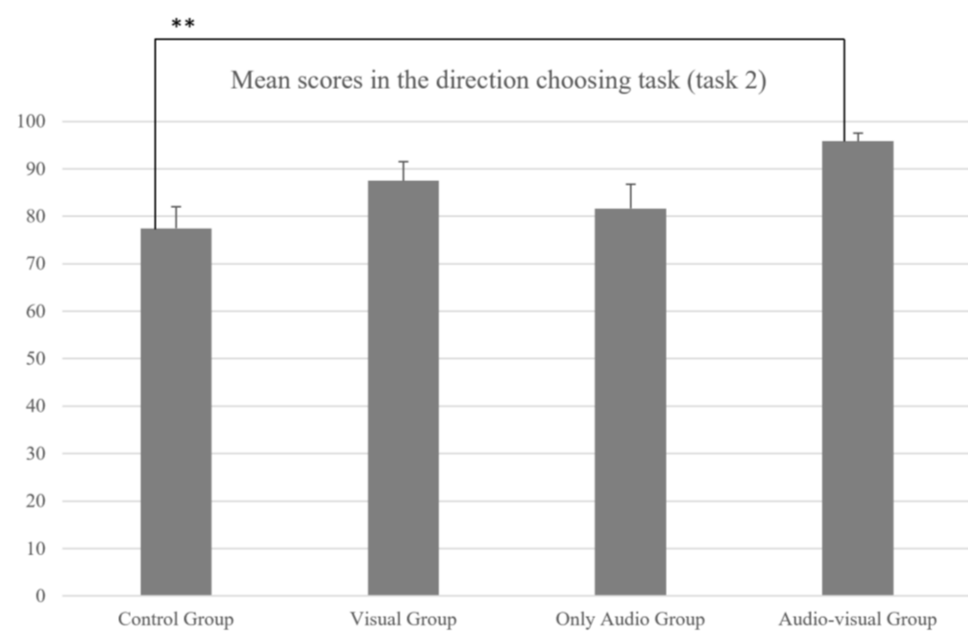


Figure 8. Mean scores in the direction choosing (Task 2) across the experiment groups. Effects of gender (P= 0.027), groups (P= 0.009) and interaction between gender and group (P = 0.124). Data represent Mean ± standard error of the mean (error bars). Significant differences are indicated by asterisks that denote a significance level of *p* < .05. Direction choosing was influenced significantly by gender and group.

Table 4. Mean scores and p values in different group in task 2. Means with lowercase letters indicate significant difference at P<0.05 between groups within each gender. Means with different uppercase letters indicate significant difference at P<0.05 between gender within each group.

Gender	Groups	Mean	Std. Error	P Value		
				Gender	Group	Gender*Group
Female	Control	68.33^{cA}	5.49	0.027	0.009	0.124
	Visual	90.00^{ab}				
	Only-audio	73.30^{acA}				
	Audio-visual	93.33^{ab}				
Male	Control	86.66^{aB}				
	Visual	85.00^{a}				
	Only-audio	90.00^{aB}				
	Audio-visual	98.33^{a}				

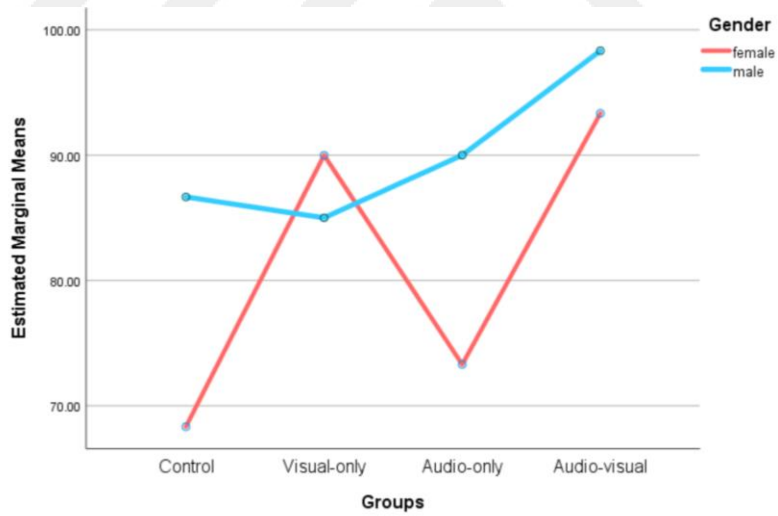


Figure 9. Difference in performance between the genders in different groups in task 2.

Task 3 (Sorting task) analysis: Comparisons of percentages of correctly ordered pictures indicated a significant effect of the experiment group on performance; F (3,72) = 4.944, p= 0.004, $\eta 2$ = 0.171 (observed power= 0.897). No significant effect of gender and no interaction between gender and groups were detected. Tukey HSD post hoc test indicated a difference between group 1 and group 4 (p=0.008) and a trend between 2 and 4 (p=0.072). No difference was detected between group 1 and group 2 (p=0.984), 1 and 3 (p=0.320), 2 and 3 (p=0.528), and 3 and 4 (p=0.491). The mean scores between males and females show a trend toward group 4 (mean score=86.875) performing better than group 3 (mean score=71.87), group 2 (mean score =57.50), and group 1 (mean score=53.75). Figure 10 and Table 5 present the data in each gender across the different experiment groups.

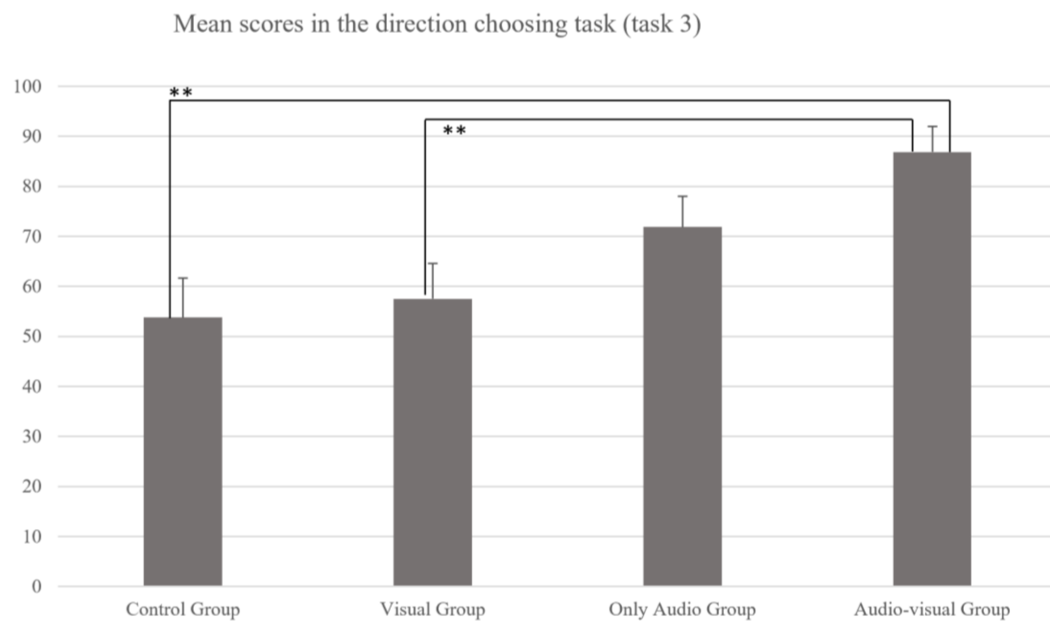


Figure 10. Effects of gender (P= 0.85), groups (P= 0.004) and interaction between gender and group (P = 0.928) in the Sorting task. Significant differences are indicated by asterisks that denote a significance level of $p < .05$. Data represent the Mean ± standard error of the mean (error bars). Sorting task was influenced significantly only by group.

Table 5. Mean scores and p values in different group. Means with different letters indicate significant difference at P<0.05 between groups within each gender.

Gender	Groups	Mean	Std. Error	P Value		
				Gender	Group	Gender*Group
Female	Control	51.25[a]	9.60	0.85	0.004	0.928
	Visual	55.00[a]				
	Only-audio	71.25[a]				
	Audio-visual	90.00[b]				
Male	Control	56.25[a]				
	Visual	60.00[a]				
	Only-audio	72.50[a]				
	Audio-visual	83.75[a]				

Task 4 (Sketch-mapping) analysis: In this task, the aim was to analyze whether the experiment group had any impact on passing or failing drawing the sketch map. Since the data were categorical, a Chi-square test was used to analyze the data. Similar to the other tasks; first, the effect of gender on task performance was analyzed. Results indicated no significant effect of gender between the groups, X^2= 0.952, p=0.329, and a significant difference between the groups, X^2= 13.759, p=0.003. Z scores were compared to see where the significance existed; p-values were adjusted with the Bonferroni method to avoid type 1 error (Beasley & Schumacker, 1995). The results suggested a significant difference between passed or failed sketch maps in group 1 and group 4 (X2=12.379, P<0.001), 2 and 4 (X2=8.640, p=0.003), 3 and 4 (X2=5.584, p=0.018). However, no difference was found between groups 1 and 2 (X2=0.440, P=0.507), 1 and 3 (X2=1.667, p=0.197), 2 and 3 (X2=0.404, p=0.525) in the proportion of passed or failed drawn sketch maps. The percentages of the correct answers within each group were compared. 30.0% in group 1, 40.0% in group 2, 50% in group 3, and 85.0% of the participants in group 4

successfully drew the sketch-mapping task. Table 6 presents the percentages of the correct and the wrong sketch maps.

Table 6. Number and percentages of correct and wrong sketch-maps (Task 4) across the groups

	Control group	**Visual-only**	**Audio-only group**	**Audio-visual**
Wrong	14	12	10	3
Within Groups	70.0%	60.0%	50.0%	15.0%
Correct	6	8	10	17
Within Groups	30.0%	40.0%	50.0%	85.0%

In addition to analyzing the percentage of correctly drawn routes in task 4, an additional analysis was conducted on whether or not the final part of the route, which is the neurology department, was correctly remembered. The reason behind this is explained in Figures 16 and 17. The neurology department has a unique sound environment that is different from the previous sections. Thus, to further analyze whether the entire department and its exit were remembered correctly, the groups were merged based on whether or not they had any audio. In that sense, the data on groups 1 and 2 were merged as the no-audio group, and groups 3 and 4 were merged as the audio-group. The results of a Chi-square test indicated a significant difference between the groups (X^2= 8.584, p=0.003). The crosstabs are depicted in table 7.

Table 7. Scores in Task 4 with merged groups

	No-audio-group	**Audio-group**
Wrong	24	11
Within Groups	60.0%	31.4%
Correct	16	29
Within Groups	35.6%	72.5%

Task 5 (Pointing task) analysis: The results indicated a significant effect of experiment group on performance; $F (3,72) = 13.201$, $p<0.001$, $\eta2 = 0.355$ (observed power=1.000). There was no significant effect of gender $F (1,72) = 0.130$, $p=0.720$, $\eta2 = 0.002$ and no interaction between gender and experiment group $F (1,72) = 1.130$, $p=0.343$, $\eta2 = 0.045$. Tukey HSD post hoc test indicated a significant difference between group 1 and group 2 ($p=0.014$), between group 1 and group 3 ($p<0.001$), 1 and 4 ($p<0.001$), and 2 and 4 ($p=0.023$). There was no significant difference between groups 2 and 3 ($p=0.539$), and 3 and 4 ($p=0.389$). The average deviation from the correct direction was the lowest for group 4 with 17.99 degrees, followed by group 3 with 37.62 degrees and group 2 with a 54.18-degree deviation. Group 1 had the worst performance with a 92.60-degree deviation. Figure 11 and Table 8 represent the data analysis in the pointing task.

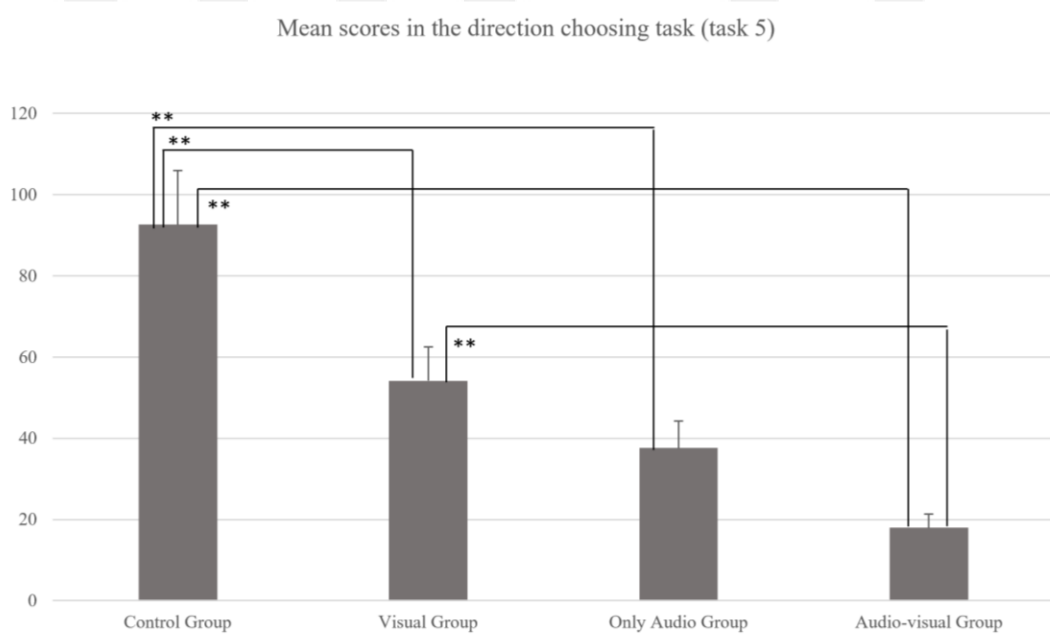


Figure 11. Effects of gender (P= 0.72), groups (<0.001) and interaction between gender and group (P = 0.343) in the pointing task 5. Data represent the Mean ± standard error of the mean (error bars). Significant differences are indicated by asterisks that denote a significance level of $p < .05$. Pointing task was influenced significantly only by group.

Table 8. Mean scores and p values in different group. Means with different letters indicate significant difference at P<0.05 between groups within each gender.

Gender	Groups	Mean	Std. Error	P Value		
				Gender	Group	Gender*Group
Female	Control	95.78[a]	12.33	0.72	<0.001	0.343
	Visual	47.73[bcd]				
	Only-audio	51.63[cd]				
	Audio-visual	13.56[d]				
Male	Control	89.43[a]				
	Visual	60.65[ab]				
	Only-audio	23.63[b]				
	Audio-visual	22.43[b]				

Overall, the results indicate a significant effect of the experiment group on acquiring spatial knowledge. Table 9 summarizes the ANOVA results and mean scores of the tasks across the experiment groups.

Table 9. Summary of ANOVA and mean scores across all tasks

Tasks	df	F	p	Experiment Groups	Scores *
Landmark placement	3	16.411	p<0.001	Control group	0.499
				Visual-only	0.497
				Audio-only group	0.355
				Audio-visual-only	0.777
Direction choosing	3	4.119	0.009	Control group	77.94
				Visual-only	87.49
				Audio-only group	81.64
				Audio-visual-only	95.83
Scene sorting	3	4.944	0.004	Control group	53.75
				Visual-only	57.50
				Audio-only group	71.87
				Audio-visual-only	86.87
Sketch-mapping	3	13.759 [a]	0.003	Control group	30 [b]
				Visual-only	40
				Audio-only group	50
				Audio-visual-only	55
Pointing task	3	13.201	p<0.001	Control group	92.60
				Visual-only	54.18
				Audio-only group	37.62
				Audio-visual-only	17.99

[a] X^2 values have been reported here.
[b] is the percentages of correctly drawn sketch maps.
* Scores are the mean average between the genders

5.2. Perceptual Analysis of the Sound Environment

To understand the participants' perception of the overall sound environment, the participants in groups 3 and 4 were asked to watch the video again and fill in Method A of the ISO/TS 12913-2:2018 (ISO, 2018) questionnaire after finishing the spatial knowledge tasks. Figure 12 shows the categories of the sounds heard by the participants in both groups. Human sounds were the dominant sounds in both groups.

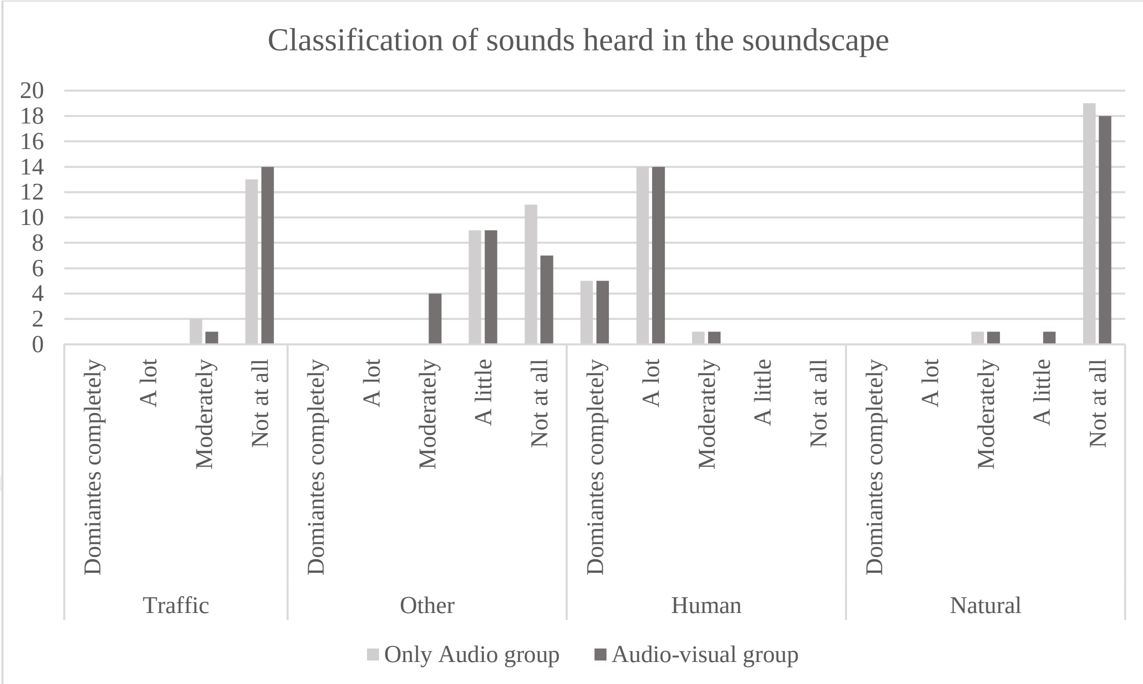


Figure 12. Classification of sounds heard in the soundscape

The radar graph presented in figure 13 shows the participants' perception of the sound environment through two orthogonal components of valence (annoying-pleasant) and activation (uneventful-eventful). Any perceptual outcome in the pleasant region is a positive sound environment (pleasant, calm, vibrant), while outcomes located in the annoying region make up a negative sound environment. The emotional assessment of the sound environment shows convergence towards the eventful-chaotic-annoying region that presents a negative sound environment.

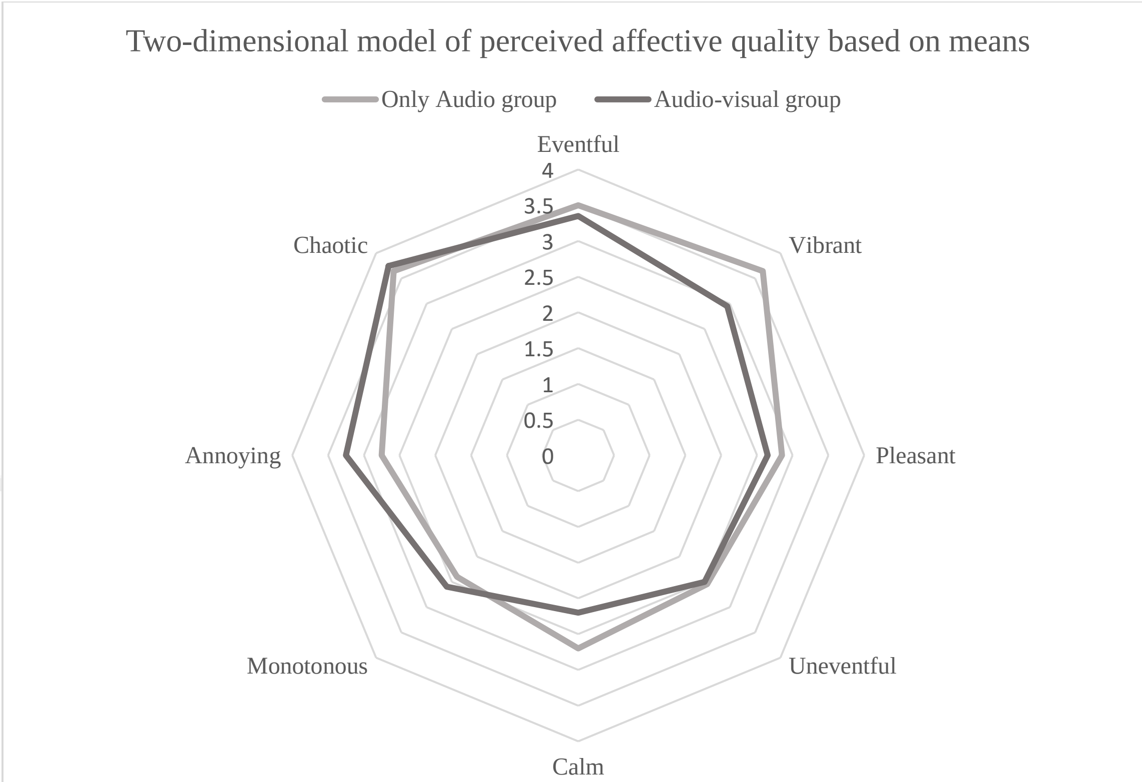


Figure 13. Two-dimensional model of perceived affective quality based on means

Figure 14 and figure 15 present participants' assessment of the sound environment and its appropriateness, respectively. The majority of the participants in group 3 rated the sound environment as neither good nor bad, while the majority of the participants in group 4 rated it as good. In terms of the sound environments' appropriateness, the majority of the participants in both groups rated it as either moderate or very much appropriate.

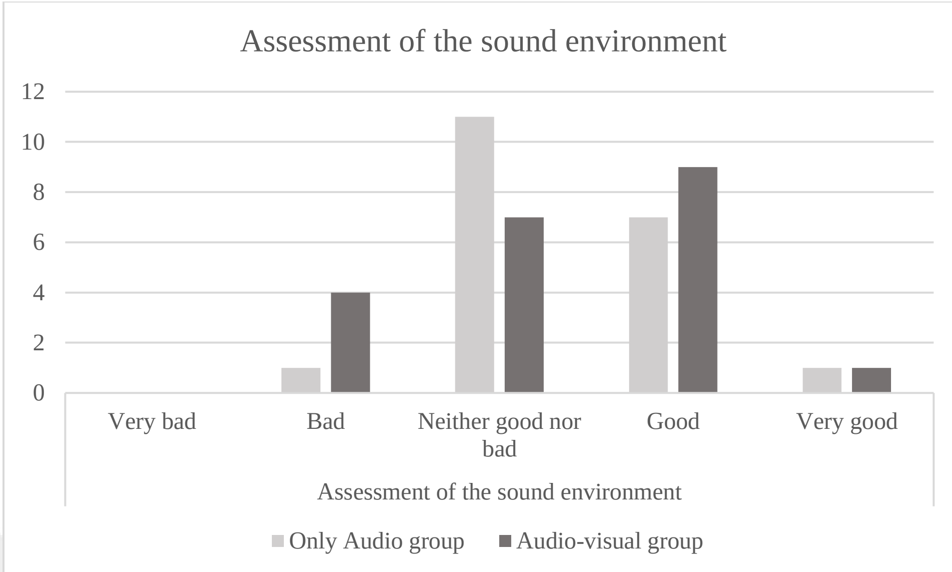


Figure 14. Assessment of the sound environment

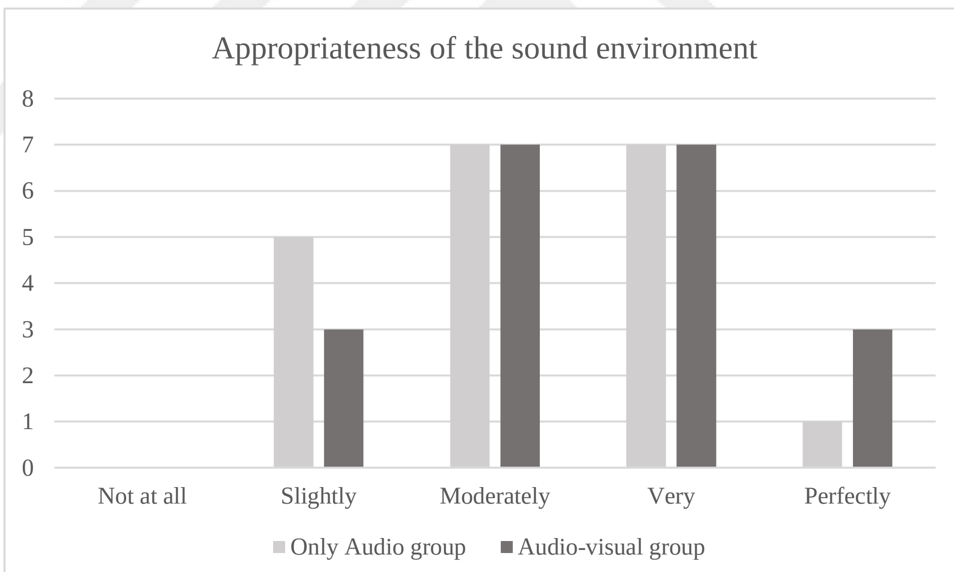


Figure 15. Appropriateness of the sound environment

5.3. Physical Analysis of the Sound Environment

This section discusses the role of the sound environment and its mechanism on how it may have promoted spatial knowledge by analyzing the recorded sound's content. To provide an empirical analysis of the sound environment, a detailed time-frequency analysis, not limited to temporal ones, was conducted, depicted in Fig.16. The spectrogram reveals the changes in the frequency content of the signal over time. The Fourier coefficient of each time-frequency pixel has been encoded in color in which the dark red and blue indicate two extremes of high and low coefficient amplitude, respectively. Based on this time-frequency content, the spectrogram has been divided into several temporal segments indicated by dashed red vertical red lines. The first segment (0-31s) is a temporal portion of the signal from the entrance to the escalators, which shows specific high-frequency content around 400 Hz with a wide bandwidth. The second segment (31s-75s) has a different time-frequency pattern indicating less prominent high-frequency content. This part of the route is from the escalators to the beginning of the patient admission desks. The third segment (75s-92s) has lower frequency variations and less prominent features in the frequency content that matches the acoustic experience of the participants along the patient administration desks. In the next segment (92s-132s), the elevator area has unique tones, which can be seen as short-term bursts around frequencies 0.5kHz and 1.2kHz. The fifth segment (132s-156s) indicates the transient time from the elevator area towards the neurology department entrance, which has distinct patterns than previous ones. This segment has a low amplitude auditory event and is generally quieter than previous segments. The final segment (156s-185s) depicted in figure 17, has distinct frequency content and patterns in low and mid frequency levels in the neurology department. If the analyzed segments are matched to the route's video, it can be seen that each sound segment has taken place in a different space of the outpatient polyclinic. A change in the sound environment's content takes place with a change in the route's direction. The change in amplitude and frequency of the sound environment along the route may have attracted the participants' attention to the route and other visual elements, resulting in better performance in the spatial knowledge task.

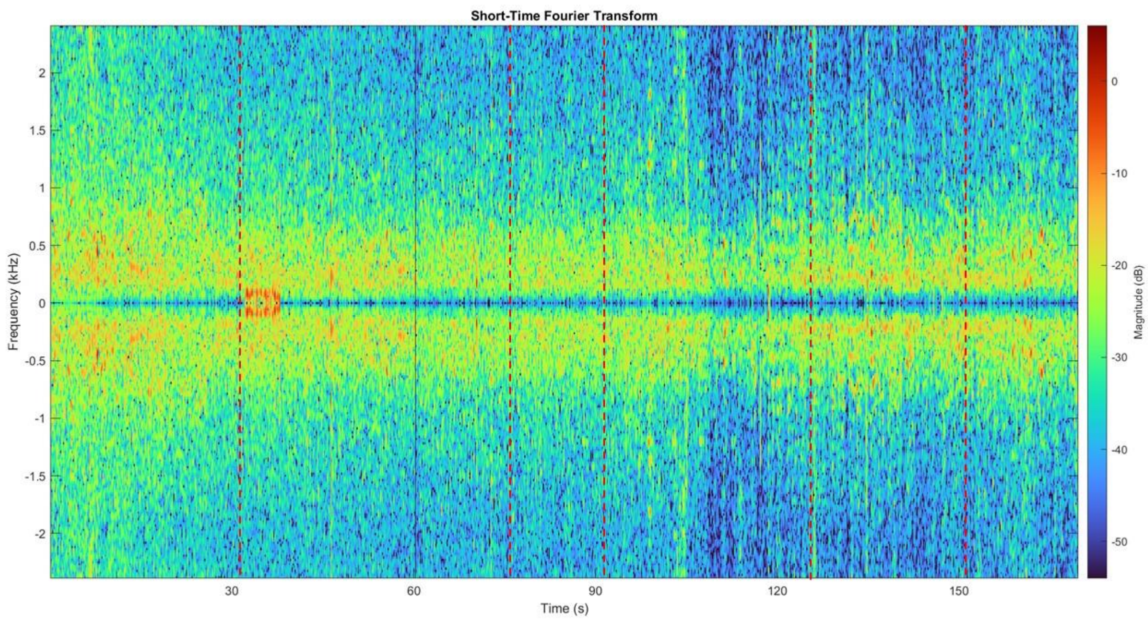


Figure 16. Short-time frequency transform (STFT) of the sound signal

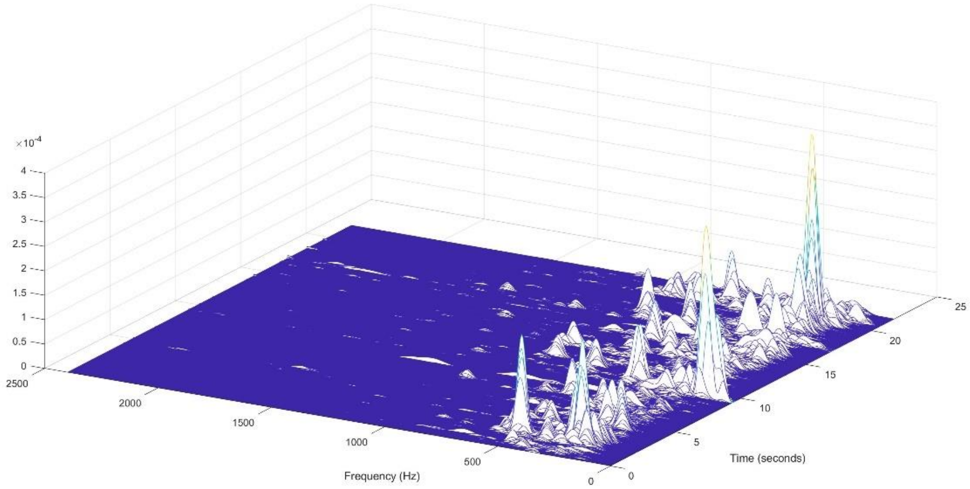


Figure 17. Short-time frequency transform (STFT) of the sound signal in the neurology department

To better grasp the acoustic qualities of the landmarks associated with a sound that stands out from the background, the excerpt was cropped from 30-39 seconds and 135-148 seconds. As seen in the 3D short-time frequency transform figures (figures 18 and 19), there are apparent changes in the audio signal that may have had a role in making the landmarks more memorable.

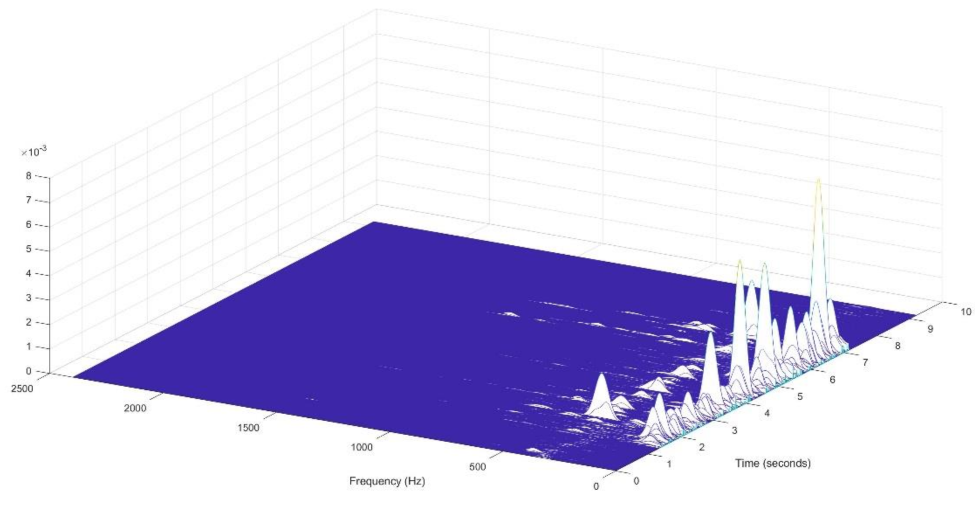


Figure 18. Short-time frequency transform (STFT) of the escalators

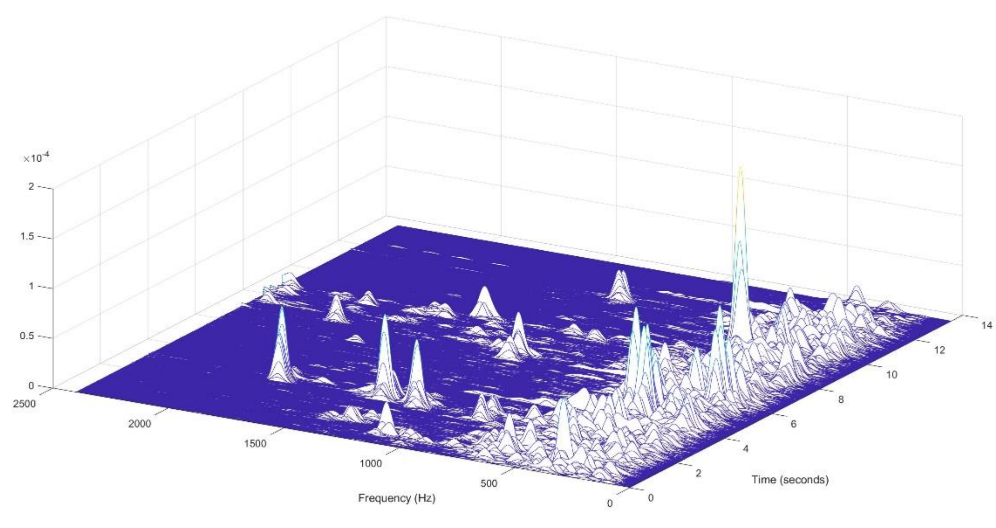


Figure 19. Short-time frequency transform (STFT) of the elevators

CHAPTER 6

DISCUSSION

This study examined whether adding the sound environment would enhance spatial knowledge task performance in a virtual outpatient polyclinic. A significant effect of the experiment group on spatial knowledge acquisition was found in all tasks. The audio-visual group had the best performance among the groups in all of the tasks, which confirms H1a. Another finding of the study was that there was no significant difference between the performance of the audio-only group and the visual-only group. Thus, H1b is also confirmed. Although the video that the audio-only group watched was wiped of all the landmarks such as escalators, admission desks, and elevators, the performance of the participants was comparable to the other groups. In the landmark placement task, the audio-visual group had a significantly higher performance than all the other groups. At the same time, there was no difference between the performance of the audio-only group and the visual and control groups. Considering that no landmarks were available in this group, it can be concluded that the sound environment is sufficient to provide landmark knowledge. Based on the percentages reported in table 3, it can be seen that the landmarks with sound were remembered better in the audio-only and audio-visual groups. This finding confirms H2 that hypothesized landmarks associated with a sound that stands against the background would be more memorable. The escalator is the landmark that has been correctly placed on the plan the most in all groups. The visitor's elevator is the second landmark that has been correctly placed. In the case of the escalator, memorability cannot be directly related to the unique sound qualities that the object produces. Its location in the central void, size and the sounds associated with it may have created a memorable landmark. The visitors' elevator has visible signage on its top and is associated with unique sounds. The insignificant difference between the control and visual group may be because of the signage. In contrast, the difference between the visual and audio-visual groups may be linked to the effect of sound. The second elevator is not located in the direct visual field; however, we can hear beeping sounds as we approach this elevator. This elevator is missed by almost 90% of the participants in groups 1, 2, and 3, whereas 55% of the participants in the audio-visual group have remembered it correctly. The audio-visual associations in this landmark may be one reason that it is remembered better in the audio-visual group.

Gender was one of the independent variables in the analysis. No significant effect of gender was detected in the tasks except the direction choosing task. This finding confirms H1d that males and females would perform similarly in spatial knowledge tasks. In this task, males performed better than females, while there were also significant differences between the females. Females have a relatively lower performance in the control and audio-only group. In the case of the experiment groups, the control group had a significantly lower performance than the audio-visual group, but the visual-only, audio-only, and audio-visual groups had a relatively similar performance. This task was the only one that required the participants to watch the video again with pauses in the decision points. Therefore, there may be a ceiling effect on the performance of all groups. Although there is a significant difference between males and females in all groups, all the participants had a relatively high performance (more than 70%). In the sorting task, groups 1 and 2 performed significantly less than the audio-visual group. Again, the audio-only group had a similar performance to the audio-visual group. The audio-visual group had a significantly higher performance. Considering the unavailability of landmarks in the audio-only group, the existence of the sound environment has been found sufficient to achieve route knowledge similar to landmark knowledge.

The audio-visual group had significantly higher performance in the sketch-mapping task, similar to the previous tasks. There was no significant difference between the performance of the control, visual and audio-only groups. In the pointing task, the control group had a significantly lower performance than the other groups. This finding approves H1c, which hypothesized that the control group would have the lowest performance among the groups. While the visual-only group had a lower performance than the audio-visual group, there was no difference between the performance of the audio-only group and the audio-visual group. Thus, similar to landmark and route knowledge, survey knowledge can also be achieved through the sound environment in the absence of visual information. This finding indicates that spatial knowledge may be gained without landmarks, which is in line with the findings of Allen (1988). It should also be mentioned that there was no significant difference between the visual and control group except for the pointing task. This shows that visual signage used in isolation does not necessarily enhance performance, as stated in the introduction (Lee et al., 2014; Rousek & Hallbeck, 2011).

The audio-visual group's significantly higher performance is consistent with the theoretical framework in Figure 1 that suggests gathering information from different modalities would lead to better memory and, therefore, better spatial knowledge. In the audio-visual group, both the phonological loop (sound environment) and visuospatial sketchpad (signage and the surrounding visual environment) are processing information. The dual processing of information may explain the high performance of the audio-visual group in comparison to the other groups. Another speculation is that the sound environment, with its fluctuations across the route, had a better pop-out effect, which is one of the characteristics of good landmarks (Lynch, 1960). The simulated virtual polyclinic is visually uniform with no lighting and color contrast between different route sections. At the same time, the sound environment has unique and discernible peaks and dips that may have made the visually uniform spaces distinguishable from each other. However, rather than any environmental sound, the exact sound environment of the traveled route in the outpatient polyclinic with its own unique physical and perceptual characteristics was used. Based on the short-time frequency transform analysis of the signal, it can be seen that the frequency and amplitude of the signal change along the route. Loudness or amplitude, a subjective characteristic of sound, is a perceptual cue for humans and allows them to distinguish different sounds and is related to pressure level and energy distribution in frequency and time (Buus et al., 1997; Jepsen et al., 2008; Secchi et al., 2017). The changes in frequency and amplitude of the signal along the route may have attracted the participants' attention to the decision points that helped them perform better in spatial knowledge tasks. The analysis of the short-time frequency transform approves H3 and H4, which hypothesized that the physical properties of the sound environment and the shifts in amplitude and frequency that are congruent with architectural landmarks in the space lead to higher performance in spatial knowledge tasks. Another explanation could be that visual information provided from signage and landmarks add semantic context to the sound information from the sound environment, leading to a better performance in spatial knowledge tasks.

Comparing the result to the studies mentioned in the theoretical background on the qualities of landmarks, certain similarities can be derived. As discussed earlier, size and contrast with the background are qualities that are associated with good landmarks. In the case of the sound environment, the changes in the amplitude are comparable to bigger landmarks, while the peaks and dips that are different than the background indicate contrast. Persistency was another feature of efficient landmarks. While the escalator and the elevator are persistent and similar to local landmarks, the announcement sounds in the neurology department may represent global soundmarks. Regarding location, the escalator and the elevator are located at decision points; more research needs to be conducted on landmarks associated with unique sounds and located along the route.

Furthermore, stimulation of the auditory cortex leads to increased activation in the visual cortex (Tranel et al., 2003). The addition of the sound environment may have enhanced activation of the visual cortex leading to a better performance in the audio-visual group. Furthermore, as the radar graph in Figure 13 indicates, the sound environment was perceived as chaotic and annoying, associated with arousal. Based on the findings of Thompson et al. (2001), a sound stimulus that is moderately arousing can enhance spatial abilities. The arousing nature of the sound environment may be another reason why the sound environment led to a higher spatial knowledge performance. This finding also confirms H3. It should also be mentioned that although the sound environment is perceived negatively, the participants have assessed it as appropriate because appropriate differs from desired (Axelsson, 2015; Orhan & Yilmazer, 2021). Another interesting point is that the participants in the audio-visual group assessed the sound environment as more pleasant than the audio-only group. This finding is in line with studies on audio-visual interactions in the environment assessment that have found that comfort assessment is higher when visual information is added to a clip (Preis et al., 2015).

Audio and visual information in the built environment interact and affect one another (Jeon & Jo, 2020). Audio stimuli that correspond with visual stimuli have a leading effect on visual attention (Liu et al., 2020). In our study, the availability of certain sounds in the sound environment that correspond with a visual element may have attracted the participants' attention, leading to higher performance in spatial knowledge tasks. An example of this audio-visual interaction can be seen in the elevators. The elevator is seen, and the sound of its doors opening and closing is heard, in addition to floor announcements and beeping in the background. Furthermore, meaning is another factor that explains how humans process signage and landmarks. Passini et al. (2000) suggest that reference points are distinctive from each other by form, function, and meaning. A closer look at what has been remembered in the tasks suggests that the combination of sounds that withhold meaning with visual signage and landmarks (the elevator or the increased announcement sounds in the neurology department) may have enhanced task performance in the audio-visual group.

Furthermore, considering the use of sound in isolation, a significantly better performance of the audio-visual group can be seen. At the same time, in most tasks, there was no significant difference between the visual and audio-only groups and audio-only and audio-visual groups. While the combination of visual and audio cues has led to better performance, there is no difference between the performance of the visual and the audio-only group. Thus, the sound alone does not lead to a better performance than visual signage, which is in line with the findings of Liu et al. (2020). In their study on railway stations, Liu et al. (2020) conclude that audio-visual interactions and the leading effect of sounds on visual elements can be used in the process of wayfinding system design.

In this study, an active wayfinding task was not conducted, but good spatial knowledge leads to good wayfinding performance. The findings are also consistent with those of Werkhoven et al. (2014). They compared the effect of visual, auditory, and audiovisual landmarks on spatial memory and navigation in a virtual maze and found better performance in maze drawing, adjacency, and wayfinding tasks for the audio-visual group. Another study with comparable results was conducted by Hamburger and Röser

(2014). They compared wayfinding performance for verbal, visual, and acoustic landmarks (animal sounds) in a virtual environment. In their study, acoustic landmarks resulted in good recognition and performance.

In contrast to the findings of the current study, Chandrasekera et al. (2015) found no significant effect of soundscape on wayfinding in a virtual maze. The first experiment group in their study had only soundscape landmarks, the second group had only visual landmarks, and the third had both visual and soundscape landmarks. The effect of the soundscape was significant on immersion; however, it did not have any significant effect on wayfinding. The reasons behind the contrasting findings can be that in this study, the sound environment of the outpatient polyclinic was used as a whole, representing an existing/naturalistic environment, while they used a church, a marketplace, and a school as visual and soundscape landmarks. Another difference is that while this study used different tasks to measure aspects of spatial knowledge, they only used the mean time to reach the goal as a measure for wayfinding performance.

Another finding of the study is that there was no significant difference between the performance of the visual-only and the control group in all tasks except for the pointing task. This may be explained by Arthur and Passini (1992) 's work that states adding signage to facilitate wayfinding does not overcome architectural failures because the ability to read the space is more critical than in situ sign system and signage (Carpman & Grant, 1995; Erkan, 2018). Rousek and Hallbeck (2011) and Lee et al. (2014) indicate that even well-designed signs do not provide enough information to ease wayfinding. Some studies suggest that users ignore graphical expressions and sign objects during wayfinding (Dogu & Erkip, 2000) because the visual system is already occupied with the route's information (Hamburger & Röser, 2014). In the pointing task, individual factors, visuospatial working memory, and rotation abilities affect task performance (Meneghetti et al., 2018). This may explain the significant difference between the groups in this task. More research needs to be done about the other factors that may have caused this significant difference.

CHAPTER 7

CONCLUSIONS

The study confirms the existence of a difference between spatial knowledge acquisition among different experiment groups. The audio-visual groups' high performance demonstrates the beneficial effect of the sound environment on spatial knowledge acquisition. However, the study has its own limitations. One limitation is that it cannot determine whether adding any type of sound would lead to similar results. Other routes and other complex interior spaces such as airports and shopping malls need to be investigated to see if similar results would be achieved. Other limitations of this study are having a non-immersive virtual environment and tasks that are solely based on passive exploration. Although passive exploration has yielded similar results to active exploration studies, adding a task based on active exploration may have enriched this study. Furthermore, the sample size consists of a large number of graduate students and design students, which may have biased the results. Moreover, there is the carry-on effect from one task to another. Despite these limitations, this study contributes to the available research on spatial knowledge in hospitals.

A developed spatial knowledge leads to improved wayfinding performance. Thus, it is essential to investigate alternative and cost-efficient factors other than visual stimuli that affect spatial knowledge acquisition. Modalities apart from vision are suitable for developing mental spatial images that lead to successful navigation. Visual information can be ignored simply by looking in another direction; however, this is not the case for audio information. Thus, it may be easier to use sound as a resource for spatial knowledge acquisition. This may be important for the aging population and patients with visual disabilities who rely on hearing for spatial information. As mentioned earlier, the participants in the audio-visual group had a significantly higher performance than the other groups; furthermore, the group with audio-only had a similar or better performance than the visual-only. This indicates that even without visual landmarks, the sound environment may compensate and provide sufficient cues for acquiring spatial knowledge. The landmarks that were placed correctly on the sketch map were generally the ones with a unique sound. This finding can be used to create soundmarks that aid spatial knowledge and thus wayfinding. Considering navigation issues associated with visual elements such as signage and the positive effect of adding the sound environment in spatial knowledge tasks, more studies should consider the role specific sound sources can play as soundmarks. Hospitals are generally associated with high sound levels due to reflections from hard surfaces and noise from equipment and people, with little consideration in designing the sound environment. The sound environment of the outpatient polyclinic in this study was perceived negatively; however, its addition to the virtual environment aided spatial knowledge acquisition. Thus, even adverse components of the sound environment can be used positively. From a design perspective, our study is a stepping stone for future studies that would focus on sound characteristics such as loudness, pitch, and affective qualities in the formation of soundmarks that can be employed at crossroads, transition spaces, or joint points to aid spatial knowledge acquisition. Furthermore, considering the positive impact of the sound environment on spatial knowledge tasks, further research can be conducted on adding or masking specific sound sources to determine their impact on spatial knowledge tasks and how they may improve the sound environment of outpatient polyclinics.

Although, speculations on why and how the addition of the sound environment of the outpatient polyclinic enhanced spatial knowledge tasks, more research needs to be conducted on the reasons why this happened. Research using eye-tracking technologies can detect how the addition of the sound environment changes attention towards landmarks and decision points. Moreover, transfer appropriate processing framework can be adapted to investigate the matches between encoding and retrieval in the presence and absence of sound.

This study also indicates that, at the very least, spatial knowledge acquisition based on auditory information can be achieved without instructing the participants. The participants in all groups were not given any explicit information or instruction on paying attention to the visual or auditory information throughout the route, which provides grounds for future studies that would employ the same sound sources but with different instructions to see whether there is a difference between intentional and incidental attention to auditory information.

In conclusion, auditory information provided by the sound environment may enhance spatial knowledge acquisition in virtual spaces; however, the performance results are not as accurate as those achieved with a combination of audio and visual stimuli. Humans gather large amounts of information with our eyes despite the limited directionality of the visual field. The ears are multidirectional and can gather information from various sources. Different types of ambient sounds (natural and artificial) may contain information about their direction, distance, and source that can help humans gain information from the environment. Thus, this study is a stepping stone for future studies that employ and design sound as a resource to facilitate spatial knowledge acquisition.

Based on the results following conclusion can be drawn.

1. A combination of visual signage and sound environment resulted in higher performance across landmark, route, and survey tasks.
2. No significant difference was found between the performance of the visual-only and the control group that shows that signage alone cannot aid spatial knowledge in virtual outpatient polyclinics.
3. The sound environment would be an efficient tool in enhancing spatial knowledge in virtual outpatient polyclinics.

4. The landmarks associated with a sound may compensate for the lack of visual landmarks that can help design a wayfinding system for users with visual disabilities.

References

Abdalrahman, Z., & Galbrun, L. (2020). Audio-visual preferences, perception, and use of water features in open-plan offices. *The Journal of the Acoustical Society of America, 147*(3), 1661-1672.

Acun, V., & Yilmazer, S. (2018). A grounded theory approach to investigate the perceived soundscape of open-plan offices. *Applied acoustics, 131*, 28-37.

Acun, V., & Yilmazer, S. (2019). Combining grounded theory (GT) and structural equation modelling (SEM) to analyze indoor soundscape in historical spaces. *Applied acoustics, 155*, 515-524.

Adeli, M., Rouat, J., & Molotchnikoff, S. (2014). Audiovisual correspondence between musical timbre and visual shapes. *Frontiers in human neuroscience, 8*, 352.

Aginsky, V., Harris, C., Rensink, R., & Beusmans, J. (1997). Two strategies for learning a route in a driving simulator. *Journal of Environmental Psychology, 17*(4), 317-331.

Albert, W., Reinitz, M. T., Beusmans, J., & Gopal, S. (1999). The role of attention in spatial learning during simulated route navigation. *Environment and planning A, 31*(8), 1459-1472.

Allen, G. L. (1988). The acquisition of spatial knowledge under conditions of temporospatial discontinuity. *Psychological Research, 50*(3), 183-190.

Allen, G. L., & Golledge, R. (1999). Wayfinding behavior: Cognitive mapping and other spatial processes. In: JHU Press.

Allen, G. L., Kirasic, K. C., Dobson, S. H., Long, R. G., & Beck, S. (1996). Predicting environmental learning from spatial abilities: An indirect route. *Intelligence, 22*(3), 327-355.

Arthur, P., & Passini, R. (1992). *Wayfinding: people, signs, and architecture*.

Axelsson, Ö. (2015). *How to measure soundscape quality.* Paper presented at the Proceedings of the Euronoise 2015 conference.

Axelsson, Ö., Nilsson, M. E., & Berglund, B. (2010). A principal components model of soundscape perception. *The Journal of the Acoustical Society of America, 128*(5), 2836-2846.

Baddeley, A. (1992). Working memory. *Science, 255*(5044), 556-559.

Baskaya, A., Wilson, C., & Özcan, Y. Z. (2004). Wayfinding in an unfamiliar environment: Different spatial settings of two polyclinics. *Environment and Behavior, 36*(6), 839-867.

Bateson, J. E., & Hui, M. K. (1992). The ecological validity of photographic slides and videotapes in simulating the service setting. *Journal of consumer research, 19*(2), 271-281.

Beasley, T. M., & Schumacker, R. E. (1995). Multiple regression approach to analyzing contingency tables: Post hoc and planned comparison procedures. *The Journal of Experimental Education, 64*(1), 79-93.

Berglund, B., & Nilsson, M. E. (2006). On a tool for measuring soundscape quality in urban residential areas. *Acta Acustica United with Acustica, 92*(6), 938-944.

Bell, P. A., Green, T., Fisher, J. D., & Baum, A. (2001). *Environmental psychology*: New Jersey.
Bond, B., & Stevens, S. S. (1969). Cross-modality matching of brightness to loudness by 5-year-olds. *Perception & Psychophysics, 6*(6), 337-339.
Bond, M. (2020). *Wayfinding: The Art and Science of How We Find and Lose Our Way*: Pan Macmillan.
Borella, E., Meneghetti, C., Muffato, V., & De Beni, R. (2015). Map learning and the alignment effect in young and older adults: how do they gain from having a map available while performing pointing tasks? *Psychological Research, 79*(1), 104-119.
Bosch, S. J., & Gharaveis, A. (2017). Flying solo: A review of the literature on wayfinding for older adults experiencing visual or cognitive decline. *Applied ergonomics, 58*, 327-333.
Bosco, A., Longoni, A. M., & Vecchi, T. (2004). Gender effects in spatial orientation: Cognitive profiles and mental strategies. *Applied Cognitive Psychology: The Official Journal of the Society for Applied Research in Memory and Cognition, 18*(5), 519-532.
Boynton, G. M. (2005). Attention and visual perception. *Current opinion in neurobiology, 15*(4), 465-469.
Brown, L. N., Lahar, C. J., & Mosley, J. L. (1998). Age and gender-related differences in strategy use for route information: A" map-present" direction-giving paradigm. *Environment and Behavior, 30*(2), 123-143.
Buchtel, H. A., & Butter, C. M. (1988). Spatial attentional shifts: Implications for the role of polysensory mechanisms. *Neuropsychologia, 26*(4), 499-509.
Burkins, A., & Kopper, R. (2015). *Wayfinding by auditory cues in virtual environments.* Paper presented at the 2015 IEEE Virtual Reality (VR).
Butler, A. J., James, T. W., & James, K. H. (2011). Enhanced multisensory integration and motor reactivation after active motor learning of audiovisual associations. *Journal of Cognitive Neuroscience, 23*(11), 3515-3528.
Buus, S., Florentine, M., & Poulsen, T. (1997). Temporal integration of loudness, loudness discrimination, and the form of the loudness function. *The Journal of the Acoustical Society of America, 101*(2), 669-680.
Caduff, D., & Timpf, S. (2008). On the assessment of landmark salience for human navigation. *Cognitive processing, 9*(4), 249-267.
Cain, R., Jennings, P., & Poxon, J. (2013). The development and application of the emotional dimensions of a soundscape. *Applied acoustics, 74*(2), 232-239.
Camgöz, N., Yener, C., & Güvenç, D. (2004). Effects of hue, saturation, and brightness: Part 2: Attention. *Color Research & Application: Endorsed by Inter-Society Color Council, The Colour Group (Great Britain), Canadian Society for Color, Color Science Association of Japan, Dutch Society for the Study of Color, The Swedish Colour Centre Foundation, Colour Society of Australia, Centre Français de la Couleur, 29*(1), 20-28.
Cao, L., Lin, J., & Li, N. (2019). A virtual reality based study of indoor fire evacuation after active or passive spatial exploration. *Computers in Human Behavior, 90*, 37-45.

Carassa, A., Geminiani, G., Morganti, F., & Varotto, D. (2002). Active and passive spatial learning in a complex virtual environment: The effect of efficient exploration. *Cognitive processing, 3*(4), 65-81.

Carpman, J. (1984). No More Mazes Research about Design for Wayfinding in Hospitals. The Patient and Visitor Participation Project, university of Michigan Replacement Hospital Program, The University of Michigan. *Ann Arbor, Michigan*.

Carpman, J., & Grant, M. (1995). Comparing architectural and verbal wayfinding clues. *Progressive architecture, 76*(2), 81.

Carretié, L. (2014). Exogenous (automatic) attention to emotional stimuli: a review. *Cognitive, Affective, & Behavioral Neuroscience, 14*(4), 1228-1258.

Chandrasekera, T., Yoon, S.-Y., & D'Souza, N. (2015). Virtual environments with soundscapes: a study on immersion and effects of spatial abilities. *Environment and Planning B: Planning and Design, 42*(6), 1003-1019.

Choi, J., McKillop, E., Ward, M., & L'Hirondelle, N. (2006). Sex-specific relationships between route-learning strategies and abilities in a large-scale environment. *Environment and Behavior, 38*(6), 791-801.

Chrastil, E. R., & Warren, W. H. (2013). Active and passive spatial learning in human navigation: Acquisition of survey knowledge. *Journal of experimental psychology: learning, memory, and cognition, 39*(5), 1520.

Chun, M. M., & Turk-Browne, N. B. (2007). Interactions between attention and memory. *Current opinion in neurobiology, 17*(2), 177-184.

Claessen, M. H., van der Ham, I. J., Jagersma, E., & Visser-Meily, J. M. (2016). Navigation strategy training using virtual reality in six chronic stroke patients: a novel and explorative approach to the rehabilitation of navigation impairment. *Neuropsychological rehabilitation, 26*(5-6), 822-846.

Cogné, M., Auriacombe, S., Vasa, L., Tison, F., Klinger, E., Sauzéon, H., & Joseph, P.-A. (2018). Are visual cues helpful for virtual spatial navigation and spatial memory in patients with mild cognitive impairment or Alzheimer's disease? *Neuropsychology, 32*(4), 385.

Cohen, J. (1988). Statistical power analysis Jbr the behavioral. *Sciences. Hillsdale (NJ): Lawrence Erlbaum Associates*, 18-74.

Coleman, R., Lebbon, C., & Myerson, J. (2003). Design and empathy. *Inclusive Design*, 478-499.

Coluccia, E., Iosue, G., & Brandimonte, M. A. (2007). The relationship between map drawing and spatial orientation abilities: A study of gender differences. *Journal of Environmental Psychology, 27*(2), 135-144.

Coluccia, E., & Louse, G. (2004). Gender differences in spatial orientation: A review. *Journal of Environmental Psychology, 24*(3), 329-340.

Commins, S., Duffin, J., Chaves, K., Leahy, D., Corcoran, K., Caffrey, M., Thornberry, C. (2019). NavWell: A simplified virtual-reality platform for spatial navigation and memory experiments. *Behavior research methods,* 1-19.

Commins, S., & Fey, D. (2019). Understanding the role of distance, direction and cue salience in an associative model of landmark learning. *Scientific reports, 9*(1), 1-13.

Connor, C. E., Egeth, H. E., & Yantis, S. (2004). Visual attention: bottom-up versus top-down. *Current biology, 14*(19), R850-R852.

Conroy, R. (2001). *Spatial navigation in immersive virtual environments*: University of London, University College London (United Kingdom).
Couclelis, H. (1996). Verbal directions for way-finding: Space, cognition, and language. In *The construction of cognitive maps* (pp. 133-153): Springer.
Couclelis, H., Golledge, R. G., Gale, N., & Tobler, W. (1987). Exploring the anchor-point hypothesis of spatial cognition. *Journal of Environmental Psychology, 7*(2), 99-122.
Coutrot, A., Guyader, N., Ionescu, G., & Caplier, A. (2012). Influence of soundtrack on eye movements during video exploration. *Journal of Eye Movement Research, 5*(4), 2.
Credé, S., Thrash, T., Hölscher, C., & Fabrikant, S. I. (2019). The acquisition of survey knowledge for local and global landmark configurations under time pressure. *Spatial Cognition & Computation, 19*(3), 190-219.
Cytowic, R. E. (2002). *Synesthesia: A union of the senses*: MIT press.
Dabbs Jr, J. M., Chang, E.-L., Strong, R. A., & Milun, R. (1998). Spatial ability, navigation strategy, and geographic knowledge among men and women. *Evolution and human behavior, 19*(2), 89-98.
Dalirnaghadeh, D., & Yilmazer, S. (2022). The effect of sound environment on spatial knowledge acquisition in a virtual outpatient polyclinic. *Applied Ergonomics, 100*, 103672.
Dalton, R., & Bafna, S. (2003). The syntactical image of the city: A reciprocal definition of spatial elements and spatial syntaxes.
Darken, R. P., & Peterson, B. (2014). Spatial orientation, wayfinding, and representation. In.
Darken, R. P., & Sibert, J. L. (1996). *Wayfinding strategies and behaviors in large virtual worlds.* Paper presented at the Proceedings of the SIGCHI conference on Human factors in computing systems.
Devlin, A. S. (2014). Wayfinding in healthcare facilities: Contributions from environmental psychology. *Behavioral sciences, 4*(4), 423-436.
Dodiya, J., & Alexandrov, V. N. (2008). *Use of auditory cues for wayfinding assistance in virtual environment: music aids route decision.* Paper presented at the Proceedings of the 2008 ACM symposium on Virtual reality software and technology.
Dogu, U., & Erkip, F. (2000). Spatial factors affecting wayfinding and orientation: A case study in a shopping mall. *Environment and Behavior, 32*(6), 731-755.
Downs, R. M., & Stea, D. (1973). *Cognitive maps and spatial behavior: Process and products*: na.
Downs, R. M., & Stea, D. (2011). Cognitive Maps and Spatial Behaviour: Process and Products, The Map Reader: Theories of Mapping Practice and Cartographic Representation. In: John Wiley & Sons, Ltd. Published.
Driver, J., & Spence, C. (1998). Attention and the crossmodal construction of space. *Trends in cognitive sciences, 2*(7), 254-262.
Dubois, D., Guastavino, C., & Raimbault, M. (2006). A cognitive approach to urban soundscapes: Using verbal data to access everyday life auditory categories. *Acta Acustica United with Acustica, 92*(6), 865-874.

Dzulkifli, M. A., & Mustafar, M. F. (2013). The influence of colour on memory performance: A review. *The Malaysian journal of medical sciences: MJMS, 20*(2), 3.
Elvins, T. T., Nadeau, D. R., Schul, R., & Kirsh, D. (2001). Worldlets: 3-D thumbnails for wayfinding in large virtual worlds. *Presence, 10*(6), 565-582.
Erkan, İ. (2018). Examining wayfinding behaviours in architectural spaces using brain imaging with electroencephalography (EEG). *Architectural Science Review, 61*(6), 410-428.
Evans, G. W., Skorpanich, M. A., Gärling, T., Bryant, K. J., & Bresolin, B. (1984). The effects of pathway configuration, landmarks and stress on environmental cognition. *Journal of Environmental Psychology, 4*(4), 323-335.
Evans, K. K., & Treisman, A. (2010). Natural cross-modal mappings between visual and auditory features. *Journal of vision, 10*(1), 6-6.
Farrell, M. J., Arnold, P., Pettifer, S., Adams, J., Graham, T., & MacManamon, M. (2003). Transfer of route learning from virtual to real environments. *Journal of Experimental Psychology: Applied, 9*(4), 219.
Fastl, H., & Zwicker, E. (2006). *Psychoacoustics: facts and models* (Vol. 22): Springer Science & Business Media.
Friedman, A., & Kohler, B. (2003). Bidimensional regression: assessing the configural similarity and accuracy of cognitive maps and other two-dimensional data sets. *Psychological methods, 8*(4), 468.
Gallistel, C. R. (1990). *The organization of learning*: The MIT Press.
Gardony, A. L., Taylor, H. A., & Brunyé, T. T. (2016). Gardony Map Drawing Analyzer: Software for quantitative analysis of sketch maps. *Behavior research methods, 48*(1), 151-177.
Gärling, T., Böök, A., & Lindberg, E. (1986). Spatial orientation and wayfinding in the designed environment: A conceptual analysis and some suggestions for postoccupancy evaluation. *Journal of architectural and planning research*, 55-64.
Gärling, T., Böök, A., Lindberg, E., & Nilsson, T. (1981). Memory for the spatial layout of the everyday physical environment: Factors affecting rate of acquisition. *Journal of Environmental Psychology, 1*(4), 263-277.
Gaunet, F., Vidal, M., Kemeny, A., & Berthoz, A. (2001). Active, passive and snapshot exploration in a virtual environment: influence on scene memory, reorientation and path memory. *Cognitive Brain Research, 11*(3), 409-420.
Gibson, D. (2009). *The wayfinding handbook: Information design for public places*: Princeton Architectural Press.
Giudice, N. A. (2018). Navigating without vision: Principles of blind spatial cognition. In *Handbook of behavioral and cognitive geography*: Edward Elgar Publishing.
Giudice, N. A., Bakdash, J. Z., & Legge, G. E. (2007). Wayfinding with words: spatial learning and navigation using dynamically updated verbal descriptions. *Psychological Research, 71*(3), 347-358.
Giudice, N. A., Bakdash, J. Z., Legge, G. E., & Roy, R. (2010). Spatial learning and navigation using a virtual verbal display. *ACM Transactions on Applied Perception (TAP), 7*(1), 1-22.

Giudice, N. A., & Tietz, J. D. (2008). *Learning with virtual verbal displays: effects of interface fidelity on cognitive map development.* Paper presented at the International Conference on Spatial Cognition.
Golledge, R. G. (1999). *Wayfinding behavior: Cognitive mapping and other spatial processes*: JHU press.
Golledge, R. G. (2003). Human wayfinding and cognitive maps. In *The Colonization of Unfamiliar Landscapes* (pp. 49-54): Routledge.
Golledge, R. G., Jacobson, R. D., Kitchin, R., & Blades, M. (2000). Cognitive maps, spatial abilities, and human wayfinding. *Geographical review of Japan, Series B., 73*(2), 93-104.
Götze, J., & Boye, J. (2016). Learning landmark salience models from users' route instructions. *Journal of Location Based Services, 10*(1), 47-63.
Green, M., & Jacob, R. (1991). SIGGRAPH'90 Workshop report: software architectures and metaphors for non-WIMP user interfaces. *ACM SIGGRAPH Computer Graphics, 25*(3), 229-235.
Greenroyd, F. L., Hayward, R., Price, A., Demian, P., & Sharma, S. (2018). A tool for signage placement recommendation in hospitals based on wayfinding metrics. *Indoor and Built Environment, 27*(7), 925-937.
Gunther, R., Kazman, R., & MacGregor, C. (2004). Using 3D sound as a navigational aid in virtual environments. *Behaviour & Information Technology, 23*(6), 435-446.
Hagtvedt, H., & Brasel, S. A. (2016). Cross-modal communication: sound frequency influences consumer responses to color lightness. *Journal of Marketing Research, 53*(4), 551-562.
Hamburger, K., & Röser, F. (2014). The role of landmark modality and familiarity in human wayfinding. *Swiss Journal of Psychology*.
Han, C., Jun, S., & Junling, L. (2008). *Modelling and simulation wayfinding in unfamiliar campus environment.* Paper presented at the 2008 Fourth International Conference on Natural Computation.
Haq, S., Hill, G., & Pramanik, A. (2005). *Comparison of configurational, wayfinding and cognitive correlates in real and virtual settings.* Paper presented at the Proceedings of the 5th International Space Syntax Symposium.
Haq, S., & Zimring, C. (2003). Just down the road a piece: The development of topological knowledge of building layouts. *Environment and Behavior, 35*(1), 132-160.
Harniss, M., Brown, P. A., & Johnson, K. L. (2015). Cognitive technologies for wayfinding.
Harrell, W. A., Bowlby, J. W., & Hall-Hoffarth, D. (2000). Directing wayfinders with maps: The effects of gender, age, route complexity, and familiarity with the environment. *The Journal of social psychology, 140*(2), 169-178.
Hau, Y. S., Kim, J. K., Hur, J., & Chang, M. C. (2020). How about actively using telemedicine during the COVID-19 pandemic? *Journal of Medical Systems, 44*, 1-2.
Hegarty, M., Montello, D. R., Richardson, A. E., Ishikawa, T., & Lovelace, K. (2006). Spatial abilities at different scales: Individual differences in aptitude-test performance and spatial-layout learning. *Intelligence, 34*(2), 151-176.

Helvacıog, E., & Olguntürk, N. (2011). Colour contribution to children's wayfinding in school environments. *Optics & Laser Technology, 43*(2), 410-419.
Hidayetoglu, M. L., Yildirim, K., & Akalin, A. (2012). The effects of color and light on indoor wayfinding and the evaluation of the perceived environment. *Journal of Environmental Psychology, 32*(1), 50-58.
Ho, C., & Spence, C. (2005). Assessing the effectiveness of various auditory cues in capturing a driver's visual attention. *Journal of Experimental Psychology: Applied, 11*(3), 157.
Hohol, M., Baran, B., Krzyżowski, M., & Francikowski, J. (2017). Does spatial navigation have a blind-spot? Visiocentrism is not enough to explain the navigational behavior comprehensively. *Frontiers in Behavioral Neuroscience, 11*, 154.
Houtsma, A. J. (1997). Pitch and timbre: Definition, meaning and use. *Journal of New Music Research, 26*(2), 104-115.

Howard, D., & Angus, J. (2013). *Acoustics and psychoacoustics*: Routledge.

Hubber, P. J., Gilmore, C., & Cragg, L. (2019). Mathematics students demonstrate superior visuo-spatial working memory to humanities students under conditions of low central executive processing load. *Journal of Numerical Cognition, 5*(2).
Hund, A. M., & Minarik, J. L. (2006). Getting from here to there: Spatial anxiety, wayfinding strategies, direction type, and wayfinding efficiency. *Spatial cognition and computation, 6*(3), 179-201.
Iachini, T., Ruotolo, F., & Ruggiero, G. (2009). The effects of familiarity and gender on spatial representation. *Journal of Environmental Psychology, 29*(2), 227-234.
Iaria, G., Palermo, L., Committeri, G., & Barton, J. J. (2009). Age differences in the formation and use of cognitive maps. *Behavioural brain research, 196*(2), 187-191.
Jamshidi, S., & Pati, D. (2021). A narrative review of theories of wayfinding within the interior environment. *HERD: Health Environments Research & Design Journal, 14*(1), 290-303.
Jansen-Osmann, P., & Fuchs, P. (2006). Wayfinding behavior and spatial knowledge of adults and children in a virtual environment: The role of landmarks. *Experimental Psychology, 53*(3), 171-181.
Jansen, P., Schmelter, A., & Heil, M. (2009). Spatial knowledge acquisition in younger and elderly adults. *Experimental Psychology*.
Janzen, G. (2006). Memory for object location and route direction in virtual large-scale space. *Quarterly journal of experimental psychology, 59*(3), 493-508.
Jeon, J. Y., & Jo, H. I. (2020). Effects of audio-visual interactions on soundscape and landscape perception and their influence on satisfaction with the urban environment. *Building and Environment, 169*, 106544.
Jepsen, M. L., Ewert, S. D., & Dau, T. (2008). A computational model of human auditory signal processing and perception. *The Journal of the Acoustical Society of America, 124*(1), 422-438.
Johansson, L., Bergbom, I., Waye, K. P., Ryherd, E., & Lindahl, B. (2012). The sound environment in an ICU patient room—a content analysis of sound levels and patient experiences. *Intensive and Critical Care Nursing, 28*(5), 269-279.

Kalff, C., & Strube, G. (2011). *Everyday navigation in real and virtual environments informed by semantic knowledge.* Paper presented at the Proceedings of the Annual Meeting of the Cognitive Science Society.

Karimpur, H., & Hamburger, K. (2016). Multimodal integration of spatial information: The influence of object-related factors and self-reported strategies. *Frontiers in Psychology, 7*, 1443.

Kerman, U., & Altan, Y. (2012). SAĞLIK HİZMETLERİNDE KAMU ÖZEL ORTAKLIĞI UYGULAMASI. *Süleyman Demirel Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi, 17*(3), 1-23.

Kitchin, R., & Blades, M. (2002). *The cognition of geographic space* (Vol. 4): Ib Tauris London.

Kitchin, R., & Freundschuh, S. (2000). Cognitive mapping. *Cognitive mapping: Past, present and future*, 1-8.

Klatzky, R. L., Marston, J. R., Giudice, N. A., Golledge, R. G., & Loomis, J. M. (2006). Cognitive load of navigating without vision when guided by virtual sound versus spatial language. *Journal of Experimental Psychology: Applied, 12*(4), 223.

Klippel, A., & Winter, S. (2005). *Structural salience of landmarks for route directions.* Paper presented at the International Conference on Spatial Information Theory.

Kort, Y. A. d., Ijsselsteijn, W. A., Kooijman, J., & Schuurmans, Y. (2003). Virtual laboratories: Comparability of real and virtual environments for environmental psychology. *Presence: Teleoperators & Virtual Environments, 12*(4), 360-373.

Kuipers, B. (1990). Modeling spatial knowledge. *Advances in spatial reasoning, 2*, 171-198.

Kuliga, S. F., Thrash, T., Dalton, R. C., & Hölscher, C. (2015). Virtual reality as an empirical research tool—Exploring user experience in a real building and a corresponding virtual model. *Computers, environment and urban systems, 54*, 363-375.

Lapeyre, B., Hourlier, S., Servantie, X., N'Kaoua, B., & Sauzéon, H. (2011). Using the Landmark–Route–Survey framework to evaluate spatial knowledge obtained from synthetic vision systems. *Human factors, 53*(6), 647-661.

Lawton, C. A. (2010). Gender, spatial abilities, and wayfinding. In *Handbook of gender research in psychology* (pp. 317-341): Springer.

Lawton, C. A., Charleston, S. I., & Zieles, A. S. (1996). Individual-and gender-related differences in indoor wayfinding. *Environment and Behavior, 28*(2), 204-219.

Lawton, C. A., & Kallai, J. (2002). Gender differences in wayfinding strategies and anxiety about wayfinding: A cross-cultural comparison. *Sex roles, 47*(9), 389-401.

Lee, S., Dazkir, S. S., Paik, H. S., & Coskun, A. (2014). Comprehensibility of universal healthcare symbols for wayfinding in healthcare facilities. *Applied ergonomics, 45*(4), 878-885.

Lee, S., & Kline, R. (2011). Wayfinding study in virtual environments: The elderly vs. the younger-aged groups. *ArchNet-IJAR: International Journal of Architectural Research, 5*(2), 63.

Lehmann, S., & Murray, M. M. (2005). The role of multisensory memories in unisensory object discrimination. *Cognitive Brain Research, 24*(2), 326-334.

Lingwood, J., Blades, M., Farran, E. K., Courbois, Y., & Matthews, D. (2015). The development of wayfinding abilities in children: learning routes with and without landmarks. *Journal of Environmental Psychology, 41*, 74-80.

Liu, C., Kang, J., & Xie, H. (2020). Effect of sound on visual attention in large railway stations: A case study of St. Pancras railway station in London. *Building and Environment, 185*, 107177.

Löf, L., Berggren, L., & Ahlström, G. (2006). Severely ill ICU patients recall of factual events and unreal experiences of hospital admission and ICU stay—3 and 12 months after discharge. *Intensive and Critical Care Nursing, 22*(3), 154-166.

Lokki, T., & Grohn, M. (2005). Navigation with auditory cues in a virtual environment. *IEEE MultiMedia, 12*(2), 80-86.

Long, R. G., & Hill, E. (1997). Establishing and maintaining orientation for mobility. *Foundations of orientation and mobility, 1*.

Loomis, J. M., Klatzky, R. L., Avraamides, M., Lippa, Y., & Golledge, R. G. (2007). Functional equivalence of spatial images produced by perception and spatial language. In *Spatial processing in navigation, imagery and perception* (pp. 29-48): Springer.

Lovelace, K. L., Hegarty, M., & Montello, D. R. (1999). *Elements of good route directions in familiar and unfamiliar environments.* Paper presented at the International conference on spatial information theory.

Luck, S. J., & Ford, M. A. (1998). On the role of selective attention in visual perception. *Proceedings of the National Academy of Sciences, 95*(3), 825-830.

Lynch, K. (1960). *The image of the city* (Vol. 11): MIT press.

MacEachren, A. M. (1992). Application of environmental learning theory to spatial knowledge acquisition from maps. *Annals of the Association of American Geographers, 82*(2), 245-274.

Mahmood, O., Adamo, D., Briceno, E., & Moffat, S. D. (2009). Age differences in visual path integration. *Behavioural brain research, 205*(1), 88-95.

Malinowski, J. C., & Gillespie, W. T. (2001). Individual differences in performance on a large-scale, real-world wayfinding task. *Journal of Environmental Psychology, 21*(1), 73-82.

Marks, L. E. (1974). On associations of light and sound: The mediation of brightness, pitch, and loudness. *The American journal of psychology*, 173-188.

Marples, D., Gledhill, D., & Carter, P. (2020). *The Effect of Lighting, Landmarks and Auditory Cues on Human Performance in Navigating a Virtual Maze.* Paper presented at the Symposium on Interactive 3D Graphics and Games.

McMullen, K. A., & Wakefield, G. H. (2014). *3D sound memory in virtual environments.* Paper presented at the 2014 IEEE Symposium on 3D User Interfaces (3DUI).

Meilinger, T., Riecke, B. E., & Bülthoff, H. H. (2014). Local and global reference frames for environmental spaces. *Quarterly journal of experimental psychology, 67*(3), 542-569.

Memikoğlu, İ., & Demirkan, H. (2020). Exploring staircases as architectural cues in virtual vertical navigation. *International Journal of Human-Computer Studies, 138*, 102397.

Meneghetti, C., Miola, L., Toffalini, E., Pastore, M., & Pazzaglia, F. (2021). Learning from navigation, and tasks assessing its accuracy: The role of visuospatial abilities and wayfinding inclinations. *Journal of Environmental Psychology, 75*, 101614.

Meneghetti, C., Muffato, V., Borella, E., & De Beni, R. (2018). Map learning in normal aging: The role of individual visuo-spatial abilities and implications. *Current Alzheimer Research, 15*(3), 205-218.

Meneghetti, C., Muffato, V., Varotto, D., & De Beni, R. (2017). How directions of route descriptions influence orientation specificity: The contribution of spatial abilities. *Psychological Research, 81*(2), 445-461.

Menouti, K., Akiva-Kabiri, L., Banissy, M. J., & Stewart, L. (2015). Timbre-colour synaesthesia: Exploring the consistency of associations based on timbre. *Cortex, 63*, 1-3.

Michon, P.-E., & Denis, M. (2001). *When and why are visual landmarks used in giving directions?* Paper presented at the International conference on spatial information theory.

Miller, J., & Carlson, L. (2011). Selecting landmarks in novel environments. *Psychonomic bulletin & review, 18*(1), 184-191.

Min, Y. H., & Ha, M. (2020). Contribution of colour-zoning differentiation to multidimensional spatial knowledge acquisition in symmetrical hospital wards. *Indoor and Built Environment*, 1420326X20909490.

Moffat, S. D., Zonderman, A. B., & Resnick, S. M. (2001). Age differences in spatial memory in a virtual environment navigation task. *Neurobiology of aging, 22*(5), 787-796.

Mondloch, C. J., & Maurer, D. (2004). Do small white balls squeak? Pitch-object correspondences in young children. *Cognitive, Affective, & Behavioral Neuroscience, 4*(2), 133-136.

Montello, D. (2001). *Spatial Cognition. International Encyclopedia of the Social & Behavioral Sciences, 14771-14775. doi: 10.1016*. B0-08-043076-7/02492-X.

Montello, D. (2001). *Spatial Cognition. International Encyclopedia of the Social & Behavioral Sciences, 14771-14775. doi: 10.1016*.

Montello, D. R. (1993). *Scale and multiple psychologies of space.* Paper presented at the European conference on spatial information theory.

Montello, D. R. (1998). A new framework for understanding the acquisition of spatial knowledge in large-scale environments. *Spatial and temporal reasoning in geographic information systems*, 143-154.

Montello, D. R. (2005). *Navigation*: Cambridge University Press.

Montello, D. R., Lovelace, K. L., Golledge, R. G., & Self, C. M. (1999). Sex-related differences and similarities in geographic and environmental spatial abilities. *Annals of the Association of American Geographers, 89*(3), 515-534.

Montello, Daniel & Sas, Corina. (2006). Human Factors of Wayfinding in Navigation. International Encyclopedia of Ergonomics and Human Factors. 10.1201/9780849375477.ch394.

Morag, I., & Pintelon, L. (2021). Digital wayfinding systems in hospitals: A qualitative evaluation based on managerial perceptions and considerations before and after implementation. *Appl Ergon*, 103260-103260.

Morris, R. G. (1981). Spatial localization does not require the presence of local cues. *Learning and motivation, 12*(2), 239-260.
Mou, W., & McNamara, T. P. (2002). Intrinsic frames of reference in spatial memory. *Journal of experimental psychology: learning, memory, and cognition, 28*(1), 162.
Muffato, V., Meneghetti, C., & De Beni, R. (2020). The role of visuo-spatial abilities in environment learning from maps and navigation over the adult lifespan. *British journal of psychology, 111*(1), 70-91.
Muffato, V., Meneghetti, C., Di Ruocco, V., & De Beni, R. (2017). When young and older adults learn a map: The influence of individual visuo-spatial factors. *Learning and Individual Differences, 53*, 114-121.
Munion, A. K., Stefanucci, J. K., Rovira, E., Squire, P., & Hendricks, M. (2019). Gender differences in spatial navigation: Characterizing wayfinding behaviors. *Psychonomic bulletin & review, 26*(6), 1933-1940.
Nardi, D., Twyman, A. D., Holden, M. P., & Clark, J. M. (2020). Tuning in: can humans use auditory cues for spatial reorientation? *Spatial Cognition & Computation, 20*(2), 83-103.
Natapov, A., Kuliga, S., Dalton, R. C., & Hölscher, C. (2015). *Building circulation typology and space syntax predictive measures.* Paper presented at the Proceedings of the 10th International Space Syntax Symposium.
North, H. (2002). Distance distortion: A comparison of real world and computer animated environments. *Journal of Interior Design, 28*(2), 26-36.
Orhan, C., & Yilmazer, S. (2021). Harmony of context and the built environment: Soundscapes in museum environments via GT. *Applied acoustics, 173*, 107709.
Özkan, S. (2018). Türkiye'de Kamu Özel Ortaklığı Entegre Sağlık Kampüsleri Standart Yatan Hasta Odaları Üzerine Bir İnceleme. Yüksek Lisans Tezi, Hacettepe Üniversitesi Güzel Sanatlar Enstitüsü, Ankara.
Pan, Y. (2010). Attentional capture by working memory contents. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale, 64*(2), 124.
Papadopoulos, K., Papadimitriou, K., & Koutsoklenis, A. (2012). The Role of Auditory Cues in the Spatial Knowledge of Blind Individuals. *International journal of special education, 27*(2), 169-180.
Parong, J., Pollard, K. A., Files, B. T., Oiknine, A. H., Sinatra, A. M., Moss, J. D., Khooshabeh, P. (2020). The mediating role of presence differs across types of spatial learning in immersive technologies. *Computers in Human Behavior, 107*, 106290.
Parush, A., & Berman, D. (2004). Navigation and orientation in 3D user interfaces: the impact of navigation aids and landmarks. *International Journal of Human-Computer Studies, 61*(3), 375-395.
Passini, R. (1984). Wayfinding in architecture.
Passini, R., Pigot, H., Rainville, C., & Tétreault, M.-H. (2000). Wayfinding in a nursing home for advanced dementia of the Alzheimer's type. *Environment and Behavior, 32*(5), 684-710.
Peponis, J., Zimring, C., & Choi, Y. K. (1990). Finding the building in wayfinding. *Environment and Behavior, 22*(5), 555-590.

Péruch, P., & Wilson, P. N. (2004). Active versus passive learning and testing in a complex outside built environment. *Cognitive processing, 5*(4), 218-227.
Philbeck, J. W., & O'Leary, S. (2005). Remembered landmarks enhance the precision of path integration. *Psicológica, 26*(1), 7–24.
Picinali, L., Afonso, A., Denis, M., & Katz, B. F. (2014). Exploration of architectural spaces by blind people using auditory virtual reality for the construction of spatial knowledge. *International Journal of Human-Computer Studies, 72*(4), 393-407.
Pick, H., & Palmer, C. (1986). Perception and representation in the guidance of spatially coordinated behavior. *Motor development in children: Aspects of coordination and control*, 135-145.
Posner, M. I. (1978). *Chronometric explorations of mind*: Lawrence Erlbaum.
Posner, M. I., Snyder, C. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General, 109*(2), 160.
Preis, A., Kociński, J., Hafke-Dys, H., & Wrzosek, M. (2015). Audio-visual interactions in environment assessment. *Science of the total environment, 523*, 191-200.
Presson, C. C., & Montello, D. R. (1988). Points of reference in spatial cognition: Stalking the elusive landmark. *British Journal of Developmental Psychology, 6*(4), 378-381.
Qiu, X., Wen, L., Wu, C., Yang, Z., Wang, Q., Li, H., & Wang, D. (2020). Impact of Learning Methods on Spatial Knowledge Acquisition. *Frontiers in Psychology, 11*.
Raimbault, M., & Dubois, D. (2005). Urban soundscapes: Experiences and knowledge. *Cities, 22*(5), 339-350.
Raubal, M. (2008). Wayfinding: Affordances and Agent Simulation. In: Citeseer.
Raubal, M., & Winter, S. (2002). *Enriching wayfinding instructions with local landmarks.* Paper presented at the International conference on geographic information science.
Read, M. A. (2003). Use of color in child care environments: Application of color for wayfinding and space definition in Alabama child care environments. *Early Childhood Education Journal, 30*(4), 233-239.
Richardson, A. E., Montello, D. R., & Hegarty, M. (1999). Spatial knowledge acquisition from maps and from navigation in real and virtual environments. *Memory & Cognition, 27*(4), 741-750.
Richter, K.-F., & Winter, S. (2014). Landmarks. *Springer Cham Heidelberg New York Dordrecht London. doi, 10*, 978-973.
Rodgers, M. K., Sindone III, J. A., & Moffat, S. D. (2012). Effects of age on navigation strategy. *Neurobiology of aging, 33*(1), 202. e15-22.
Rodrigues, R., Coelho, R., & Tavares, J. M. R. (2020). Users' perceptions of signage systems at three Portuguese hospitals. *HERD: Health Environments Research & Design Journal, 13*(3), 36-53.
Röser, F., Hamburger, K., Krumnack, A., & Knauff, M. (2012). The structural salience of landmarks: results from an on-line study and a virtual environment experiment. *Journal of Spatial Science, 57*(1), 37-50.
Rousek, J., & Hallbeck, M. (2011). Improving and analyzing signage within a healthcare setting. *Applied ergonomics, 42*(6), 771-784.

Ruddle, R. A., Payne, S. J., & Jones, D. M. (1997). Navigating buildings in" desk-top" virtual environments: Experimental investigations using extended navigational experience. *Journal of Experimental Psychology: Applied, 3*(2), 143.

Ruddle, R. A., Payne, S. J., & Jones, D. M. (1998). Navigating large-scale “desk-top” virtual buildings: Effects of orientation aids and familiarity. *Presence, 7*(2), 179-192.

Ruddle, R. A., & Péruch, P. (2004). Effects of proprioceptive feedback and environmental characteristics on spatial learning in virtual environments. *International Journal of Human-Computer Studies, 60*(3), 299-326.

Ruddle, R. A., Volkova, E., Mohler, B., & Bülthoff, H. H. (2011). The effect of landmark and body-based sensory information on route knowledge. *Memory & Cognition, 39*(4), 686-699.

Ryherd, E., West, J. E., Busch-Vishniac, I. J., & Waye, K. P. (2008). Evaluating the hospital soundscape. *Acoustics today, 4*(4), 22-29.

Sandstrom, N. J., Kaufman, J., & Huettel, S. A. (1998). Males and females use different distal cues in a virtual environment navigation task. *Cognitive Brain Research, 6*(4), 351-360.

Sandvad, J. (1999). Auditory perception of reverberant surroundings. *The Journal of the Acoustical Society of America, 105*(2), 1193-1193.

Sayers, H. (2004). Desktop virtual environments: a study of navigation and age. *Interacting with computers, 16*(5), 939-956.

Schwering, A., Li, R., & Anacta, V. J. A. (2013). *Orientation information in different forms of route instructions.* Paper presented at the Short paper proceedings of the 16th AGILE conference on geographic information science, Leuven, Belgium.

Secchi, S., Lauria, A., & Cellai, G. (2017). Acoustic wayfinding: A method to measure the acoustic contrast of different paving materials for blind people. *Applied ergonomics, 58*, 435-445.

Sharma, G., Kaushal, Y., Chandra, S., Singh, V., Mittal, A. P., & Dutt, V. (2017). Influence of landmarks on wayfinding and brain connectivity in immersive virtual reality environment. *Frontiers in Psychology, 8*, 1220.

Shelton, A. L., & McNamara, T. P. (2001). Systems of spatial reference in human memory. *Cognitive psychology, 43*(4), 274-310.

Shu, S., & Ma, H. (2018). The restorative environmental sounds perceived by children. *Journal of Environmental Psychology, 60*, 72-80.

Siegel, A. W., & White, S. H. (1975). The development of spatial representations of large-scale environments. In *Advances in child development and behavior* (Vol. 10, pp. 9-55): Elsevier.

Skorupka, A. (2009). *Comparing human wayfinding behavior in real and virtual environment.* Paper presented at the Proceedings of the 7th International Space Syntax Symposium.

Smilek, D., Dixon, M. J., Cudahy, C., & Merikle, P. M. (2002). Synesthetic color experiences influence memory. *Psychological science, 13*(6), 548-552.

Sorrows, M. E., & Hirtle, S. C. (1999). *The nature of landmarks for real and electronic spaces.* Paper presented at the International conference on spatial information theory.

Spence, C., & Driver, J. (1996). Audiovisual links in endogenous covert spatial attention. *Journal of experimental psychology: Human perception and performance, 22*(4), 1005.

Spence, C., Driver, J., & Driver, J. C. (2004). *Crossmodal space and crossmodal attention*: Oxford University Press.

Spence, C. J., & Driver, J. (1994). Covert spatial orienting in audition: Exogenous and endogenous mechanisms. *Journal of experimental psychology: Human perception and performance, 20*(3), 555.

Stankiewicz, B. J., & Kalia, A. A. (2007). Acquistion of structural versus object landmark knowledge. *Journal of experimental psychology: Human perception and performance, 33*(2), 378.

Steck, S. D., & Mallot, H. A. (2000). The role of global and local landmarks in virtual environment navigation. *Presence, 9*(1), 69-83.

Sun, X., Li, X., Ji, L., Han, F., Wang, H., Liu, Y., Li, Z. (2018). An extended research of crossmodal correspondence between color and sound in psychology and cognitive ergonomics. *PeerJ, 6*, e4443.

Talsma, D., Senkowski, D., Soto-Faraco, S., & Woldorff, M. G. (2010). The multifaceted interplay between attention and multisensory integration. *Trends in cognitive sciences, 14*(9), 400-410.

Tang, C.-H., Wu, W.-T., & Lin, C.-Y. (2009). Using virtual reality to determine how emergency signs facilitate way-finding. *Applied ergonomics, 40*(4), 722-730.

Tas, A. C., Luck, S. J., & Hollingworth, A. (2016). The relationship between visual attention and visual working memory encoding: A dissociation between covert and overt orienting. *Journal of experimental psychology: Human perception and performance, 42*(8), 1121.

Thompson, W. F., Schellenberg, E. G., & Husain, G. (2001). Arousal, mood, and the Mozart effect. *Psychological science, 12*(3), 248-251.

Thorndyke, P. W., & Hayes-Roth, B. (1982). Differences in spatial knowledge acquired from maps and navigation. *Cognitive psychology, 14*(4), 560-589.

Tolman, E. C. (1949). *Purposive behavior in animals and men*: Univ of California Press.

Torresin, S., Albatici, R., Aletta, F., Babich, F., & Kang, J. (2019). Assessment methods and factors determining positive indoor soundscapes in residential buildings: A systematic review. *Sustainability, 11*(19), 5290.

Torresin, S., Albatici, R., Aletta, F., Babich, F., Oberman, T., Siboni, S., & Kang, J. (2020). Indoor soundscape assessment: A principal components model of acoustic perception in residential buildings. *Building and Environment, 182*, 107152.

Tranel, D., Damasio, H., Eichhorn, G. R., Grabowski, T., Ponto, L. L., & Hichwa, R. D. (2003). Neural correlates of naming animals from their characteristic sounds. *Neuropsychologia, 41*(7), 847-854.

Tversky, B., Franklin, N., Taylor, H. A., & Bryant, D. J. (1994). Spatial mental models from descriptions. *Journal of the American society for information science, 45*(9), 656-668.

Van der Burg, E., Olivers, C. N., Bronkhorst, A. W., & Theeuwes, J. (2008). Pip and pop: nonspatial auditory signals improve spatial visual search. *Journal of experimental psychology: Human perception and performance, 34*(5), 1053.

van der Ham, I. J., Faber, A. M., Venselaar, M., van Kreveld, M. J., & Löffler, M. (2015). Ecological validity of virtual environments to assess human navigation ability. *Frontiers in Psychology, 6*, 637.

Vilaró, A., Duchowski, A. T., Orero, P., Grindinger, T., Tetreault, S., & Di Giovanni, E. (2012). How sound is the Pear Tree Story? Testing the effect of varying audio stimuli on visual attention distribution. *Perspectives, 20*(1), 55-65.

Von Stulpnagel, R., Kuliga, S., Büchner, S. J., & Holscher, C. (2014). *Supra-individual consistencies in navigator-driven landmark placement for spatial learning.* Paper presented at the Proceedings of the Annual Meeting of the Cognitive Science Society.

Waller, D., & Hodgson, E. (2013). Sensory contributions to spatial knowledge of real and virtual environments. In *Human walking in virtual environments* (pp. 3-26): Springer.

Waller, D., & Lippa, Y. (2007). Landmarks as beacons and associative cues: their role in route learning. *Memory & Cognition, 35*(5), 910-924.

Wallet, G., Sauzéon, H., Pala, P. A., Larrue, F., Zheng, X., & N'Kaoua, B. (2011). Virtual/real transfer of spatial knowledge: Benefit from visual fidelity provided in a virtual environment and impact of active navigation. *Cyberpsychology, Behavior, and Social Networking, 14*(7-8), 417-423.

Ward, J., Huckstep, B., & Tsakanikos, E. (2006). Sound-colour synaesthesia: To what extent does it use cross-modal mechanisms common to us all? *Cortex, 42*(2), 264-280.

Weisberg, S. M., Badgio, D., & Chatterjee, A. (2018). Feel the way with a vibrotactile compass: Does a navigational aid aid navigation? *Journal of experimental psychology: learning, memory, and cognition, 44*(5), 667.

Weisberg, S. M., & Newcombe, N. S. (2016). How do (some) people make a cognitive map? Routes, places, and working memory. *Journal of experimental psychology: learning, memory, and cognition, 42*(5), 768.

Weisman, J. (1981). Evaluating architectural legibility: Way-finding in the built environment. *Environment and Behavior, 13*(2), 189-204.

Wen, W., Ishikawa, T., & Sato, T. (2011). Working memory in spatial knowledge acquisition: Differences in encoding processes and sense of direction. *Applied Cognitive Psychology, 25*(4), 654-662.

Werkhoven, P., van Erp, J. B., & Philippi, T. G. (2014). Navigating virtual mazes: The benefits of audiovisual landmarks. *Displays, 35*(3), 110-117.

Westerdahl, B., Suneson, K., Wernemyr, C., Roupé, M., Johansson, M., & Allwood, C. M. (2006). Users' evaluation of a virtual reality architectural model compared with the experience of the completed building. *Automation in construction, 15*(2), 150-165.

Williams, B., Narasimham, G., Westerman, C., Rieser, J., & Bodenheimer, B. (2007). Functional similarities in spatial representations between real and virtual environments. *ACM Transactions on Applied Perception (TAP), 4*(2), 12-es.

Wilson, P. N., & Péruch, P. (2002). The influence of interactivity and attention on spatial learning in a desk-top virtual environment. *Cahiers de Psychologie Cognitive/Current Psychology of Cognition*.

Witmer, B. G., Bailey, J. H., Knerr, B. W., & Parsons, K. C. (1996). Virtual spaces and real world places: Transfer of route knowledge. *International Journal of Human-Computer Studies*, *45*(4), 413-428.

Wright, R. D., & Ward, L. M. (1994). Shifts of visual attention: An historical and methodological overview. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale, 48*(2), 151.

Wright, R. D., & Ward, L. M. (2008). *Orienting of attention*: Oxford University Press.

Yang, Y., & Diez-Roux, A. V. (2012). Walking distance by trip purpose and population subgroups. *American journal of preventive medicine, 43*(1), 11-19.

Ye, K., Luo, H., Kang, J., & Wu, S. (2020). Indoor sound environments and visual media displays: A case study on canteens. *Building and Environment*, 106831.

Yesiltepe, D., Conroy Dalton, R., & Ozbil Torun, A. (2021). Landmarks in wayfinding: a review of the existing literature. *Cognitive processing, 22*(3), 369-410.

Yesiltepe, D., Dalton, R. C., Ozbil Torun, A., Coutrot, A., Hornberger, M., & Spiers, H. (2020). *A study on visual and structural characteristics of landmarks and experts' and non-experts' evaluations.* Paper presented at the German Conference on Spatial Cognition.

Yost, W. A. (2001). Chapter Fourteen Auditory Localization and Scene Perception. *Blackwell Handbook of Sensation and Perception*, 437.

Zijlstra, E., Hagedoorn, M., Krijnen, W. P., van der Schans, C. P., & Mobach, M. P. (2016). Route complexity and simulated physical ageing negatively influence wayfinding. *Applied ergonomics, 56*, 62-67.

Zimmermann, J. F., Moscovitch, M., & Alain, C. (2016). Attending to auditory memory. *Brain research, 1640*, 208-221.

Zimring, C. (1990). The costs of confusion: Non-monetary and monetary costs of the Emory University hospital wayfinding system. *Atlanta: Georgia Institute of Technology, 91*(2).

Bilkent Universitesi
Akademik İşler Rektör Yardımcılığı

Tarih : 28 Şubat 2022

Gönderilen Semiha Yılmazer

Tez Danışmanı : Donya Dalirnaghadeh

Gönderen : H. Altay Güvenir
İnsan Araştırmaları Etik Kurulu Başkanı

Konu : *"The effect of ..."* çalışması etik kurul onayı

Üniversitemiz İnsan Araştırmaları Etik Kurulu, 28 Şubat 2022 tarihli görüşme sonucu, *"The effect of sound environment on spatial knowledge acquisition in a virtual outpatient polyclinic"* isimli çalışmanız kapsamında yapmayı önerdiğiniz etkinlik için etik onay vermiş bulunmaktadır. Onay, ekte verilmiş olan çalışma önerisi, çalışma yürütücüleri ve bilgilendirme formu için geçerlidir.

Bu onay, yapmayı önerdiğiniz çalışmanın genel bilim etiği açısından bir değerlendirmedir. Çalışmanızda, kurulumuzun değerlendirmesi dışında kalabilen özel etik ve yasal sınırlamalara uymakla ayrıca yükümlüsünüz.

Kovid-19 salgını nedeniyle konulmuş olan kısıtlamaların yürürlükte olduğu süre içinde, tüm komite toplantıları elektronik ortamda yapılmaktadır; aşağıda isimleri bulunan Bilkent Üniversitesi Etik Kurulu Üyeleri adına bu yazıyı imzalama yetkisi kurul başkanındadır.

Etik Kurul Üyeleri:

Ünvan / İsim	**Bölüm / Uzmanlık**	
Prof.Dr. H. Altay Güvenir	Bilgisayar Mühendisliği	Başkan
Prof.Dr. Erdal Onar	Hukuk	Üye
Prof.Dr. Haldun Özaktaş	Elektrik ve Elektronik Müh.	Üye
Doç.Dr. Işık Yuluğ	Moleküler Biyoloji ve Genetik	Üye
Dr. Öğr. Üyesi Burcu Ayşen Ürgen	Psikoloji	Üye
Dr. Öğr. Üyesi Didem Özkul McGeoch	İletişim ve Tasarımı	Yedek Üye
Dr. Öğr. Üyesi A.Barış Özbilen	Hukuk	Yedek Üye

Kurul karar/toplantı No: 2022_02_28_01

Bilkent Üniversitesi İnsan Araştırmaları Etik Kurulu Hakkında:

- Kurul aşağıda ünvan, isim, uzmanlık alanı/bölümü belirtilen 5 asli ve 2 yedek üyeden oluşur:

  Prof.Dr. H. Altay Güvenir (Başkan), Bilgisayar Mühendisliği
  Prof.Dr. Erdal Onar, Hukuk
  Prof.Dr. Haldun Özaktaş, Elektrik ve Elektronik Mühendisliği
  Doç.Dr. Işık Yuluğ, Moleküler Biyoloji ve Genetik
  Dr.Öğr. Üyesi Burcu Ayşen Ürgen, Psikoloji
  Dr. Öğr. Üyesi Didem Özkul Mcgeoch (Yedek Üye), İletişim ve Tasarımı
  Dr.Öğr. Üyesi Arif Barış Özbilen (Yedek Üye), Hukuk

- Kurul toplantılarına katılamayan asli üyelerin yerine yedek üyeler görevlendirilir.
- Kurul en az 3 üye ile toplanabilir.
- Bir başvurunun onay alması konusunda olumsuz oy kullanan üyeler bunu onay belgesindeki isimlerinin yanına muhalefet notu düşerek belirtirler.
- Bir başvurunun onay alabilmesi için en az 3 üyenin olumlu oy kullanması gerekir. Onay belgesinde isimlerinin yanında muhalefet notu bulunmaması, o üyelerin olumlu oy kullandıkları anlamına gelir.

(Form Student_EN*)

Ethics form for graduate and undergraduate students - human participants

Note - group projects fill in one copy with all your names on it. Consult your project supervisor for advice before filling in the form.

Your name(s): Donya Dalirnaghadeh **Project Supervisor: Semiha Yilmazer**

A. Write your name(s) and that of your supervisor above.
B. Read section 2 that your supervisor will have to sign. Make sure that you cover all these issues in section 1. Discuss what you are going to put on the form with your project supervisor.
C. Sign the form and get your project supervisor to complete section 2 and sign the form.

1. Project Outline (to be completed by student(s))

(i) Full Title of Project:

The effect of sound environment on spatial knowledge acquisition in a virtual outpatient polyclinic

(ii) Aims of project:

In a virtual environment, we would explore the effect of sound on spatial knowledge. The experiment setting involves varying levels of visual and audio cues.

(iii) What will the participants have to do? (brief outline of procedure; please draw attention to any manipulation that could possibly be judged as deception; *for survey work, a copy of the survey should be attached to this form*):

The participants will be randomly assigned to one of the four experiment groups. First, they will watch a passive exploration video of a route in an outpatient polyclinic and afterwards they will be asked to do five different wayfinding tasks.

(iv) What sort of people will the participants be and how will they be recruited? In the case of children state age range. (*Any participant who has not lived through his/her 18th birthday is considered to be a child!*)

The participants will be healthy students and employees from Bilkent University and they will be recruited via convenience sampling.

*If you are testing children or other vulnerable individuals, state whether all applicants have CRB** clearance*

(v) What sort stimuli or materials will your participants be exposed to? Tick the appropriate boxes and then explain the form that they take in the space below, please draw attention to any content that could conceivably upset your participants).
Questionnaires[ ]; Pictures[ ]; Sounds [ ]; Words[ ]; Caffeine[ ]; Alcohol[ ]; Other[ ].

Questionnaires, pictures and sounds.

- * Adapted from *www.york.ac.uk/depts/psych/www/research/ethics/HumanProjForm.doc*
- ** Criminal Records Bureau – Please attach relevant clearance documentation.

(vi) Consent Informed consent must be obtained for all participants before they take part in your project. The form should clearly state what they will be doing, drawing attention to anything they could conceivably object to subsequently. It should be in language that the person signing it will understand. It should also state that they can withdraw from the study at any time and the measures you are taking to ensure the confidentiality of data. If children are recruited from schools you will require the permission of the head teacher, and of parents. Children over 14 years should also sign an individual consent form themselves. When testing children you will also need Criminal Records Bureau clearance. Testing to be carried out in any institution (prison, hospital, etc.) will require permission from the appropriate authority. (Please include documentation for such permission.)

Who will you seek permission from?

The study does not require a permit.

Please attach the consent form you will use. Write the "brief description of study" in the words that you will use to inform the participants here.

This study is designed to gather data for a PhD dissertation entitled "The effect of sound environment on spatial knowledge acquisition in a virtual outpatient polyclinic" prepared at Bilkent University, Department of Interior Architecture and Environmental Design. The information you share will only be used for academic purposes and will not be associated with you. Collected data will be analyzed by SPSS and other statistical analysis programs. The results of these analyzes can be published in doctoral dissertation, conference reports and / or journal articles; however, all information will be kept strictly confidential and anonymized. Your data will be stored in a secure system. If you would like a copy of the published thesis or article, please contact the researcher. Participation in this study is voluntary, so please do not feel obligated to participate. You will not face any penalties for refusing to participate, and you may withdraw at any stage of the study.
For more information contact ddalirnaghadeh@bilkent.edu.tr
If you agree to participate in the survey, you will be asked to watch a passive video of an outpatient hospital route and then fill out the questionnaire on wayfinding tasks. You will also be asked to answer demographic questions.
The survey takes about 15 minutes; but since there is no time limit, you can use as much time as you want. The study includes a learning and a testing phase, in the learning phase, you will be asked to watch a video of a route in a virtual outpatient clinic. After the learning phase, you will be asked to perform certain tasks. The route would start at the outpatient clinic and after visiting several decision points, you would enter the neurology department, navigate through it and then make an exit. That would be the end of the route. Please pay attention to the route and different elements that you see or hear in the video.
There is no predictable disadvantage for your participation. If you are unhappy or have more doubts at any stage of the survey, please address your concerns first to the researcher by sending an e-mail (ddalirnaghadeh@bilkent.edu.tr) to the researcher. You also have the right to leave the survey at any time.

(vii) Debriefing - how and when will participants be informed about the experiment, and what information you intend to provide? If there is any chance that a participant will be 'upset' by taking part in the experiment what measures will you take to mitigate this?

The participants will be contacted via email and will be given brief information about the experiment procedure. There is no predictable disadvantage of the participation, however, if they feel uncomfortable at any stage they can abandon the survey.

(viii) What procedures will you follow in order to guarantee the confidentiality of participants' data? Personal data (name, addresses etc.) should only be stored if absolutely necessary and then only in such a way that they cannot be associated with the participant's experimental data.

Name of the participants will not be asked. All information will be kept strictly confidential and anonymized. The data will be stored in a secure system.

(vii) Give brief details of other special issues the ethics committee should be aware of.

(viii) Tick any of the following that apply to your project
[ ] it uses Bilkent facilities;
[ ] it uses stimuli designed to be emotive or aversive;
[ ] it requires participants to ingest substances (e.g., alcohol);
[ ] it require participants to give information of a personal nature;
[ ] it involves children or other vulnerable individuals;
[ ] it could put you or someone else at risk of injury.

Student's signature: .... date: ..March....2022
(all students must sign if this is a group project, please initial all other pages)

The signatures here signify that researchers will conform to the accepted ethical principles endorsed by relevant professional bodies, in particular to

Declaration of Helsinki (WMA):
http://www.wma.net/en/30publications/10policies/b3/index.html

Ethical Principles of Psychologists and Code of Conduct (APA):
http://www.apa.org/ethics/code2002.html

Ethical Standards for Research with Children (SCRD):
http://www.srcd.org/about-us/ethical-standards-research

2. Supervisor's assessment (supervisor to complete - circle yes or no)

Yes/No - I confirm that I have secured the resources required by this project, including any workshop time, equipment, or space that are additional to those already allocated to me.

Yes/No - The design of this study ensures that the dignity, welfare and safety of the participants will be ensured and that if children or other vulnerable individuals are involved they will be afforded the necessary protection.

Yes/No - All statutory, legislative and other formal requirements of the research have been addressed (e.g., permissions, police checks)

Yes/No - I am confident that the participants will be provided with all necessary information before the study, in the consent form, and after the study in debriefing.

Yes/No - I am confident the participant's confidentiality will be preserved.

Yes/No - I confirm that students involved have sufficient professional competency for this project.

Yes/No - I consider that the risks involved to the student, the participants and any third party are insignificant and carry no special supervisory considerations. If you circle "no" please attach an explanatory note.

No/Yes - I would like the ethics committee to give this proposal particular attention. (Please state why below)

Supervisor's signature: ....

date: ....

Please e-mail an electronic version of this word processed form (without signatures) along with other application material to the committee to start the evaluation process. Paper copies of all application material, (properly signed where indicated, and initialed on all other pages) should be sent after possible modifications suggested by the committee are finalized.

Bilkent University does not allow the use of students of research investigators as participants. Students who have the potential of being graded by the investigators during or following the semester(s) in which the study is being carried out should not participate in the study. Students may not receive any credit for any university course, with the exception of the GE250/GE251 courses, for their participation. The GE250 and GE251 (Collegiate Activities I and II) courses include an optional activity which encompasses volunteering as a participant in a research project.

(Form Staff_EN*)

Staff Application Form for Experiments with Human Participants

(A separate application form must be completed for each experiment and staff member.)

Please check one: ___ ***I need a formal approval letter for an external agency (TÜBİTAK, etc.)***

✓ ***An internal communication letter informing me of the approval will be sufficient***

1. Name of applicant (graduate students should indicate their supervisors)

Semiha Yilmazer

2. Funder of grant/studentship if any:

3. Full title of experiment/project

The effect of sound environment on spatial knowledge acquisition in a virtual outpatient polyclinic

4. When do you wish to start data collection: _March 2022

5. Aims of project:

In a virtual environment, we would explore the effect of sound on spatial knowledge. The experiment setting involves varying levels of visual and audio cues.

6. What will the participants have to do? (Provide a brief outline of procedure, *for survey work, a copy of the survey should be attached to this form.*) Please indicate if the participants may be exposed to stimuli which may upset them:

The participants will be randomly assigned to one of the four experiment groups. First, they will watch a passive exploration video of a route in an outpatient polyclinic and afterwards they will be asked to do five different wayfinding tasks.

7. What sort of people will the participants be and how will they be recruited? In the case of children state age range. (*Any participant who has not lived through his/her 18th birthday is considered to be a child!*)

The participants will be healthy students and employees from Bilkent University and they will be recruited via convenience sampling.

I have CRB clearance yes / no**

8. Arrangements for consent and debriefing (attach information sheet and consent form)

This study is designed to gather data for a PhD dissertation entitled "The effect of sound environment on spatial knowledge acquisition in a virtual outpatient polyclinic" prepared at Bilkent University, Department of Interior Architecture and Environmental Design. The information you share will only be used for academic purposes and will not be associated with you. Collected data will be analyzed by SPSS and other statistical analysis programs. The results of these analyzes can be published in doctoral dissertation, conference reports and / or journal articles; however, all information will be kept strictly confidential and anonymized. Your data will be stored in a secure system. If you would like a copy of the published thesis or article, please contact the researcher.
Participation in this study is voluntary, so please do not feel obligated to participate. You will not face any penalties for refusing to participate, and you may withdraw at any stage of the study.
For more information contact ddalirnaghadeh@bilkent.edu.tr
If you agree to participate in the survey, you will be asked to watch a passive video of an outpatient hospital route and then fill out the questionnaire on wayfinding tasks. You will also be asked to answer demographic questions.

---

* Adapted from *www.york.ac.uk/depts/psych/www/research/ethics/StaffPGEthicsForm.doc*

** Criminal Records Bureau – clearance is required for non-university personnel, including students, for experiments involving children. Please attach relevant documentation.

The survey takes about 15 minutes; but since there is no time limit, you can use as much time as you want. The study includes a learning and a testing phase, in the learning phase, you will be asked to watch a video of a route in a virtual outpatient clinic. After the learning phase, you will be asked to perform certain tasks. The route would start at the outpatient clinic and after visiting several decision points, you would enter the neurology department, navigate through it and then make an exit. That would be the end of the route. Please pay attention to the route and different elements that you see or hear in the video.
There is no predictable disadvantage for your participation. If you are unhappy or have more doubts at any stage of the survey, please address your concerns first to the researcher by sending an e-mail (ddalirnaghadeh@bilkent.edu.tr) to the researcher. You also have the right to leave the survey at any time.

9. How will you guarantee confidentiality of participants?

Name of the participants will not be asked. All information will be kept strictly confidential and anonymized. The data will be stored in a secure system.

10. **Please e-mail an electronic version of this word processed form (without signatures) along with other application material to the committee to start the evaluation process. Paper copies of all application material, (properly signed where indicated, and initialed on all other pages) should be sent after possible modifications suggested by the committee are finalized.**

Signature(s):

....

Supervisor, grant holder, or Principal Investigator: I am satisfied that that the procedures adopted will ensure the dignity, welfare and safety of all participants in this work.

... .

The signature above signifies that researchers will conform to the accepted ethical principles endorsed by relevant professional bodies, in particular to

Declaration of Helsinki (WMA):
https://www.wma.net/policies-post/wma-declaration-of-helsinki-ethical-principles-for-medical-research-involving-human-subjects/

Ethical Principles of Psychologists and Code of Conduct (APA):
http://www.apa.org/ethics/code2002.html

Ethical Standards for Research with Children (SCRD):
http://www.srcd.org/about-us/ethical-standards-research

Bilkent University does not allow the use of students of research investigators as participants. Students who have the potential of being graded by the investigators during or following the semester(s) in which the study is being carried out should not participate in the study. Students may not receive any credit for any university course, with the exception of the GE250/GE251 courses, for their participation. The GE250 and GE251 (Collegiate Activities I and II) courses include an optional activity which encompasses volunteering as a participant in a research project.

Appendix B

This study is designed to gather data for a PhD dissertation entitled "A Wayfinding study in a virtual outpatient clinic with soundscape" prepared at Bilkent University, Department of Interior Architecture and Environmental Design. The information you share will only be used for academic purposes and will not be associated with you. For more information contact ddalirnaghadeh@bilkent.edu.tr

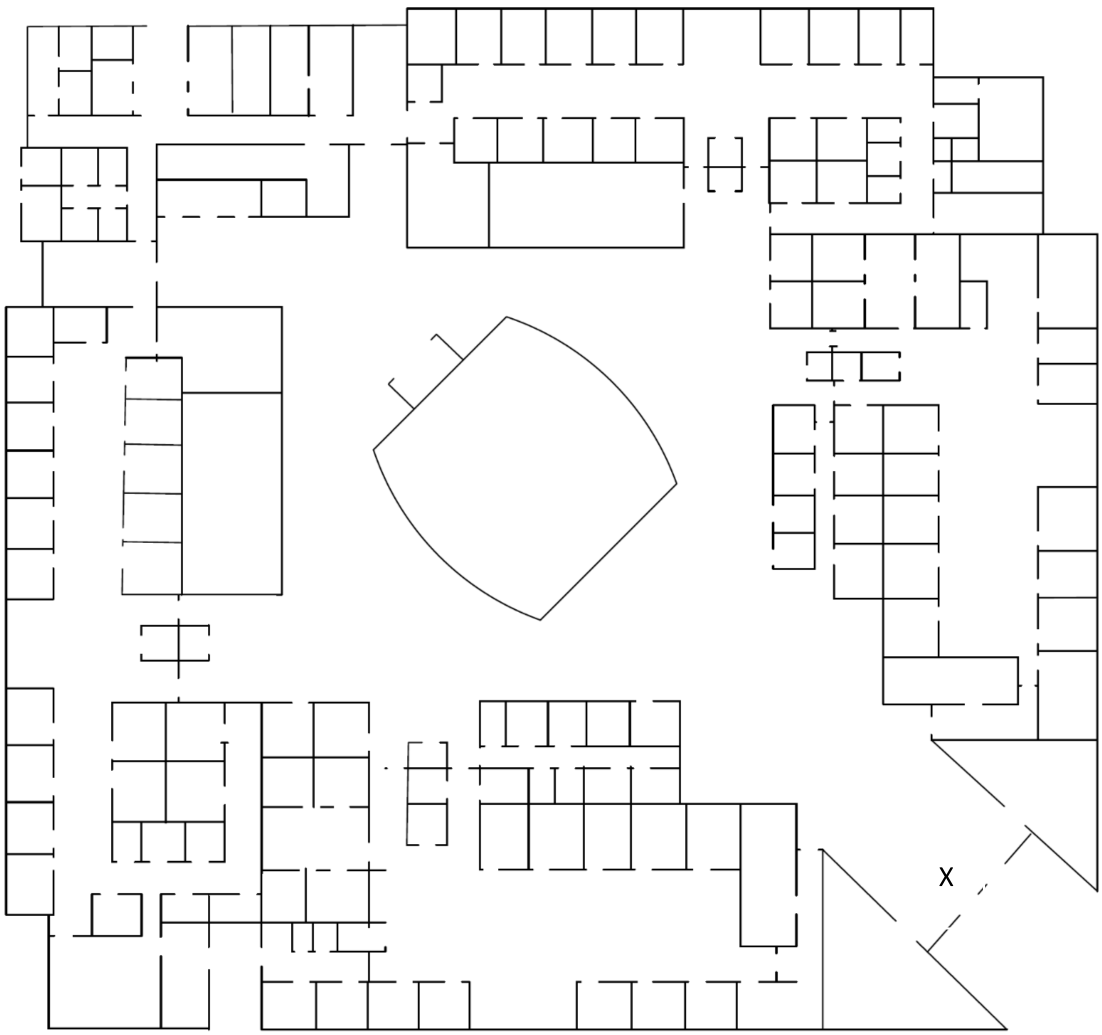
☐ I agree to participate in the study

The study includes a learning and a testing phase, in the learning phase, you will be asked to watch a video of a route in a virtual outpatient clinic. After the learning phase, you will be asked to perform certain tasks. The route would start at the outpatient clinic and after visiting several decision points, you would enter the neurology department, navigate through it and then make an exit. That would be the end of the route. Please pay attention to the route and different elements that you see or hear in the video.

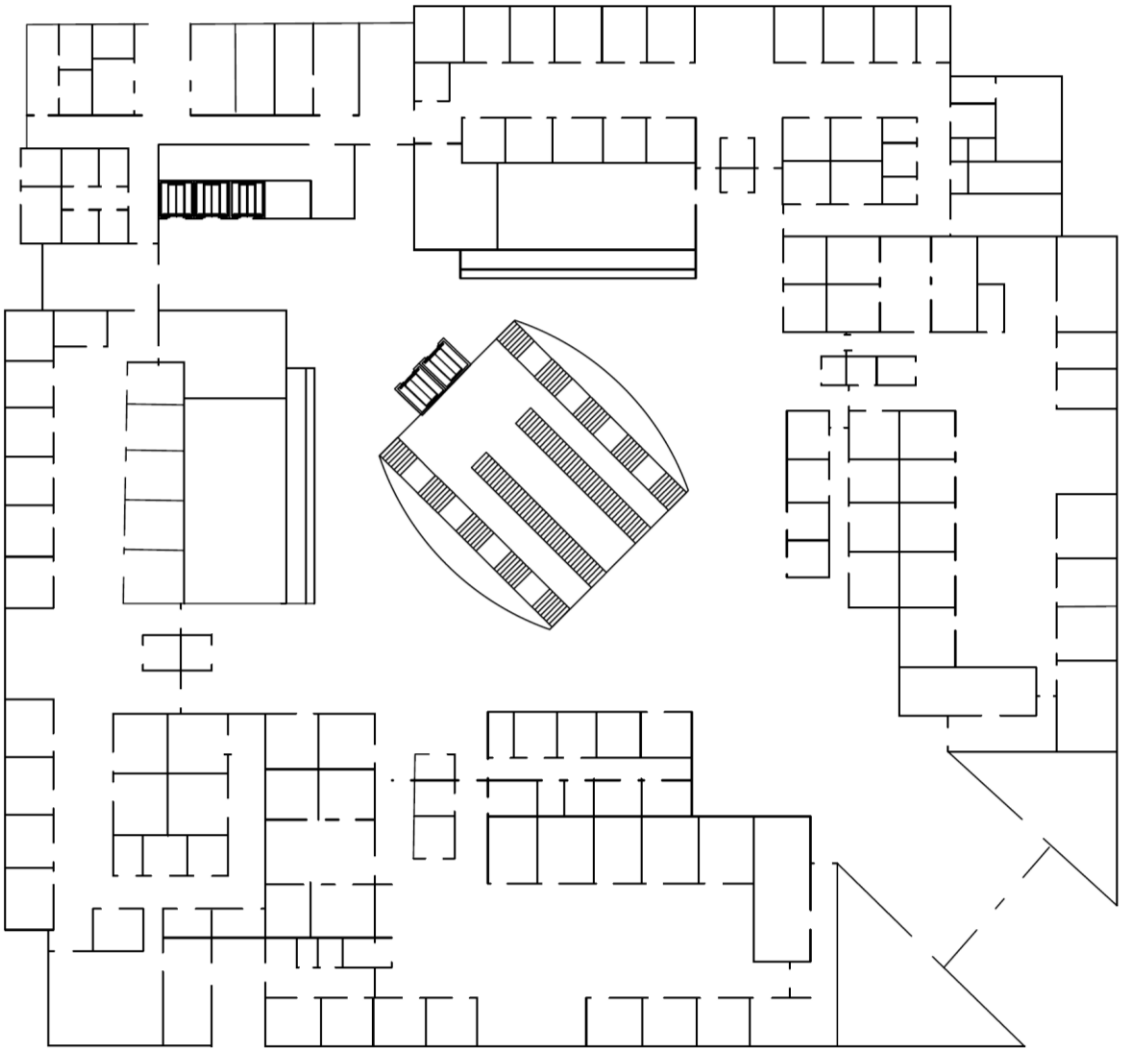
Section A: Please answer the following questions.

1. Age:
2. Gender: ☐ Female☐ Male☐ Other
3. Education level☐Middle and high school or lower ☐University ☐Master/ PhD
4. Profession/ Department:
5. Nationality:
6. Have you ever visited the outpatient polyclinic in Bilkent city hospital before?
7. If yes, how many times?
8. When was the last time you visited the outpatient polyclinic in Bilkent city hospital?

Section B: Please place the escalator, staircases, elevators, and patient administration desks on the blank plan that is provided for you.



Section C: Please draw the route that you took on the provided map.

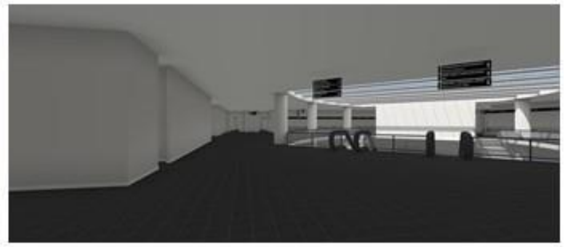


Section D: You will watch the same video that you watched in the learning phase, however, there would be a pause in specific decision points. Please indicate left, right, or straight for each decision point.

1. ☐ Straight ☐ Right ☐ Left
2. ☐ Straight ☐ Right ☐ Left
3. ☐ Straight ☐ Right ☐ Left
4. ☐ Straight ☐ Right ☐ Left
5. ☐ Straight ☐ Right ☐ Left
6. ☐ Straight ☐ Right ☐ Left

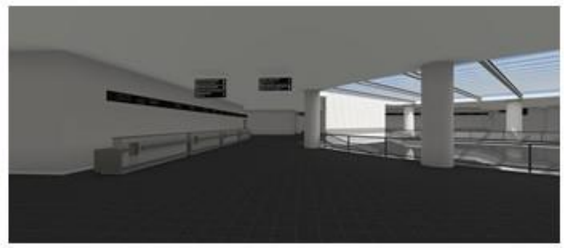
Section E: Please put the pictures in the order that you visited in the route.

1

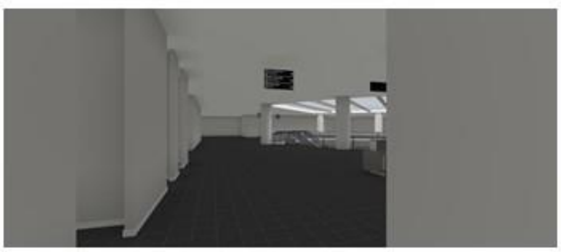


2

3

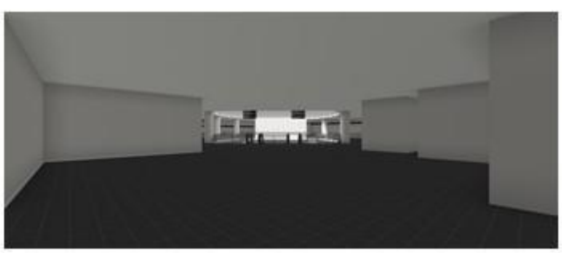


4



5

6



7

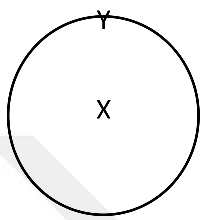
8

Section F: Please answer the following questions by drawing an arrow on the circle as shown in the example,.

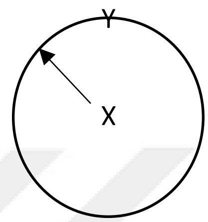
Example:

You are standing at the entrance (X) and facing towards the escalator (Y). Please point to the first administration desk.

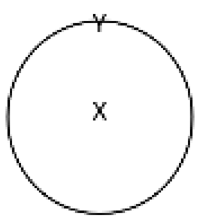
Given:



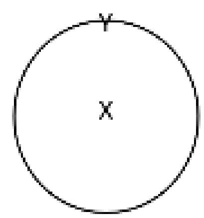
Answer:



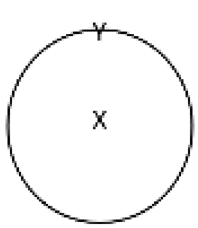
1. You are standing at the first administration desk (X) and facing towards the escalators (Y). Please point to the neurology department entrance.



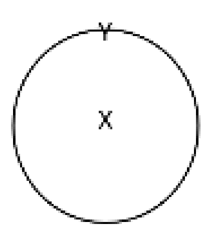
2. You are standing at the visitor elevators (X) and facing towards the second administration desk (Y). Please point to the staircases.



3. You are standing at the neurology department exit (X) and facing towards the first administration desk (Y). Please point to the main entrance.



4. You are standing at the escalators (X) and facing the main entrance (Y). Please point to the visitor elevators.



Appendix C

Figure C.2 presents a version of the sound source identification scale. It consists of a question and an additional instruction. Thereafter follows a list of four response scales. The heading of each response scale in the list presents a type of sound source, or part thereof, including some examples to guide the respondent.

To what extent do you hear the following four types of sounds? Please tick off on response alternative per type of sound					
	Not at all	A little	Moderately	A lot	Dominates completely
Traffic noise (e.g., cars, buses, trains, air planes)					
Other noise (e.g., sirens, construction, industry, loading of goods)					
Sounds from human beings (e.g., conversation, laughter, children at play, footsteps)					
Natural sounds (e.g., singing birds, flowing water, wind in vegetation)					

NOTE: the first scale has the heading "traffic noise" and the second completes the category with the heading "other noise". The term "noise" is used instead of "technological sounds". The term "noise" is not intended as a value judgement.

Figure C.2- Questionnaire part 1 related to the sound source identification

Figure C.3 presents an alternative. It includes one response scale for each of the three main types of sound sources.

To what extent do you hear the following three types of sounds? Please tick off on response alternative per type of sound					
	Not at all	A little	Moderately	A lot	Dominates completely
Noise (e.g., traffic, construction, industry)					
Sounds from human beings (e.g., conversation, laughter, children at play, footsteps)					

Natural sounds (e.g., singing birds, flowing water, wind in vegetation)	

Figure C.3- Questionnaire part 1 related to the sound source identification

C.3.1.3 Questionnaire part 2: Perceived affective quality

Figure C.4 presents the second part of the questionnaire and is related to the perceived affective quality. It consists of a question and an additional instruction. Thereafter flows a list of eight response scales with an affective attribute in the heading.

For each of the 8 scales below, to what extent do you agree or disagree that the present surrounding sound environment is…
Please tick off one response alternative per scale.

	Strongly agree	Agree	Neither agree, nor disagree	Disagree	Strongly disagree
-Pleasant					
-Chaotic					
-Vibrant					
-Uneventful					
-Calm					
-Annoying					
-Eventful					
-Monotonous					

Figure C.4- Questionnaire part 2 related to the perceived affective quality

C.3.1.4 Questionnaire part 3: Assessment of the surrounding sound environment

Figure C.5 presents an alternative. It includes one response scale for each of the three main types of sound sources.

Overall, how would you describe the present surrounding sound

Very good	Good	Neither good, nor bad	Bad	Very bad
☐	☐	☐	☐	☐

Figure C.5- Questionnaire part 3 related to the assessment of the surrounding sound environment

C.3.1.5 Questionnaire part 4: Appropriateness of the surrounding sound environment

Figure C.6 presents a five-point ordinal-category scale related to the 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 C.6- Questionnaire part 4 related to the assessment of the appropriateness of the surrounding sound environment.

Appendix D

Task 1 (Landmark placement on a sketch): In this task we presented the participants with a schematic plan of the outpatient polyclinic that showed the beginning of the route and asked them to place the escalator, the staircases, the elevators, and the patient administration desks on the blank plan as accurately as possible similar to previous studies (Meneghetti, Muffato, Varotto, & De Beni, 2017; Muffato, Meneghetti, Di Ruocco, & De Beni, 2017). For scoring purposes, we scanned the completed sketch maps and uploaded each plan to Gardony Map Drawing Analyzer (GMDA version 1.2) (Gardony, Taylor, & Brunyé, 2016). This software is based on a bidimensional regression method and it makes comparisons between the landmarks' location on the map and their Cartesian coordinates that are previously calculated on the target layout. The program generates several parameters. Similar to previous studies, we considered the square root of the canonical organization (SQRT-CO), ranging from 0 to 1, as a global index of accuracy (Muffato et al., 2017). Figure 6 presents one example of the data produced by the Gardony Map Drawing Analyzer on the landmark placement task filled by one of the participants. SQRT-CO score of this participant was 1 out of 1.

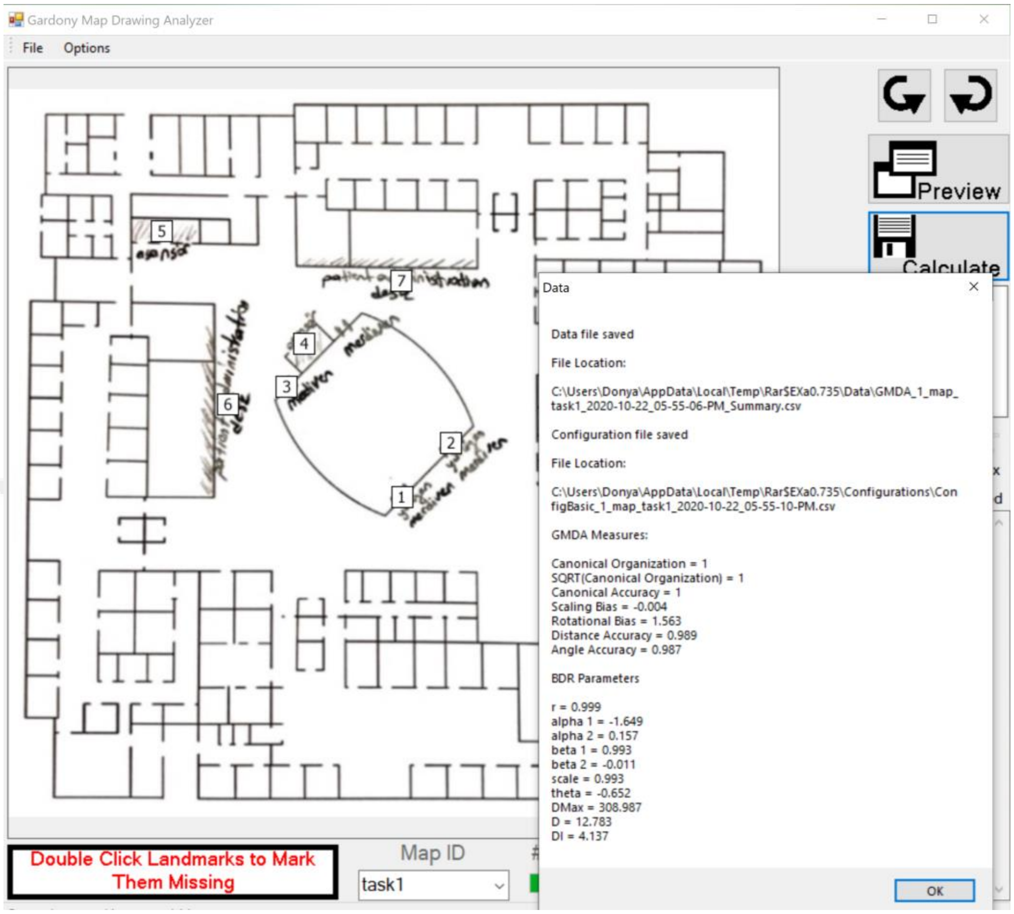


Figure 1. An example of landmark placement on a sketch map and its data analysis

Task 2 (Sketch-mapping task): In this task, we presented the participants with the plan showing the location of the escalators, the staircases and other architectural elements and asked them to draw the route they had watched on the video on the provided plan similar to previous studies (Wallet et al., 2011). In tasks like this, either the errors and omissions in changes of direction in the sketches are counted (Wallet et al., 2011) and then expressed as percentages or a pass or fail method is used to analyze the data (Cogné et al., 2018). We used a pass or fail method for analysis. Figure 7 represents two different examples of sketch mapping task.

(**a**) (**b**)

Figure 2. A sample of landmark placement on a sketch map and its data analysis: (**a**) A sample of a failed answer (**b**) A sample of a passed answer.

Task 3 (Scene sorting task): In this task, we presented the participants with a series of eight pictures taken along the route and asked them to sort them in a chronological order similar to previous studies (Wallet et al., 2011). In this task, we counted the sorting errors. This score was then compared to the best potential score (i.e., 8) in order to obtain percentages.

Task 4 (Pointing tasks): In this task, we asked the participants to imagine standing at a given landmark, facing another, and pointing to a third (Muffato et al., 2017). We used one example for familiarizing the participants with the pointing task. For each item, the question was written at the top and the answer was given using a circle. For scoring purposes, we considered the circular mean of the minimum angles between each participant's response and the correct direction (0–180°) (Borella, Meneghetti, Muffato, & De Beni, 2015; Muffato et al., 2017). Final pointing score consisted of the mean error score for the four pointing tasks. Figure 9 shows two correctly answered pointing tasks and two with an average error score of 37.5 degrees.

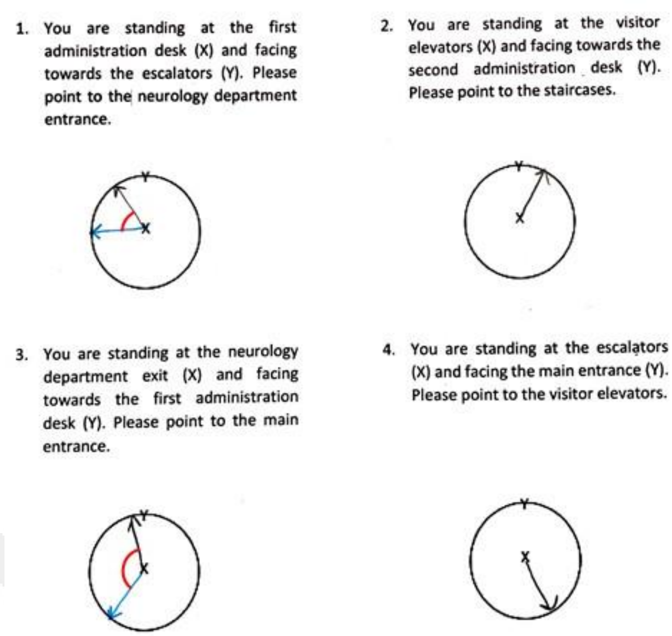


Figure 3. A sample of pointing tasks completed by a participant; the black arrows are the answers that are given by the participant. There is an error rate of 30 degrees in question 1 and 120 degrees in question 3. Question 2 and 4 have been answered correctly. The mean error rate of all questions are 37.5 degrees.

Appendix E

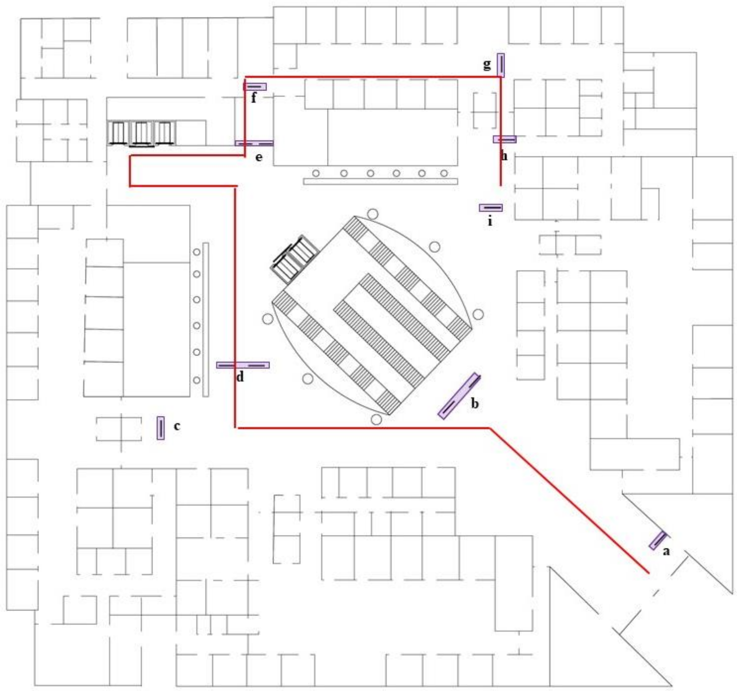
a.
Polyclinics
Patient admission desks
Visitors elevator

b.
Infectious diseases
EEG
Market- ATM- Parking
Dermatology
Neurology
Cafeterias

c.
Physiotherapy
Blood testing

d.
Inpatient service
Endoscopy- Angiography
Interventional radiology
Neurology-Orthopedy radiology
Cafeterias

e.
Interventional radiology
Neurology-Orthopedy radiology
Endoscopy-Angiography
Cafeterias



f.
Endoscopy-Angiography

g.
Specimen processing
WC
Lactation and baby care room

h.
WC

i.
Exit- Cafeterias
Inpatient service