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Virtual environments with soundscapes: a study on immersion and effects of spatial abilities

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Abstract. In this study we explore how soundscapes can be used as navigational aids in virtual environments and empirically investigate the correlation between immersiveness in virtual environments and spatial abilities when soundscapes are used as landmarks for wayfinding. We attempt to advance knowledge regarding auditory cues contributing to enhanced immersive and navigational experience in virtual environments. Findings are likely to be utilized in effective design for physical environments and wayfinding.

Keywords: virtual environments, immersiveness, soundscapes, wayfinding, navigation

1 Introduction

Previous virtual environment studies point to the value of immersion and presence. One element which is not adequately addressed is the role of 'sound' in enhancing immersion and presence in these virtual environments. Most research conducted on the use of sound in immersive virtual environments has focused on computer engineering and human–computer interaction viewpoints (Bargar et al, 1994; Begault, 1994; Naef et al, 2002; Tsingos et al, 2004). This study examines the role of soundscapes in virtual environments from an architectural and urban design perspective. We explore the concept of soundscapes as landmarks to aid the wayfinding process in virtual environments. The primary hypothesis of the study is that soundscapes can be used as auditory landmarks to increase the ease of navigation and immersion in virtual environments. The study attempts to test whether soundscapes enhance immersiveness and to identify relationships between the user's spatiocognitive abilities and the level of immersiveness in virtual environments. The study will help designers and researchers interested in alternate navigational methods for virtual environments to better understand how soundscapes can be used in creating navigational tools for virtual environments.

2 Background

2.1 Soundscapes

Research in the area of virtual environments has focused mainly on display parameters and interaction-related issues (Adams and Hannaford, 1999; Hendrix and Barfield, 1996; Levine and Mourant, 1996; Sturman et al, 1989). Apart from these, sound provides one of the most important elements in enhancing immersive qualities of virtual environments (Blauert, 1997).

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A soundscape is defined as the overall sonic environment of an area (Porteous and Mastin, 1985) or as an environment of sound with emphasis on the way the sound is perceived and understood by the individual or by a society (Truax, 2001), which can be a sound or a combination of sounds that creates an environment or an atmosphere. Soundscapes studies have been conducted in a number of fields, such as health physiology, physics, psychology, artificial intelligence, urban planning, and sociology (Niessen et al, 2010). Our interest lies in studies that concentrate on soundscape usage in both virtual and physical spatial arrangements. Tardieu et al (2004) used soundscapes to identify different spaces inside a train station. They investigated how soundscapes could be used to make train station environments more efficient. In another study, soundscapes were used to create an auditory navigation system for vehicles (Cohen et al, 2006). A number of studies have also been conducted on how sound is used for navigation within virtual environments. Dodiya and Alexandrov (2008) explored how music could be used in making route decisions in virtual environments and discussed how sound cues affect the wayfinding process. They proposed a virtual environment with continuous music streaming (rather than voice cues) in order to assist the users in their route selection process.

Soundscape perception is influenced by cognitive effects such as the meaning of a soundscape and its components, as well as how information is conveyed by a soundscape (Davies et al, 2013). Davies et al (2013) further stated that an important variable in soundscape perception is simply how people think about different sounds. Research has been conducted on soundscapes in virtual environments, with the main consideration given to gaming environments. Garcia (2006) analyzed the use of sound in the videogame *Grand Theft Auto* and proposed that sound played a major role in creating a temporary cultural model that the player adopted during game time that was different from his or her actual cultural beliefs. It is proposed in this study that sound helped define the quality of that particular virtual world, which was violent and isolated, and such presentation of the world allowed the player to engage more easily with the persona or the character of the game. Moffat and Kiegler (2006) investigated the effects of music in games on emotions. They used the game *The Journey to Wild Divine* in their experimental setup and then observed and recorded user emotions using eye-tracking systems. They suggested that music, via emotion, can influence subjects' perception and assessment of a situation. In a similar study, Berndt et al (2006) discussed techniques of composing and arranging music in immersive environments. Their study concentrated on how sound is affected by distance.

Merabet and Sánchez (2009) focused on user-centered, audio-based methods of virtual navigation in computer gaming. They used two games, *Audio Metro* and *Audio Doom*, to analyze the ease of navigation in virtual environments with only sound cues. In their study, blind children navigated within these environments. They state that the virtual environments designed for the study serve as novel rehabilitative approaches to improve spatial navigation, problem-solving skills, and overall confidence in individuals with visual impairment. Walker and Lindsay (2003) looked at sounds as beacons for navigating within virtual environments and studied this effect using two experiments where the beacon size was differentiated in capture radius. They stated that different beacon sounds led to markedly different performances. Furthermore, they stated that a larger capture radius resulted in faster completion times and shorter path lengths.

In another study, three-dimensional (3D) sound was used as a navigational aid in virtual environments (Gunther et al, 2004). The researcher devised an experiment to determine whether incorporating spatialized sound in a virtual environment influences the rate at which people acquired spatial knowledge, helping them to locate objects in the environment. Also, some studies have demonstrated that auditory-landmark-type sound objects are instrumental in creating an auditory-induced circular vection or an illusory self-motion sensation (Väljamäe et al, 2009). Soundscapes have also been used as implicit navigational aids where the subjects are encouraged to explore a certain area using a guiding soundscape (Komninos et al, 2012).

There are number of studies that look at navigation in virtual environments and provide other factors that affect navigation. Balakrishnan and Sundar (2011) discuss the role of narrative transportation in virtual environments and in enhancing the sense of presence as well as navigability. Whereas previous studies suggest the importance of auditory cues and soundscapes for navigation in virtual environments, some studies also indicate that soundscapes enhance the realism and immersiveness in the virtual environment for the user (Finney and Janer, 2010).

2.2 Immersion and presence

Immersion has been defined in a number of ways. Typically, immersion is used to describe the experience of becoming engaged in the virtual environment experience while retaining some awareness of one's surroundings (Baños et al, 2004; Singer and Witmer, 1999). Dede (2009, page 67) defined immersion as the "subjective impression that one is participating in a comprehensive, realistic experience." Brown and Cairns (2004, page 1299) describe immersion as "a sense of being cut off from the world you actually inhabit". In order to gain a better understanding of immersion, it would be pertinent to understand other concepts which are used with it, such as presence, flow, and engagement.

Presence has been described being similar to immersion and has been defined as "being in a normal state of consciousness and having the experience of being inside a virtual environment" (Brockmyer et al, 2009, page 625). Draper et al (1998) defined presence as a mental state in which a user feels physically present within the computer-mediated environment. Slater et al (1994) defined presence as a sense of 'being there'. According to Slater et al (1994) presence seems to have connotations of a subjective phenomenon.

Immersion is defined as a concept very much related to the concept of presence. Witmer and Singer (1998) stated that immersion is a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experience, and further state that it leads to the feeling of presence. Further, Sanchez-Vives and Slater (2005, page 333) refer to immersion as the technical capability of the system to deliver a surrounding and convincing environment with which the participant can interact. Their definition of immersion relates to the fact that immersion is a property of the system and not a human response. Jennett et al (2008) stated that presence is more a state of mind, whereas immersion is an experience in time. Although certain games with no tie to a physical world can provide immersion, they cannot provide a sense of presence. Brown and Cairns (2004) presented three levels of immersion in considering video games. The first level, where a player overcomes the barriers of learning control and other gamer preferences, is termed *engagement*. According to Brown and Cairns (2004), when the player gets further involved in the game, he or she has reached the second level, which the researchers define as *engrossment.* This is where the gamers' emotions become directly affected by the game and the controls became 'invisible'. Further involvement takes the gamer to the final level of *total immersion*, where he or she overcomes the barriers of empathy and atmosphere. They report that in this stage, the players of a game describe a sense of presence.

Ermi and Mäyrä (2005) stated that there are three types of immersion: sensory immersion (related to audiovisual aspects of games), challenge-based immersion (related to challenges the game provides), and imaginative immersion (related to how the player uses their imagination within the game environment).

Studies have suggested different ways of measuring immersion. Some have suggested using physical movement of the body such as eye movement and measuring immersion through eye tracking. Other studies have used subjective questionnaires to measure immersion (Jennett et al, 2008). Witmer and Singer (1998) stated that their presence questionnaire taps both aspects of presence: involvement and immersion.

The idea of auditory immersion is not new. Renaissance composers such as Giovanni Gabrieli were known to integrate the 3D aspects of sound or music in their compositions to create a more immersive musical experience. In such techniques, instrumental groups or choirs were located to the left, right, front, and back of the audience to create a surround-sound effect, where each group has its distinctive, unique qualities but produces a larger musical soundscape as a whole (Berndt et al, 2006).

In discussing the use of soundscapes in videogames, Jørgensen (2006) stated that the overall soundscape contributes to a sense of presence in a game by creating an illusion of the game world as an actual space. He also noted that in sound-enhanced virtual environments, users receive information that the visual system is not able to process, such as objects situated outside the line of sight. These environments also enable the user to comprehend activities taking place in locations other than where he or she is immediately stationed.

Different types of sounds and soundscapes used in computer games and videogames enhance the realism of the virtual game environment. We focus on how soundscapes can be used as landmarks in virtual environments in order to increase the ease of navigation and immersion.

Taking into account these various definitions, this study identifies presence and engagement as outcomes of immersion and operationalized immersion through the Witmer and Singer (1998) questionnaire.

2.3 Wayfinding or navigation, and immersiveness

Distinctive environmental features that act as reference points in large-scale environments (virtual or physical) are termed landmarks (Vinson, 1999). The use of landmarks in navigation has been investigated in a number of fields, such as urban planning (Lynch, 1960), geography (Golledge and Stinson, 1997), and psychology (Chase, 1986).

Vinson (1999) stated that there are two issues to consider in designing landmarks in a virtual environment: the physical features of the landmark; and the way that the landmark becomes distinctive in the environment. Evans et al (1982) provided features that make a landmark more memorable (significant height, complex shape, bright exterior, large visible signs) and that make its location easier to recall (expensive building materials, free-standing structure, surrounded by landscaping, unique exterior color and texture).

The potentials of creating and designing soundscapes in urban spaces have been discussed in previous studies (Zhang and Kang, 2007), and urban theory provides certain rules that increase the ease of navigating an environment. In our study we use Lynch's (1960) idea about landmarks, and we use soundscapes to provide landmarks in the virtual environment. Lynch's concepts of urban theory have been well established and have been used in different fields. We incorporated his ideas on landmarks and how they help in navigating cities. Even though he discusses aspects of visual landmarks in physical space, in our study we look at soundscape landmarks and visual landmarks in virtual space and investigate how they can help navigation.

Other studies have shown that increasing the immersiveness of a virtual environment enhances *imageability*, a term coined by Lynch, and the ease of navigating within that environment (Robertson et al, 1997). Similarly, when an environment is easier to navigate, it should be more immersive.

As defined by Lynch (1960), imageability refers to the quality of a space that gives it a high probability of evoking a strong image in the observer. Lynch claims that in order for a city to be navigable, its imageability should be enhanced. Determining a route between two points and traveling from one point to another within a city requires it to be legible or imageable. Lynch proposed that landmarks, nodes, districts, paths, and edges are the elements that enhance legibility or imageability in a city.

The terms *wayfinding* and *navigation* are often used to describe the process of moving through space which includes complex cognitive processes and physical movements. Whereas wayfinding is thought to be the cognitive component of making one's way through space (Passini, 1984), navigation is considered to be the locomotive dimension (Cheng, 1998).

In navigating through environments, people tend to locate landmarks and use them as wayfinding guides. Because visual landmarks are often prominently elevated (in physical as well as virtual environments), a landmark becomes less visible when the person is closer to it, and at a certain distance a landmark begins to merge with the rest of the environment. Soundscape landmarks may assist the users in these situations, because soundscapes act as 3D auditory landmarks. As the person's proximity to the landmark increases, the sound level appears to increase; as the proximity decreases, the sound level appears to decrease. The ability to identify the landmark is not affected by the field of vision. There have been many studies that emphasize the importance of using landmarks for navigation in both physical and virtual environments. Vinson (1999) provided a set of guidelines on how to use landmarks to increase navigability in virtual environments. In his study he used research on human navigation in real environments to formulate guidelines for landmark design and stated that landmarks not only indicate position and orientation but also contribute to the development of spatial knowledge. Although some studies have investigated how landmarks are selected for navigation by users (Steck and Mallot, 2000) others have looked at how the brain functions when navigating within large virtual environments (Maguire et al, 1998)

The importance of using sound for navigation has been established through a number of research studies. The most remarkable discoveries in modern navigational systems have been the development of instruments such as radar and sonar, which employ sound to locate objects. Sound cues have also been studied extensively as navigational aids (Brewster, 1998; Walker and Lindsay, 2003). Some research has suggested using sound cues as navigational aids for the visually impaired (Loomis et al, 1998).

3 Method

The convenience sample of subjects that we selected was assigned randomly to one of three groups and was tested first for spatiocognitive abilities. The groups were provided with three virtual environments: one group with soundscape and visual landmarks, the second group with only visual landmarks, and the third group with only soundscape landmarks. After navigating through the environment, the subjects were given a questionnaire that assessed the level of immersiveness they experienced.

3.1 Experiment

A total of forty-two architecture undergraduate students from a Mid-western school (twenty-eight women, fourteen men) participated in this study. Subjects had normal to corrected-normal vision and normal hearing (both by self-report). This study uses a between-subject design.

The primary hypothesis of the study was that soundscapes can be used as auditory landmarks to increase the ease of navigation and immersiveness in virtual environments. The main objectives of the study were to identify (1) the role of soundscapes when users navigate in a virtual environment and (2) the cognitive spatial skills of individuals that may affect the subjective immersiveness in virtual environments when soundscapes are used as navigational aids. The independent variable considered in the study was the spatiocognitive abilities of the subjects, and the dependent variable considered was the perceived immersiveness of the environment.

The experiment was divided into three main sections:

- preexperiment questionnaire;
- immersive experiment;
- postexperiment questionnaire.

3.1.1 *Preexperiment questionnaire (measuring the independent variable)*

All forty-two subjects answered the preexperiment questionnaire, which was presented in three sections. The first section asked for basic demographic information from the subjects. The second section obtained information regarding their spatiocognitive abilities. The third section aimed to obtain information regarding the subjects' ability to read maps.

In creating the instrument for the preexperiment questionnaire to measure subjects' spatiocognitive abilities, we created a composite tool consisting of elements adapted from other established scales such as the Shepard and Metzler (1971) tool. Even though some studies mention that there are two main factors of spatiocognitive abilities—spatial visualization and spatial orientation (Stumpf and Eliot, 1999)—there appears to be no clear consensus regarding the number of dimensions of figural spatial ability and their interpretations. In this study, our objective was to measure mental rotation ability, two-dimensional (2D) object construction ability, 3D object deconstruction ability, and map-reading ability.

3.1.2 *Immersive experiment*

In order to minimize distractions, the experiment was conducted in an isolated room without windows and with only one door. A single InFocus IN34 DLP projector (1024 × 768 dpi, ANSI 2500) was positioned facing a mirror behind an 8 ft×6 ft screen. Altec Lansing VS2620 PC multimedia speakers were used as sound sources. We used a Genius wireless joystick as the control device.

Each subject was asked to sit in a chair placed in front of the projector screen for approximately 5–10 min. For optimal viewing, each participant sat 48 inches from the screen. During the experiment the lights were switched off and the door was closed, leaving just the subject and the researcher in the room (see figure 1).

3.1.3 *The virtual environment*

In order to minimize visual cues, a maze environment (figure 2) with nonrepeating configurations with only material maps on the walls was created using the software programs Unity 2.6 and 3D Studio Max 2011. The maze was created by using a random maze image file generated with MAZE-GEN 3.0. We used a first-person navigational method so that the condition was the

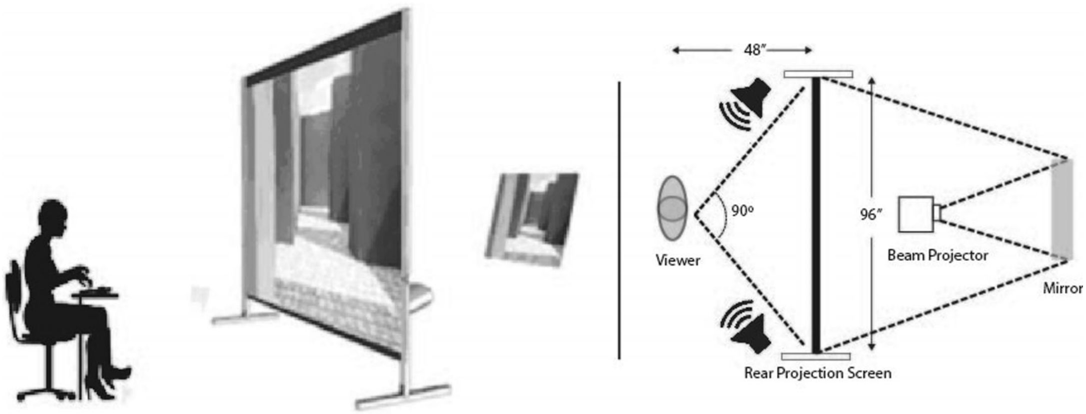

Figure 1. Rear-projector virtual reality system.

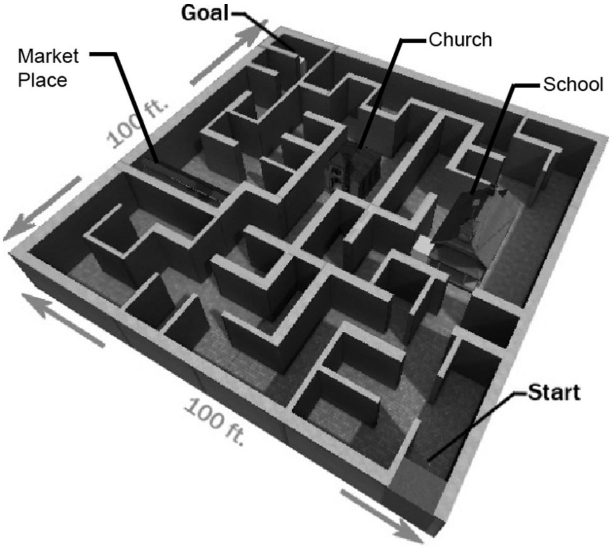

Figure 2. Maze layout.

same for both visual and auditory environments. It has also been shown that a first-person view in a virtual environment generates more sense of presence than a third-person view (Kallinen et al, 2007); thus, we used a first-person view in the virtual environment.

Before the subjects were exposed to the virtual environment, they were introduced to a training environment for 5 minutes so each individual could learn the joystick controls. After the brief training session, the researcher provided oral instructions on how and where to navigate in the virtual environment.

The study consisted of three conditions. In all three conditions the visual maze was present. What was varied was the characteristics of the landmarks: in condition 1 the landmarks were auditory in nature, in condition 2 the landmarks were visual in nature, and in condition 3 landmarks were both visual and auditory in nature.

- condition 1: the virtual environment did not contain visual landmarks (buildings) and *contained only soundscape landmarks*;
- condition 2: the virtual environment *contained only visual landmarks* (buildings) and did not contain any soundscape landmarks;
- condition 3: the virtual environment contained *visual landmarks* (buildings) *and soundscape landmarks*.

The forty-two subjects were assigned randomly to the three groups. From the starting point located at the left-hand corner of the nearest edge, they navigated within the maze using

(a) (b) (c)

Figure 3. Condition types. (a) condition 1: only auditory landmarks; (b) condition 2: only visual landmarks; (c) condition 3: both visual and auditory landmarks.

a joystick to find the goal object at the furthest right-hand corner of the environment. The study has a between-groups design rather than a within-group design to prevent a learning effect.

In condition 1 the virtual environment presented to subjects contained only the soundscape landmarks for a church, school, and marketplace (visual elements of these soundscapes had been removed). In condition 2, only the visual landmarks were present (the soundscape landmarks had been removed). In condition 3, the virtual environment contained visual landmarks of the church, school, and market place, which were accompanied by the relevant soundscape landmarks.

3.1.4 *Postexperiment questionnaire (measuring the dependent variable)*

All forty-two subjects answered the postexperiment questionnaire, which posed questions regarding the immersive experience in the virtual environment. The questions presented were aimed at providing an indication of the effect that soundscapes have in generating immersiveness, and it was devised as a seven-point Likert scale (1–7) based on previously established scales (Witmer and Singer, 1998). Jennett et al (2008) stated that immersion can be measured both subjectively and objectively.

Different studies have used various methods to measure immersion, giving consideration to the operational definition of the study. Witmer and Singer's (1998) questionnaire measures immersive tendencies directly, and studies have used this questionnaire as an established method for measuring immersion (Brockmyer et al, 2009).

3.1.5 *Instrument*

The spatial ability questionnaire contained nine items measuring spatial abilities (SP 01–09) and three items on map-using abilities (Map 01–03). Subdimensions within the spatial ability questions were identified and were categorized into three subsections that measured mental rotation ability, 2D object construction ability, and 3D object deconstruction ability.

There have been many studies that have looked at the spatial abilities of individuals (Carroll, 1993; Thurstone, 1938; Vernon, 1950). Previous studies stated that there are two main types of spatial ability: visualization and orientation (Hegarty and Waller, 2004; McGee, 1979). Kauffman (2007) stated that *visualization* means the ability to mentally rotate objects and *orientation* refers to the ability to retain spatial orientation with respect to one's body. Studies on spatial abilities have looked at spatial relationships in three dimensions and two dimensions (Miyake et al, 2001) and have used visualization tests to assess these skills.

We focus on mental rotation ability, 2D and 3D spatial relationships (through the two variables of 2D object construction ability and 3D object deconstruction ability). *Mental rotation ability* is defined as the ability to mentally rotate shapes and objects. *2D object construction ability* is defined as the ability to formulate relationships between 2D shapes, and *3D object deconstruction ability* is defined as the ability to formulate relationships between 3D shapes.

The immersive experience questionnaire contained seventeen items: fourteen items aimed at measuring immersiveness (Immersive 01–14) and three items designed to measure their cognitive mapping ability. Using factor analysis, three categories were identified in the immersion questionnaire: auditory immersiveness (AI), environmental experience immersiveness (EE), and environmental involvement immersiveness (EI). AI, EE, and EI yielded Cronbach's α values of 0.88, 0.086, and 0.64, respectively (see table 1). Total immersiveness (TI) yielded Cronbach's value of 0.76. EE measured the subjects' interactivity and engagement in the virtual environment. Even though the results support the idea that the virtual environment was highly immersive, the subjects' ability to interact with the environment was low due to the fact that it was not designed to be interactive. This might

Table 1. Cronbach's α values for measured variables.

Variable	Cronbach's α
Auditory immersiveness (AI)	0.88
Environmental experience immersiveness (EE)	0.86
Environmental involvement immersiveness (EI)	0.64
Total immersiveness (TI)	0.76

provide the reason why EI yielded a low but acceptable α value (0.64). DeVellis (1991) stated that an α value of 0.60–0.65 is undesirable yet acceptable; hence, all Cronbach's α values suggest the reliability of the individual tools.

4 Results

Regression modeling was used to determine the effects of the spatial ability of the subjects on their immersiveness in the virtual environments. All analyses were performed by using procedures in the SAS statistical package JMP Version 8.0.

The descriptive summary of measured baseline spatial abilities by condition type is shown in table 2.

A series of simple regression analyses was used to test whether spatial abilities significantly predicted subjects' rating of immersiveness in the three environments.

Mental rotation ability of the subjects was analyzed using simple regression modeling against the dependent variables, EE, EI, AI, TI, and the time taken to complete the exercise in the three different environments. The results of these tests were significant only in condition 1 (see table 3).

Table 2. Descriptive summary of baseline spatial ability by condition. Mean values, with standard deviation in parentheses.

Variable	Condition		
	1 sound only, $n = 14$	2 vision only, $n = 13$	3 sound+Vision, $n = 15$
Mental rotation ability	3.64 (1.34)	3.85 (1.21)	4.13 (0.91)
2D object construction ability	1.78 (0.70)	2.31 (0.75)	2.00 (0.93)
3D object deconstruction ability	0.50 (0.52)	0.46 (0.52)	0.67 (0.49)
Map-using ability	0.79 (0.34)	0.82 (0.22)	0.84 (0.25)
Cognitive mapping ability	0.62 (0.34)	0.46 (0.35)	0.53 (0.25)

Table 3. Regression analyses in condition 1 (soundscape landmarks only).

Regression	R^2	df	β	F
Subjects' mental rotation abilities on environmental experience immersiveness	0.31	13	0.46	5.28
Subjects' mental rotation abilities on environmental involvement immersiveness	0.46	13	0.78	10.47
Subjects' mental rotation abilities on total immersiveness	0.42	13	0.52	8.85
Subjects' mental rotation abilities on completion time	0.38	13	−1.04	7.29

We considered the correlation between mental rotation ability on the EE that the subjects experienced in condition 1. The result of the regression between subjects' mental rotational abilities and EE in auditory immersive environments (condition 1) indicated that the two predictors explained 31% of the variance [$R^2 = 0.31$, $F(1, 13) = 5.28$, $p < 0.05$]. It was found that mental rotation abilities significantly predicted high EE in auditory immersive environments (condition 1) ($\beta = 0.46$, $t_{13} = 2.3$, $p < 0$ .05).

To understand the correlation between mental rotation ability and other types of immersiveness, we analyzed the correlation between mental rotation ability and EI. The result of the regression between subjects' mental rotation abilities and EI in auditory immersive environments (condition 1) indicated that the two predictors explained 47% of the variance [$R^2 = 0.46$, $F(1, 13) = 10.47$, $p < 0.05$]. It was found that mental rotation abilities predicted significantly high EI in auditory immersive environments (condition 1) ($\beta = 0.78$, $t_{13} = 3.24$, $p < 0.05$).

The result of the regression between subjects' mental rotation abilities and TI in auditory immersive environments (condition 1) indicated that the two predictors explained 42% of the variance [$R^2 = 0.42$, $F(1, 13) = 8.85$, $p < 0.05$]. It was found that mental rotation abilities predicted significantly high immersiveness in auditory immersive environments ($\beta = 0.52$, $t_{13} = 2.97$, $p < 0.05$).

The task completion time was also a dependent variable in our study. The result of the regression between subjects' mental rotation abilities and completion time of the immersive exercise in auditory immersive environments (condition 1) indicated that the two predictors explained 38% of the variance [$R^2 = 0.38$, $F(1, 13) = 7.29$, $p < 0.05$]. The results suggest that higher mental rotation abilities predict reduced completion time of the immersive exercise in auditory immersive environments ($\beta = -1.04$, $t_{13} = -2.7$, $p < 0.05$).

Regression modeling also suggested that the completion time of the immersive exercise depended on the immersiveness (EE, EI, and AI) of the virtual environment (see table 4).

Significant results yielded in the regression between subjects' completion time of the immersive exercise and EI in auditory immersive environments (condition 1) indicated that the two predictors explained 34% of the variance [$R^2 = 0.34$, $F(1, 13) = 6.29$, $p < 0.05$]. It was found that longer completion time of the immersive exercise predicted reduced environmental involvement immersiveness in auditory immersive environments (condition 1) ($\beta = -1.04$, $t_{13} = -2.7$, $p < 0.05$).

In condition 3 significant results were identified for all three types of immersiveness with task completion times. The result of the regression between subjects' completion time of the immersive exercise and EE in visual+auditory immersive environments (condition 3) indicated that the two predictors explained 47% of the variance [$R^2 = 0.47$, $F(1, 13) = 11.86$, $p < 0.05$]. It was found that longer completion time of the immersive exercise predicted

Table 4. Regression analyses of independent variable on completion time.

Regression	R^2	df	β	F
Subjects' environmental involvement immersiveness on completion time of the immersive exercise (Condition 1)	0.34	13	−1.04	6.29
Subjects' environmental experiential immersiveness on completion time of the immersive exercise (Condition 3)	0.47	14	−1.53	11.86
Subjects' auditory immersiveness on completion time of the immersive exercise (Condition 3)	0.37	14	−1.38	7.81
Subjects' environmental involvement immersiveness on completion time of the immersive exercise (Condition 3)	0.27	14	−0.98	6.10
Subjects' total immersiveness on completion time of the immersive exercise (condition 3)	0.69	14	−2.02	28.53

reduced EE in visual+auditory immersive environments (condition 3) ($\beta = -1.53$, $t_{13} = -3.44$, $p < 0.05$).

For AI, the result of the regression between the subjects' completion time of the immersive exercise and AI in visual+auditory immersive environments (condition 3) indicated that the two predictors explained 37% of the variance [$R^2 = 0.37$, $F(1, 13) = 7.81$, $p < 0.05$]. It was found that longer completion time of the immersive exercise predicted reduced AI in visual+auditory immersive environments (condition 3) ($\beta = -1.38$, $t_{13} = -2.79$, $p < 0.05$).

The result of the regression between subjects' completion time of the immersive exercise and EI in visual+auditory immersive environments (condition 3) indicated that the two predictors explained 27% of the variance [$R^2 = 0.27$, $F(1, 13) = 6.1$, $p < 0.05$]. It was found that longer completion time of the immersive exercise predicted reduced EI in visual+auditory immersive environments (condition 3) ($\beta = -0.98$, $t_{13} = -2.47$, $p < 0.05$).

TI in condition 3 yielded significant results with task completion time. The result of the regression between subjects' completion time of the immersive exercise and TI in visual+auditory immersive environments (condition 3) indicated that the two predictors explained 69% of the variance [$R^2 = 0.69$, $F(1, 13) = 28.53$, $p < 0.05$]. It was found that higher completion time of the immersive exercise predicted reduced immersiveness in visual+auditory immersive environments ($\beta = -2.02$, $t_{13} = -5.34$, $p < 0.05$).

Additionally, an independent-samples *t*-test was conducted to compare the overall completion times of the immersive exercise of men and women. There was a significant difference in completion times of the immersive exercise between men (M = 2.57, SD = 1.61) and women (M = 4.95, SD = 2.45) (conditions: $t_{40} = -3.28$, $p = 0.002$). These results suggest that men's completion times in the immersive exercise are faster than those of women.

An independent-samples *t*-test was conducted to compare the mental rotation ability of men and women. There was a significant difference in mental rotation ability between men (M = 4.5, SD = 0.65) and women (M = 3.57, SD = 1.23) (conditions: $t_{40} = -2.63$, $p = 0.012$).

Table 5. Descriptive summary of immersiveness by condition. Standard deviations are given in parentheses.

Variable	Condition					
	sound, $n = 14$		vision, $n = 13$		sound+vision, $n = 15$	
	mean	range	mean	range	mean	range
Environmental experience immersiveness (EE)	4.90 (1.12)	3.00–6.67	4.60 (1.33)	1.50–6.17	4.80 (1.27)	2.50–6.30
Environment involvement immersiveness (EI)	4.90 (1.53)	2.50–6.50	4.80 (1.02)	4.00–7.00	5.10 (1.61)	2.00–7.00
Auditory immersiveness (AI)	5.60 (1.02)	3.67–7.00	1.50 (1.12)	0.67–5.00	5.10 (1.25)	1.67–7.00
Total immersiveness (TI)	5.06 (1.07)	2.70–6.70	3.86 (0.93)	1.60–5.00	4.79 (1.15)	2.30–6.00
Time taken to to reach goal	3.90	0.45–7.11	4.20	1.17–9.18	4.40	1.02–11.20

These results suggest that the men have higher mental rotation ability than women. We analyzed the mean value statistics for immersiveness in the three conditions, presented in table 5.

In order to understand the differences between immersiveness in the three environments an analysis of variance (ANOVA) test was conducted for the TI. The TI for the three environments was significant, $F_{2,\ 39} = 4.6618$, $p < 0.05$. Pairwise comparison using the Tukey–Kramer method showed that there is a significant difference between condition 1 (M = 5.06, SD =1.08) and condition 2 (M = 3.86, SD = 0.93).

5 Discussion

The ANOVA test showed that there is a statistically significant difference in the TI level between condition 1 and condition 2. Figure 4 indicates that whereas EE and AI are greatest in condition 1, EI is greatest in condition 3 (both visual and soundscape landmarks). TI appears to be greatest in condition 1.

Interaction with the virtual environments mainly occurs visually, and visual representations may allow more interaction than auditory representations in the virtual environment. This is why EI was greatest in condition 3. However, even though the result demonstrates that the mean score for immersiveness is greatest in environments with soundscape landmarks, a statistically significant difference was found only between conditions 1 and 2 (with the exception of the ANOVA test run for AI, which also yielded significant results showing there was a statistically significant difference between conditions 1 and 2, as well as between conditions 3 and 2. This was mainly due to the fact that condition 2 did not have any soundscape landmarks). Given that the subjects were concentrating to identify various sound cues, this could have affected their immersive state, and they would have felt more immersed in condition 1.

Further studies are needed to gather any conclusive evidence that virtual environments with only soundscape landmarks evoke a more immersive state. However, this result suggests that soundscape landmarks provide a higher level of immersiveness than visual landmarks; their effect should be considered when creating immersive environments because it has been shown in this study to be the main factor in generating the sensation of immersion in the virtual environments.

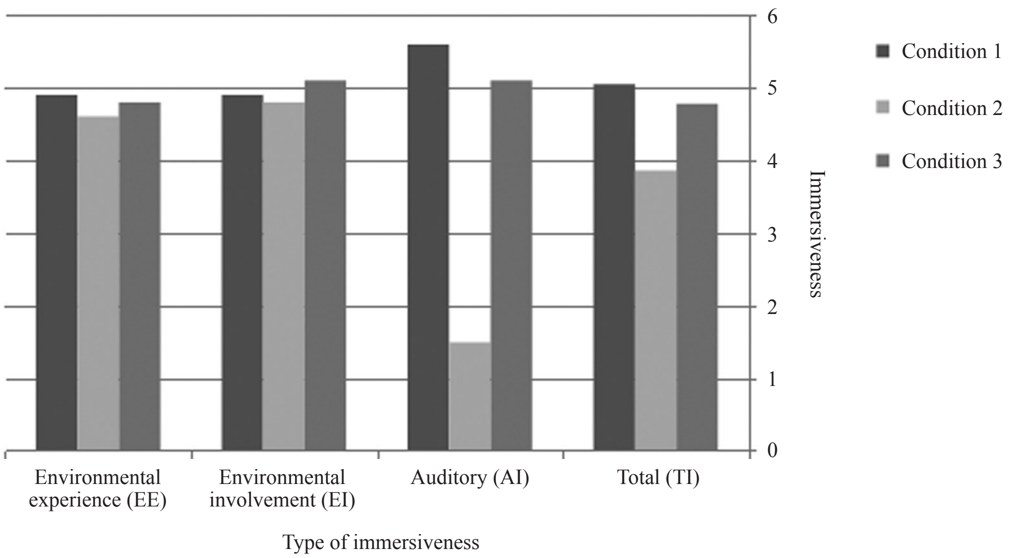

Figure 4. Graph showing the differences in immersive type between different conditions.

Even though an ANOVA test conducted among the three conditions for the mean time to reach the goal did not yield statistically significant results, the mean value for the time taken to reach the goal within the virtual environment is shortest (figure 5) condition 1 (where only soundscape landmarks were present), and data also suggest that it takes longest to reach the goal in the environment with both sound and visual landmarks (Condition 3). Hence, the data indicate that too much information (both visual and auditory) may be a hindrance to wayfinding in virtual environments. However, it is interesting that in condition 1, where only soundscape landmarks were present, subjects reached the goal in the shortest period of time. These results suggest that soundscapes provide efficient auditory landmarks, increasing the ease of navigation in virtual environments.

In our study we analyzed the effect of different spatiocognitive abilities, such as mental rotation ability, 2D object construction ability, and 3D object deconstruction ability of subjects on their immersiveness in different virtual environments. The analysis showed that mental rotation ability predicted immersiveness especially in auditory immersive environments. This is in accord with the results from our previous study (Chandrasekera et al, 2010) where we observed that an increase in subjects' spatial ability increases immersiveness in auditory immersive environments. Our present study shows that individuals with higher mental rotation abilities (a subdomain of spatial visualization ability) tend to be more immersed in auditory immersive environments. The study did not provide significant findings in terms of mental rotation ability and immersiveness in the other two environments (environment with only visual landmarks or environment with both visual and soundscape landmarks).

It has been found that complex music activates regions of the right cerebral hemisphere involved in spatial cognition (Rauscher et al, 1993). This is known as the "Mozart effect" [Even though this phenomenon has gained much attention and has been challenged, metaanalytic studies conducted by Chabris (1999) and Hetland (2000) suggest that music affects spatiotemporal tasks.] The Mozart effect has been studied extensively; some studies suggest that it is an artifact of arousal and mood (Thompson et al, 2001), although there is no clear support for this hypothesis (Hetland, 2000). Furthermore, some studies suggest that there is a direct correlation between high scores in mental rotation tests and listening to music (Aheadi et al, 2010). Hetland (2000), in his metaanalysis states, that the Mozart effect is seen for a specific type of spatial task that requires mental rotation in the absence of a physical model. Similarly, it could be argued that when the right cerebral hemisphere is activated through mental rotation tasks, the ability to identify soundscape landmarks in

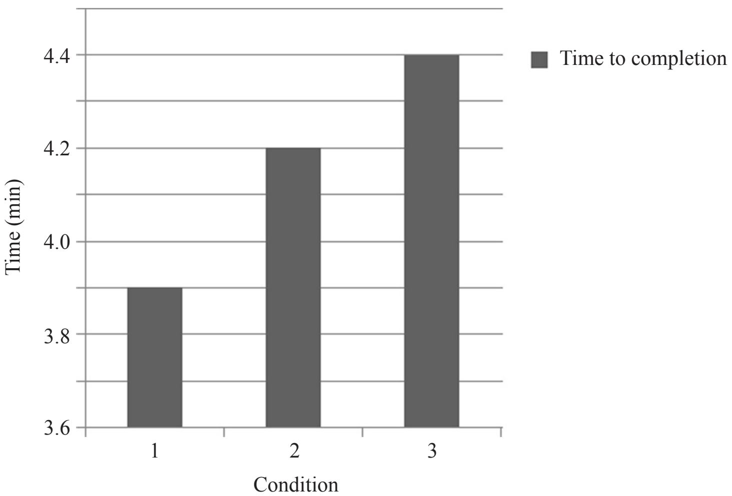

Figure 5. Graph showing the time taken to complete the task in the three condition types.

environments might increase. Thus, there is the possibility that because the mental rotation test was conducted before the virtual environment experiment, the test might have stimulated the ability of navigating in the auditory immersive environment. But this hypothesis itself has to be studied further on a different scale.

6 Conclusion

We sought to justify the main hypothesis: soundscapes can be used as auditory landmarks in increasing the ease of navigation and immersiveness in virtual environments. The main objectives of the study were to identify the role of soundscapes when individuals navigate through different spaces within a virtual environment and to identify cognitive parameters of individuals that may affect their immersiveness in virtual environments where soundscapes are used as navigational aids.

Empirical research on specific attributes of virtual environments enriches and advances the collective knowledge of contemporary spatial design and provides further understanding for its functional improvement. The present study indicates that soundscapes offered navigational aids and heightened immersiveness in virtual environments, and suggests that auditory immersion may be more important than visual immersion. The findings illustrate the significance of spatial abilities as the antecedent of immersiveness. By strategically applying the information gathered in this study, auditory elements can be used effectively alongside an individual's own spatial abilities in order to fortify the magnitude of that individual's immersiveness.

There is significant evidence to propose that even without visual landmarks, the soundscape landmarks compensate and provide a better immersive experience, which is consistent with previous studies (Lombard and Ditton, 1997). We consider this study to be a stepping stone towards understanding the effect of soundscape landmarks in providing navigational aid. Our study also suggests that there is a strong correlation between immersion in virtual environments and mental rotation abilities, especially where soundscapes are used as wayfinding landmarks. The findings of this study provide better understanding and evidence of soundscapes contributing to enhanced immersive and navigational experience within virtual environments.

There are several possible limitations to the study. The fact that the male-to-female ratio was 1:2 may affect the study, because spatial abilities are gender biased (Geary, 1996). Another limitation is that our convenient sample of architecture students might have biased the independent variable. A control of nonarchitecture students is suggested for future studies. We did not measure the base hearing ability of the subjects before the study. The hearing ability of the subjects may vary between individuals, which might have affected the results.

Even though many aspects of physical navigation can be applied to virtual environments, it must be acknowledged that the analogy has limitations. The environment used in this study was made as realistic as possible, and a questionnaire on immersiveness was given to the subjects to evaluate the immersiveness they felt. However, the authors acknowledge that the sound effects could have been improved using a 3D sound engine and high-end hardware.

With advanced knowledge regarding auditory cues in virtual environments, carefully designed user experience can improve the level of gratification and the empirical evidence found in studies on immersiveness are likely to be utilized in effective design for physical environments and wayfinding.

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