The Effects of Spatial Differentiation on Wayfinding Performance in Underground Environments

Weiqi Sun

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By: Weiqi Sun

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Signed by the final examining committee:

____________ David F. Greene __________ Chair

____________ Pierre Gauthier __________ Examiner

____________ Victor Schinazi __________ Examiner

____________ John Zacharias __________ Supervisor

Approved by: ____

Chair of Department or Graduate Program Director

____________ 20_____ ____

Dean of Faculty

Abstract

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Weiqi Sun

The goals of this study were to investigate the effect of spatial differentiation on wayfinding behaviours and spatial knowledge acquisition. The spatial differentiation included landmarks (vertical differentiation), path surfacing (horizontal differentiation) and corridor width (vertical and horizontal differentiation). Personal characteristics were also analyzed in this research, which include sex, three-dimensional game-playing frequency, self-estimated wayfinding ability and time to perform the task.

This study used twelve virtual environments (4 x 3), with four kinds of spatial differentiation (no differentiation, landmarks, path width variation, and path surfacing variation) and each group sets has three models with different but equivalent plan layouts, to stimulate part of an underground shopping mall.

The total number of participants who completed the test was 60 (37 male, 23 female). They were randomly assigned to one of four environment sets – original set, width set, surface set and landmark set. Each participant performed three tests – navigation test (exploring the virtual environment from instructions), route knowledge test (reconstituting a route between designated locations) and survey knowledge test (relocating each store at its predetermined location).

The results showed that physical differentiation yielded better wayfinding performance than no vertical or horizontal differentiation. Vertical differentiation (landmarks) is more effective than horizontal differentiation (road surfacing and width) for real navigating performance and route knowledge acquisition, but horizontal differentiation (road surfacing) is more effective than vertical differentiation (landmarks) in survey knowledge acquisition.

For individual characteristics, males performed better than females except for the route knowledge test, also showing a trend that performance improved with game playing frequency, wayfinding ability and tested times.

Furthermore, all results from the three tests are strongly correlated. Participants who performed better on the navigation test (less time spent) also performed well on spatial knowledge tests; and those who were better able to reconstitute the itinerary, were also better able to place store names in the correct location.

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1. Introduction and Objective

Wayfinding, as part of spatial orientation, is a process that we go through in our daily life. This process may be as easy as moving from one room to another or as difficult as trying to escape an interior on fire. In recent years, the term ‘wayfinding’ has to some extent replaced the notion of spatial orientation to focus, not on the person's static relation to space, but on the dynamics involved in purposeful mobility (Downs and Stea, 1973; Passini, 1980, 1984a). Wayfinding difficulties may cause problems such as loss of time, decreased safety, stress, or discomfort.

This research is motivated by the wayfinding problems in Montreal’s Underground City. The Underground City in Montreal is famous as a complex indoor setting where first-time visitors and even returning visitors are often unsure just where they are. People who are not quite familiar with the Underground City easily express a negative reaction about feeling lost or disoriented. This problem occurs frequently in many other complex indoor constructions, such as shopping malls, museums, hospitals, office building, places that are closely related to our daily life. Wayfinding difficulties may lead people to avoid these confusing places (Carpman and Grant, 2002).

Wayfinding is not only a daily activity and a complex process, but a critical issue involving several disciplines, such as urban design and planning, architecture, environmental psychology and so on (Stokols and Altman, 1987). Designers and planners have an obligation to create environments in which people not only feel comfortable, but that can also be understood easily. People prefer environments where they feel comfortable and in which they can find their way easily. Since the legibility of large-scale indoor space is usually not easy to recognize and understand, I intend to create a link between wayfinding behaviour research and practical planning and design, to develop a kind of design pattern with high legibility for complex indoor space.

Although wayfinding and orientation in complex buildings is an important criterion for environmental behaviour, research on the subject remains limited and the issue is not considered sufficiently during the design process. Based on this, I intend to investigate which spatial factors influence indoor wayfinding behaviour most, how wayfinding behaviour is influenced by these factors, and what corresponding design can be applied to improve wayfinding efficiency.

Chapter 2 reviews the literature on wayfinding and the use of virtual environments as research tools in this field, explains the concepts and terms related to wayfinding, and discusses the existing problems of indoor wayfinding activity. It reviews the physical environmental characteristics which influence wayfinding behaviour, as well as methodological issues, the feasibility of simulating a virtual environment as a tool to study wayfinding behaviour and the measures to evaluate wayfinding performance.

Chapter 3 discusses the research design and procedure applied in my research, using virtual environments to simulate underground environments. To analyze wayfinding behaviour, it used multiple analytical tools and measures including finding the specified locations in the environment, sketching the route they traveled between designed locations, and putting the name of each place they traveled into correct location on the floor plan.

Chapter 4 presents the results and statistic analysis. Chapter 5 demonstrates the conclusion and Chapter 6 discusses the limitations of the present study and outlines areas for further research and for design and planning application.

2. Literature Review

2.1 Wayfinding

Wayfinding is an interdisciplinary term, which applies to a variety of fields such as cognitive psychology, architecture, interior design, behaviour study, urban design and planning, and facilities management (Stokols and Altman, 1987).

Wayfinding and the relevant theory have been extensively studied in environmental psychology, but in other fields, the study and exploration of wayfinding is not systematic enough and the research approaches are varied and imperfect. To clarify the relevant theory and research approaches, this chapter first describes the concepts related to wayfinding, such as spatial knowledge and cognitive map. Then it discusses the problems of indoor wayfinding behaviour. Next, it explores the physical environmental characteristics that influence wayfinding behaviour. Then, it reviews the virtual environment as a tool to study wayfinding. Finally, it discusses different ways to measure wayfinding performance.

2.1.1 The Concepts Related to Wayfinding

Although the word 'wayfinding' cannot be found in the dictionary, it appears in the literature on psychology, geography or architecture quite often. Wayfinding is derived from the word 'wayfarer' and 'wayfaring' which both mean move and travel, especially on foot, in Old English. Other words with similar meanings as wayfinding include “pathfinder” (Conroy, 2001). According to Arthur and Passini (1992), the concept on wayfinding was initially proposed by Lynch (1960), who explained it in his book - The Image of The City. Since the 1970s, the word wayfinding has been widely quoted by researchers and has become an accepted academic term.

A plain and simple definition of wayfinding is “Wayfinding means knowing where you are, knowing your destination, following the best route to your destination, recognizing your destination when you arrive, and being able to reverse the whole process and finding your way back out.” (Carpman, 2000) In general, wayfinding is the process of determining and following a route between an origin and destination (Golledge, 1999). In typical wayfinding scenarios, the origin and the destination cannot be directly perceived by the traveler (Allen, 1999). Wayfinding is purposeful and goal driven. It is a problem-solving process that includes a series of phases such as decision making and decision execution (Arthur and Passini, 1992; Passini, 1984a).

2.1.1.1 The Process of Wayfinding

Wayfinding begins with a decision “to go somewhere” or “to reach some destination”. This decision creates a problem for wayfinders. They must make plans to solve it in order to reach their desired destination (Arthur and Passini, 1992). These plans represent the decisions people make in order to complete a wayfinding task.

It is important to note that the wayfinding decisions that people make always depend in part on environmental information they acquire during navigation (Chen and Stanney, 1999). People acquire information from the environment by different means: by directly perceiving it, by recalling it from previous travelling experience, or by inferring it from a combination of available information (such as from other people's descriptions or navigational instruments like the maps, compass and, in recent years, GPS- Global Position System, a navigational system involving satellites and computers that can determine the latitude and longitude of a receiver on Earth by computing the time difference for signals from different satellites to reach the receiver) (Chen and Stanney, 1999). Before that, aboriginal peoples relied on their knowledge and observation of the natural landscape, the sun, the stars, vegetation, animals, and tidal changes to guide and orientate themselves (Aporta & Higgs, 2005).

Another critical point about the wayfinding process is that it involves continuous problem-solving. Even though people may have a goal when navigating through an environment, they usually do not have a detailed plan in mind when conducting the wayfinding task. Most of the details of the decision plan are formulated during the course of actual journey (Chen and Stanney, 1999).

Each wayfinding decision implies two aspects: behaviour (e.g., turning left or going straight) and an environmental entity (e.g., intersection) (Arthur and Passini, 1992).

Executing a wayfinding decision means transforming the decision plan from an idea to an action (Elvins, 1997). Specifically, the execution of a wayfinding decision is a matching process between what is expected in the environment and what is actually perceived. A match between the perception and the expected entity results in the behavioural action part of the decision plan to be executed. However, if what is perceived differs from what is expected then the action plan must be modified to accommodate this non-conformity. In addition, wayfinding decisions are normally executed at what are called “choice points”. Choice points are locations where a wayfinder must choose between two or more directions of travel (O’Neill, 1991b).

Based on the literature, human wayfinding and orientation behaviour are influenced by the following factors: visual access, the degree of architectural differentiation, the use of signs and room numbers, floorplan configuration, and the familiarity with the environment (Gärling, Böök, and Lindberg, 1986; Weisman, 1981). People orient themselves to determine their facing direction and location, or to find the distance and the route to their destination. Human wayfinding tasks can be categorized into three general types based on their purpose. The most common type involves travelling between two places known to the traveler along a route that is familiar, an activity which could be labeled the *commute*. A second wayfinding task involves travelling into unfamiliar territory for the purpose of learning about the surrounding environment, a type of travel that could be labeled the *explore* .The third type of wayfinding task, which can be called *quest*, involves travel from a familiar place of origin to an unfamiliar destination, a place which is known to exist but which the traveler never visited before (Allen, 1999).

2.1.1.2 Spatial Knowledge

A traveler is efficient at wayfinding, when he/she is knowledgeable about the environment. One approach is structuring spatial knowledge about the physical environment to maintain orientation and find their way from one location to another. Researchers classify the spatial knowledge into three types: (1) landmark knowledge (2) route or procedure knowledge (3) survey or configuration knowledge (Allen, Siegel and Rosinski, 1978; Chen and Stanney, 1999; Goldin and Thorndyke, 1982; Kuipers, 1978).

Landmark knowledge refers to the information about the visual details of specific features or locations in the environment (Darken and Sibert, 1996). For an object to be recognized as landmark, it must be prominent, unique, and salient in appearance (size, shape, or color) or location within an environment. In many cases objects recognized as landmarks are located at significant intersections, or at places where a change in moving direction occurs (Allen, 1982).

Route knowledge (or *procedural knowledge*) refers to the information about the spatial sequence following a particular route connecting environment objects (Allen, 1999; Chen and Stanney, 1999). With experience, route knowledge can be expanded to include more specific information such as specific distances along a route, overall route length, the number of changes in direction, the number of available direction changes at choice points, and spatial relationship between routes.

Survey knowledge (or *configuration knowledge*) is “multidimensional information about the spatial relationships among environmental features” (Allen, 1999). It refers to the knowledge of understanding the layout of the space with the interrelationships of the elements obtained from the environment.

The sequence of the development of spatial knowledge differs in different researches. Traditional spatial knowledge acquisition theories states that spatial knowledge is acquired by first gaining landmark knowledge which leads to the development of route knowledge, which in turn leads to the development of survey knowledge (Siegel and White, 1975). However, subsequent theories challenged the serial nature of the development of spatial knowledge. For example, some researchers found that survey knowledge developed first (Hirtle and Hudson, 1991), and still others found that people developed and accessed route knowledge and survey knowledge simultaneously (Taylor and Tversky, 1996). The conflicting results may be an artifact of the test situation. For example, people may learn an environment, from a map or navigation. When learning it from a map, people tend to develop survey knowledge. However, when learning it from navigation, people tend to develop route knowledge (Rossano et al., 1999; Taylor and Tversky, 1996).

Regardless of which one of the theories about spatial knowledge acquisition is more accurate, landmarks and routes have occupied a prominent place in spatial knowledge, and therefore play a critical role in the wayfinding process. The degree to which the setting has distinguishable landmarks (vertical differentiation) or routes (horizontal differentiation) may also affect the type of spatial knowledge developed (Evans, 1980).

2.1.1.3 Cognitive map

Spatial knowledge helps people construct a cognitive map (Chen and Stanney, 1999). Cognitive mapping, as defined by Downs and Stea (1973), is the process of acquiring, forming, and maintaining spatial information and spatial knowledge. The sum total of environment information stored in memory, is called a cognitive map. In general, cognitive maps are mental devices and storage systems that help to simplify, code, and order the endlessly complex world of human interaction with the environment.

Cognitive maps are important aids to wayfinding because they represent how the physical environment is mentally formed in their minds (Passini, 1984a, 1984b). Once a traveler forms a comprehensive cognitive map of an environment, he/she can efficiently travel the environment with the help of this map in mind (Elvins, 1997). Information about how people perceive the physical environment can be used to design, plan and manage environments that facilitate easier use and more satisfaction during navigation. (Lynch, 1976).

Many built environments with complex configurations cannot be fully comprehended from a single vantage point (Kuipers, 1978).The development of the cognitive map depends on a continuous stream of information gathered over time as the environment is explored.

A cognitive map is a mental representation of an environment, and landmarks are a fundamental component in this representation (Darken et al., 1998; Downs and Stea, 1973). For example, a traveler can follow a sequence of landmarks to get from a starting location to a destination. The landmarks along the path not only provide verification for the traveler of being on the right path, but also provide a means by which the traveler can become correctly oriented and decide when a turn is required (e.g., "Turn right after the statue"). Landmarks also help organize large-scale spaces (Golledge, 1999). For example, a person may not know the exact location of a certain building, but would be able to narrow down the search space if the building has been mentally associated within the vicinity of a well known landmark.

Therefore, landmarks play a critical role in cognitive mapping in complex built environment, where a person's viewpoint cannot encompass the entire space. They also help people with the wayfinding process, provide memorable cues when recalling a path, and help people encode spatial relations between objects and routes (Sorrows and Hirtle, 1999).

2.1.2 Indoor Wayfinding Problems

Trying to find one's way to a certain destination is a process that takes place in every stage of our lives. The wayfinding process is important because failing to perform this task may cause frustration, irritation, anxiety, and stress (Carpman and Grant, 2002; Evans, 1980; Lawton, 1996): it can threaten our sense of well-being (Lynch, 1960), and limit personal mobility (Burns, 1998).

According to previous research, the indoor environment is more prone to be associated with wayfinding problems than the outdoor environment. Indoor wayfinding difficulties are often created by a lack of visual connection to the exterior environment (Carmody and Sterling, 1983). The exterior environment can provide useful information for wayfinding and help to maintain a point of reference. For example, judging from the look of the sky, people can speculate how long they have traveled and how far they are from their destination; the position of the sun in the sky can help people identify direction and maintain orientation (Lawton, 1996).

When distances can be calculated between landmarks and destinations, directions to destinations can be accurately indicated, shortcuts may be taken and cognitive maps can be formed in mind (Witmer et al., 2002). With lack of exterior reference and visual stimuli, it is hard to judge the direction and distance during indoor travel, so cognitive maps are hard to form in indoor spaces, which may result in a feeling of confinement, and produce a boring, monotonous environment with wayfinding difficulties (Carmody and Sterling, 1983).

Designers and planners can improve wayfinding when they understand how the physical environment affects wayfinding performance. Therefore, the next phase discusses the physical environmental factors that may affect wayfinding behaviour.

2.1.3 Environmental Factors Influence Indoor Wayfinding

The architect Kevin Lynch first used the term "wayfinding" in 1960 in *The Image of the City*. In it, he referred to maps, street numbers, directional signs, and other elements as "wayfinding devices." Wayfinding devices fall broadly into two general categories: 1) traditional devices which rely almost entirely on graphics or signage and 2) devices which are not dependent on graphics. Although most people have been habituated to consider wayfinding elements to be purely signage, it is believed that wayfinding has the potential to transcend the medium of graphics.

Traditional elements of wayfinding include signs, maps, street signs, street names, and street numbers, which are usually graphic-dependent. Most people and institutions pay more attention to such graphic-dependent elements as the only means of wayfinding, and consequently, other potential elements are being overlooked. Although not intentionally designed to be wayfinding elements, non-graphic dependent wayfinding elements exist to help people consciously or unconsciously find their way (Bozatli et al., 2004).

"Even though signage plays an important role in wayfinding, the process does not rely exclusively on signs (Muhlhausen, 2006)." Weisman (1981) identifies four general classes of environmental variables that influence wayfinding performance meant for buildings: (1) the use of signs and room numbers, (2) the complexity of spatial layout / configuration, (3) the degree of visual access, and (4) the level of architectural differentiation.

2.1.3.1 Signage

As mentioned earlier, signs and room / street numbers are traditional graphic-dependent elements for wayfinding. Architects seem to get a conclusion that facilitating people's wayfinding needs more than putting up signs, because signage cannot overcome architectural failures most of the time (Arthur and Passini 1992). The existence of an interaction between floor plan complexity and the quality of signage was demonstrated in two studies by O'Neill (1991a, 1991b). His results showed that an increase in floor plan complexity leads to a decrease in wayfinding performance. The presence of signage was an important factor but could not compensate for floor plan complexity. Therefore, wayfinding principles have to be considered during the design process—both for the overall spatial structure and for the graphic-dependent features. Some guidelines (Arthur and Passini 1992, 1990)—despite focusing on the design and placement of signage—highly stress the importance of environmental features.

2.1.3.2 Spatial Configuration

Researchers have suggested that the legibility or complexity of plan layout may affect wayfinding performance and cognitive mapping (Lynch, 1960; O'Neill, 1991a, 1991b; Passini, 1980; Weisman, 1981). Passini (1980) found that some people navigating in a large underground shopping mall relied heavily on the clarity of the spatial configuration.

Lynch suggested that a legible building telling everything about its internal organization would help travelers construct schema-like knowledge, which has had a profound influence on the fields of planning and architecture. A place that facilitates obtaining and understanding of environmental information has a high legibility factor. If the space does not have a clear spatial organization, it is not understood hence it has a low legibility factor and does not help with wayfinding. The principle of its spatial organization has to be communicated to the wayfinding travelers (Arthur and Passini, 1992). The legibility of an architectural environment has been found to affect the usefulness of a wide range of building types.

Findings suggest that people easily comprehend the physical environments if the plan layout is legible and simple. Weisman (1981) compared people's self reports of wayfinding performance in a number of settings that vary in plan layout: people tended to perceive wayfinding as more difficult in settings that were more complex and less legible. O'Neill (1991a) found that people drew more accurate sketches and found their way to a specific destination more accurately in simple layouts.

2.1.3.3 Visual Access

Not only might the overall plan of a building and its signage have a considerable impact upon wayfinding behaviour, as Gärling, Böök, and Lindberg (1986) have explained: visual access, which is difficult to achieve in a complex layout, is an important factor in facilitating one's spatial orientation and wayfinding. Legibility, which is synonymous with clarity, is also associated with the visual quality of a scene. If large parts of the building are immediately visible, and mutual intervisibility (vistas) connects the parts of the building, people have to rely less on stored spatial knowledge and can rely on information directly available in their field of vision, a notion inspired by Gibson (1983).

2.1.3.4 Physical Differentiation

As mentioned in Abu-Obeid's work (1998), having an uncomplicated floor plan is not enough to help people form clear environmental images unless it is accompanied by pictorial differentiation. According to Appleyard (1969), when buildings have clear contours and distinctive surfaces that differentiate them from their surroundings, they are usually more distinct.

Greater physical differentiation may affect wayfinding behaviour because it facilitates extracting and understanding of physical information (Abu-Obeid, 1998; Appleyard, 1969; Evans et al., 1982; Passini et al., 2000). Passini et al. (2000) found that monotony of architectural composition increased wayfinding difficulties. Abu- Ghazzeh (1996) interviewed students to rank the physical setting variables that caused spatial orientation and wayfinding problems at campus. The results showed that high degree of uniformity (lack of differentiation) was the major factor in feeling lost or disoriented.

Weisman (1981) suggested that physical differentiation refers to the extent to which one location looks different from others. Evans et al. (1982) suggested that physical differentiation can be identified with both vertical and horizontal differentiation. Now vertical and horizontal differentiation is considered separately.

2.1.3.4.1 The Vertical Differentiation

Lynch and Rivkin (1976) and Wagner et al. (1981) demonstrated that pedestrians watch vertical elements such as building facades and window displays when walking around. The permanent and distinctive vertical elements are remembered more (Appleyard, 1969; Evans et al., 1982; Lynch, 1960) and are important in navigation and orientation (Evans, 1980; Passini, 1980; Ruddle et al., 1997; Tlauka and Wilson, 1994). Lynch (1960) referred to such distinctive vertical elements as landmarks. Studies agree on the positive effects of landmarks on wayfinding. Ruddle et al. (1997) found that people navigate more accurately in simulated environments which had landmarks than those without landmarks. Tlauka and Wilson (1994) argued that landmarks are helpful but not sufficient to successfully navigate from one location to another.

This study's review of literature emphasized three important issues to consider in relation to landmarks: the type, the attributes and the location of landmarks. For the type, researchers refer to two types of landmarks, global and local (Darken and Sibert, 1993). Local landmarks, such as a flower pot or a lamp, are visible within a restricted area (Ruddle et al., 1997). Global landmarks, such as a mountain, are visible from far away and from many places (Ruddle et al., 1997). For the attributes, the most important attributes of buildings for landmark qualities include form, visibility (Appleyard, 1969) and uniqueness (Evans et al., 1982). For the location, researchers argued that landmarks are learned faster and remembered better, so are more effective when placed at locations of possible direction changes (transition points) (Allen, 1982). This research uses local landmarks, because global landmarks are rarely available in indoor environment and planners and designers can hardly manipulate global landmarks.

Landmarks within this study are given unique forms and located at intersections, and corridor width variation is also tested in another experimental group, in the expectation that wayfinding performance would be improved with the presence of this vertical differentiation.

2.1.3.4.2 The Horizontal Differentiation

Lynch and Rivkin (1976) and Wagner et al. (1981) demonstrated that when walking, people note the ground as well, for the differentiation of the road surface. Paths and their physical characters are fundamental aspects of wayfinding. It tells people where the route is, whether it leads to somewhere worthwhile, and whether or not they are allowed to take it. A path is perceived by markings on the ground with different hierarchy (Arthur and Passini, 1992).

Path hierarchy is an important factor in determining the legibility of a physical environment (Lynch, 1960). It also produces horizontal differentiation and may enhance wayfinding performance. Proper articulation of roads not only indicates the direction of movement and facilitates an understanding of the circulation system; it also gives travelers an indication of the importance of the destination and whether or not they have access to it (Arthur and Passini, 1992).

However, little research has empirically tested if this horizontal differentiation enhances people's wayfinding performance, as does the vertical differentiation. This dissertation will use variation of path surface and path width to produce path hierarchy and horizontal differentiation, which is expected to improve wayfinding performance.

2.1.3.5 Summary of Factors Influence Wayfinding Performance

Wayfinding is influenced by the physical characteristics of the environment, which has been discussed in the above review, but it is also related to personal characteristics of the wayfinder. Physical characteristics include signage, plan layout, visual access, physical differentiation and its components of vertical and horizontal differentiation. Personal characteristics include age, sex, familiarity (experience). Most studies looked at the effect of each factor alone. To better understand wayfinding, we need to consider personal and environmental factors simultaneously. In two early review papers, Moore (1979) and Evans (1980) concluded that although personal factors were widely explored, physical environmental factors were understudied.

This review of the literature showed that few studies tested the effect of the different physical differentiations (vertical/ horizontal differentiation) on wayfinding behaviour separately in a controlled environment. Hence, this study focuses on the effect of different physical differentiations on wayfinding performance, but considers them and personal characteristics simultaneously. The tests were carried out in controlled conditions. To study wayfinding in a controlled physical setting, researchers must decide on at least two kinds of factors, 1) the ways to simulate the environment, 2) the ways to measure wayfinding responses. In this study Virtual Environments (V.E.) were used to simulate the environment and multiple measures were used to test wayfinding performance. The following sections discuss the V.E. as a tool to study wayfinding and review the measures of wayfinding performance.

2.2 Virtual Environments

Wayfinding behaviour has been extensively studied in both real environments as well as in virtual environments. Because of their flexibility and relative ease of construction, wayfinding experience in virtual environments is often employed as a surrogate to predict the experience and behaviour in the real environments. This chapter provides an overview of the literature on virtual environments as a tool to study wayfinding.

2.2.1 Concept of Virtual Environment

V.E. can be defined as the presence of environments simulated by a computer that can be experienced (Sherman and Craig, 2003). In these simulations, the traveler can visualize and interact with the virtual three-dimensional spatial environment in real time. V.E.s are used in research related to physical environment to control the physical characteristics (Arthur et al., 1997; Rossano et al., 1999) or when it is hard to gather subjects in the real one (Ishikawa et al., 1998).

2.2.2 The Application and Benefit of Virtual Environment in Wayfinding Research

Researchers have observed and tested people's wayfinding behaviour in both real and virtual environments. However, with wayfinding studies conducted in the real environment, extraneous variables such as noises, people, and scents are hard to control (Satalich, G.A., 1995). Peponis et al. (1990) acknowledged that a populated space appears more attractive to individuals who are performing wayfinding activities. Haq (2001) noted the results of his study might also be influenced by light and color variations.

Haq (2001) stated that one way to investigate the role of a particular environmental variable in the wayfinding process is to control other environmental variables in a wayfinding study. One way to perform a controlled environment is to apply a simulation technique to a wayfinding study. V.E. allows the sample population to move freely to gather appropriate information and also allow the researcher to limit the extraneous variables.

2.2.3 The Limitation and Feasibility of Virtual Environment in Wayfinding Research

V.E.s may be created with sufficient detail to bring their visual fidelity close to that of the real world. Unfortunately, this requires considerable time and cost, so more often than not, fidelity is compromised and the V.E. contains less detail and, potentially, fewer landmark-type cues than the real world. Senses other than vision are usually excluded from V.E.s, although there are few technical barriers to the inclusion of sound. In the real environment, numerous environmental variables were present throughout and caused the participants to give their attention to those variables during the exploration task. However, because the extraneous environment variables in the V.E. were limited, the entire environment appeared homogeneous, thus a number of participants in the pilot study expressed a degree of boredom and demonstrated a desire to complete the task earlier.

A well-structured measurement, such as a formal observation, an interview, and/or a questionnaire, are needed to investigate which elements of the technology might affect participants' performance and cause the dissimilarities with the experiment in the real environment.

The similarity between real world behaviour and V.E. behaviours may be questioned by some people. However, some researchers have come to two promising findings: a real environment could be replicated within a V.E. for wayfinding study and most of the data collected in a V.E. demonstrated similar results with the ones in a real environment (Goldin and Thorndyke, 1982; Zacharias, 2006). The similarities of these measurements demonstrated that the participants' behaviours and performance in the V.E. were comparable with the behaviours in the real environment. When individuals' behaviour in a V.E. is comparable with the one in the real environment, then V.E. can be seen as a useful tool for architectural wayfinding research (deKort et al., 2003). These findings indicated the relevance of a V.E. application as a technique to provide a controlled environment in wayfinding research.

2.2.4 Summary of Virtual Environment as a Tool for Wayfinding Research

This study uses computer-simulated environments rather than real environments for three reasons: (1) they are dynamic and active, providing similar movement experience as the experiments in the real environment; (2) they are flexible and easy to manipulate or control the different variables of the environment; and (3) they are affordable.

2.3 Measures of Wayfinding Performance

Since Lynch's *The image of the City* (1960) described the importance of studying wayfinding tasks, a number of studies have been conducted to evaluate people's wayfinding performance. Basically, these performance measures can be categorized into two types, based on when the measures are performed and what data are collected by the measures. The first type is practical performance measures (navigation test) and the other is spatial knowledge measures after the navigation (Goldin and Thorndyke, 1982; Satalich, G.A., 1995).

2.3.1 Navigation Test

The navigation test include tasks such as finding a certain location (Rossano et al., 1999), replicating a route (O'Neill, 1991a), reversing a route (Passini et al., 1990), and finding the shortest path between two places (Passini et al., 1990).

These tasks have been measured in many ways. The most popular measures can be categorized into two types: measures of error and speed (or time). Error measures usually include accounts of wrong turns made at choice points (O'Neill, 1991a; Rossano et al., 1999), and incorrect or backtracing routes taken (O'Neill, 1991a). Time measures contain time spent in performing and planning wayfinding tasks (O'Neill, 1991a).

2.3.2 Memory Test

Memory tests have been used in assessing the short-term or long-term memory retention of many forms of information, such as describing places or routes after a trip, and identify the number or sequence of objects (e.g., landmarks) observed and encoded in memory (Appleyard, 1969; Lynch and Rivkin, 1976).

The most important feature of the memory measure is that individuals are not given any cues during the recall of information. Thus, the approach measures the way in which information is naturally encoded and normally retrieved without any bias. This approach is useful for evaluating the quantity and quality of spatial information stored. However, this measurement may reflect the individual's language or sketching ability rather than spatial knowledge. An individual may only report recalling places that are easy to describe in words or sketching.

2.3.3 Recognition Test

Recognition tests have been used to test people's landmark knowledge (Goldin and Thorndyke, 1982). Sometimes recognition tests require identification of whether an object has been seen in a particular environment; location recognition. In other cases, the object is unique and distinct from others and the task is only based on the form the object presents; landmark recognition (Goldin and Thorndyke, 1982). The recognition tests include tasks such as recognizing a scene with pictures after the trip (Dogu and Erkip, 2000) or sorting the pictures to show the route (Goldin and Thorndyke, 1982).

As Allen, Siegel and Rosinski (1978) pointed out, place recognition, including both landmark recognition and location recognition, is an essential component of successful wayfinding in large-scale environments. Both recognition tasks are effective measures to evaluate the quality and quantity of participants' landmark knowledge as reference in analyzing participants' wayfinding performance.

2.3.4 Map Sketching Test

Map sketching involves participants retrieving spatial knowledge stored in memory and presenting it in drawings. Participants are able to draw a map in this manner because it is assumed that these representations are what participants have stored in memory.

Kitchin (1997) discussed five variations of sketching: (1) the basic sketch map technique, where the researcher gives the respondent a blank sheet of paper to sketch a map. (2) the normal sketch mapping technique, where the researcher imposes constraints to obtain required data (3) the cued sketch mapping technique, where the researcher gives a portion of the map and asks the respondent to complete the specific features, (4) the longitudinal sketch mapping technique, where the researcher asks respondents to draw the map on layers of carbon tracing paper and turn the sheets over at some time intervals to study how sketch map evolves, and (5) the cloze sketch mapping technique, where the researcher covers a base map in a grid with some square deleted and has respondents fill the information in the blank squares.

Lynch (1960) believed that sketch maps were a useful tool to reveal which elements are perceived as important in the environment. It's a useful tool to study spatial knowledge and is popular in wayfinding performance measures.

2.3.5 Spatial Judgment Test

Spatial judgments are a common way to estimate stored landmark knowledge and route knowledge (Goldin and Thorndyke, 1982). These judgments include estimation of route distance between two locations and pointing out the relative direction of destinations or landmarks. The performance in distance estimates are usually calculated as the difference between the true distance and the estimated distance. For pointing task, the performance was measured as time spent to respond and the difference between the true direction and the estimated direction.

The analysis of these spatial estimations is useful in determining the type of spatial knowledge acquired from a certain environment.

2.3.6 Summary of Wayfinding Measures

There is a variety of tests to measure wayfinding performance. No one measure is better than others. Any single measures may have a bias. Thus a combination of such measures would get better result (Kitchin, 1997). This study uses multiple measures to estimate wayfinding performance comprehensively. Participants were asked to explore the environment and find some specific locations (navigation test), reconstitute the route between two specified locations (memory and map sketching test), and match the name of the place with the correct location on the map (map sketching and spatial judgment test).

3. Methodology

As the perception of environment is not established immediately but accumulated by multiple wayfinding experience, repeated exploration will gather a continuous stream of information over time, develop the cognitive map more clear and complete. According to previous studies, exploring in person facilitates the best spatial knowledge. Turning the wrong way, feeling frustration and then modifying the decision plan will manifest itself as a rich cognitive map (Elvins, 1997, Golledge, 1999); therefore the experiment in this research took a form of "task execution" to make the participants explore the environment actively and repeatedly. It gave them an opportunity to obtain the spatial knowledge required for the forming of the cognitive maps. We can investigate whether the acquisition of spatial knowledge and the performance of wayfinding tasks will be influenced by different spatial differentiations.

3.1 Experiment Equipment and Setting

3.1.1 Software

The virtual environments used in this experiment were created by Google SketchUp 7. Walkabout 3d software, a tool which allows SketchUp users to explore their designs as a full screen real-time walkthrough, produced perspective views to simulate ground-level walk-paced movement through the simulated environment. The viewpoint was set at a height of 1.70 meters, average eye level. Participants controlled their movement in the simulated environment via the arrows on the keyboard. It provided left right rotations (left / right arrows) and forward backward translations (up / down arrows), with movement restricted to the horizontal plane. Research showed that users quickly learn this form of interaction to control motion in V.E.s (Tlauka and Wilson, 1994).

3.1.2 Virtual Environmental Characteristics

Three equivalent three-dimensional virtual environments were created to simulate part of an underground shopping mall. As the capacity of working memory is usually restricted to 5-9 items (Klippel, 2003), these environments contained 7 different stores – a supermarket, an ice cream bar, a hotdog stand, a bank, a bookstore, a computer store, and a restaurant. This study attempted to simulate such environments because visitors in indoor shopping mall environments often have difficulties to find their way (Dogu and Erkip, 2000).

These three environments were constructed as an original group, from which three environments with physical differentiation were derived. Therefore, there were twelve models totally used in this experiment. The derived environments had the same dimensions, layout and stores as their original environment. The only differences were the vertical or horizontal differentiation (absence or presence of landmarks or path and corridor variation).

3.1.2.1 Original Environment

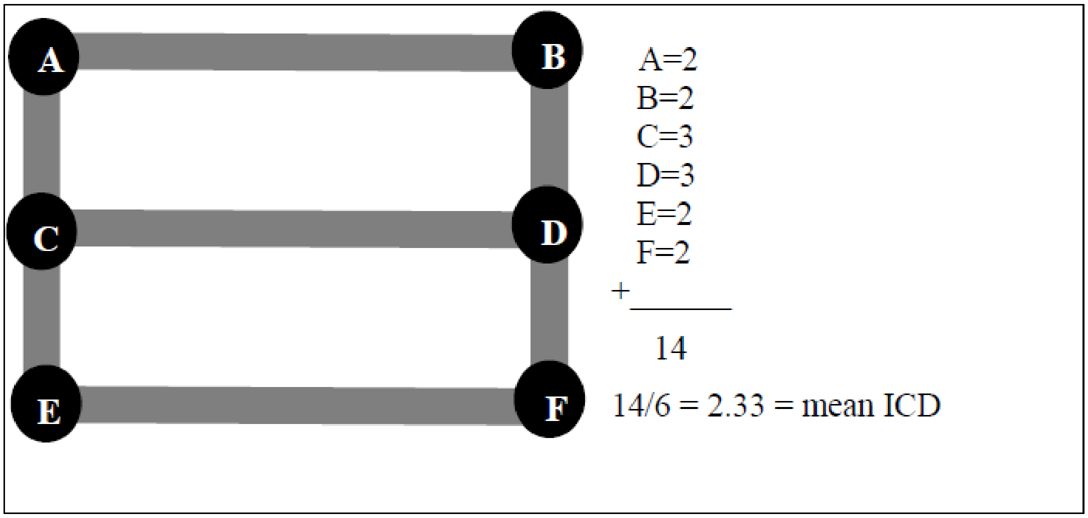
A set of three original models were constructed in such a way as to be as equivalent to one another as possible. They had the following properties in common:

(1) Complexity:

All models involved a series of 6 decision points. A decision point was a choice the participant had to take at a T-junction between right and wrong. An incorrect decision led directly to a wrong store; there were no further turns possible down from an incorrect pathway. That is to say, if the participant took a wrong turn, he had to backtrack to the previous T-junction and chose the other path.

I also used O'Neill's (1991) "Inter Connection Density" (ICD) measure to check the equivalence of the layout complexity across the three models. The measure was based on the density of interconnections at choice points. Figure 3.1 shows an example of the calculation of ICD from a plan. The number of connections at each intersection, or choice point, was listed to the right of the plan (i.e. at intersection A, one had two choices). ICD was calculated as the mean number of connections. Hence the plan had an ICD of 2.33.

Figure 3.1 An example for calculating Interconnection Density (ICD) Value



As the ICD of all the models was 3, we can consider them with the same complexity.

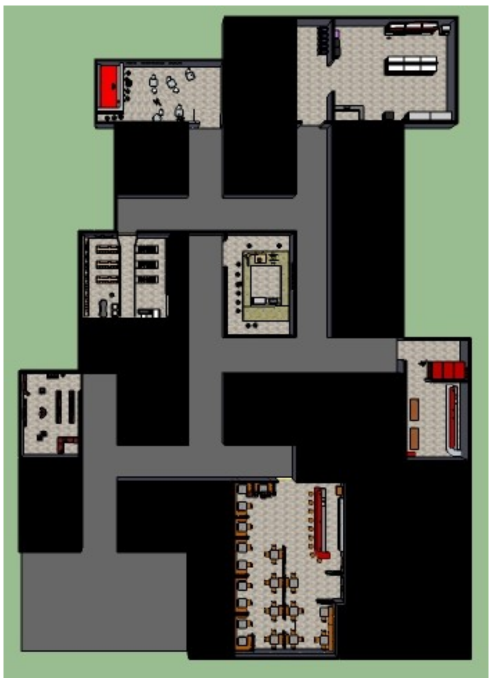
(2) Scale:

Real-world geometry was used when constructing and rendering the scene. The environments consisted of corridors, walls and rooms (stores) without windows. The height of the walls and the width of the corridors travelled were 4.0 meters throughout, the total length of the corridor (160 meters) and the length of each corridor segments were also the same size across the three environments.

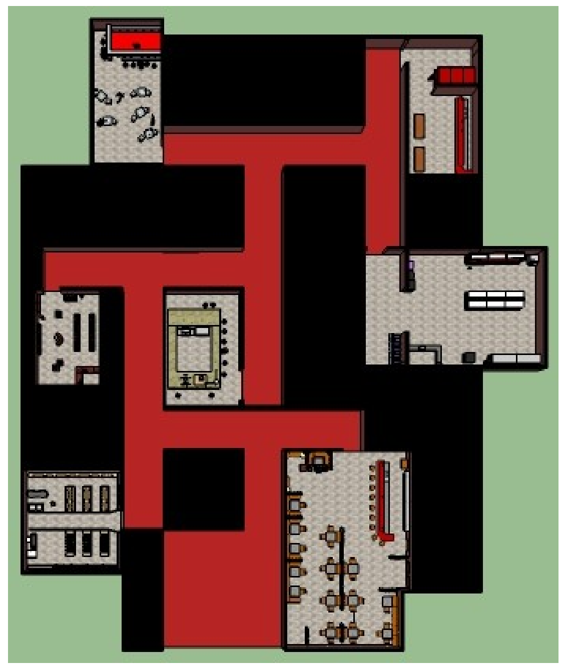
(3) Absence of Landmarks:

The original model was constructed to contain no physical landmarks, including those involving models structures. All the walls and path surface were of identical textured color to exclude the possibility that they can be considered as visual cues. At each choice point, the length and width of the hallway leading to either the correct or incorrect path was always the same, and the view towards a dead-end was indistinguishable from a view towards the correct path. This means that no physical information about this environment could be gained by static views, so the participants had to explore it in person to learn.

Figure 3.2 Three original V.E. viewed from above



Model 1



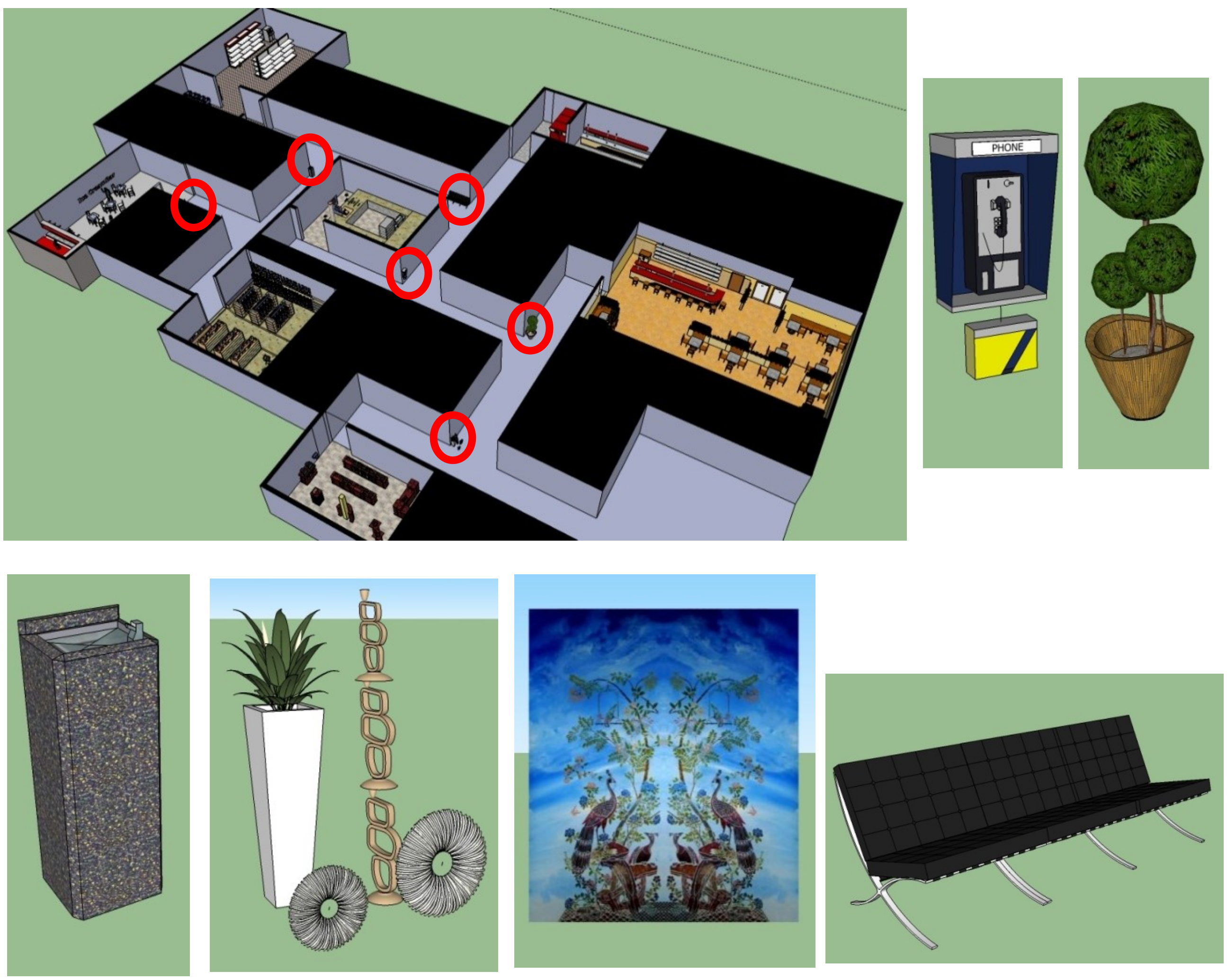
Model 2

Model 3

3.1.2.2 Environment with Vertical Differentiation (Landmarks):

For *vertical differentiation*, the environments differed according to the presence of landmarks, such as a flowerpot, a water fountain, a bench, a picture, a public phone, which were quite familiar to the participants in their daily life. Because landmarks are more effective when they are located at decision points, they were located around the T-junctions (see Figure 3.3).

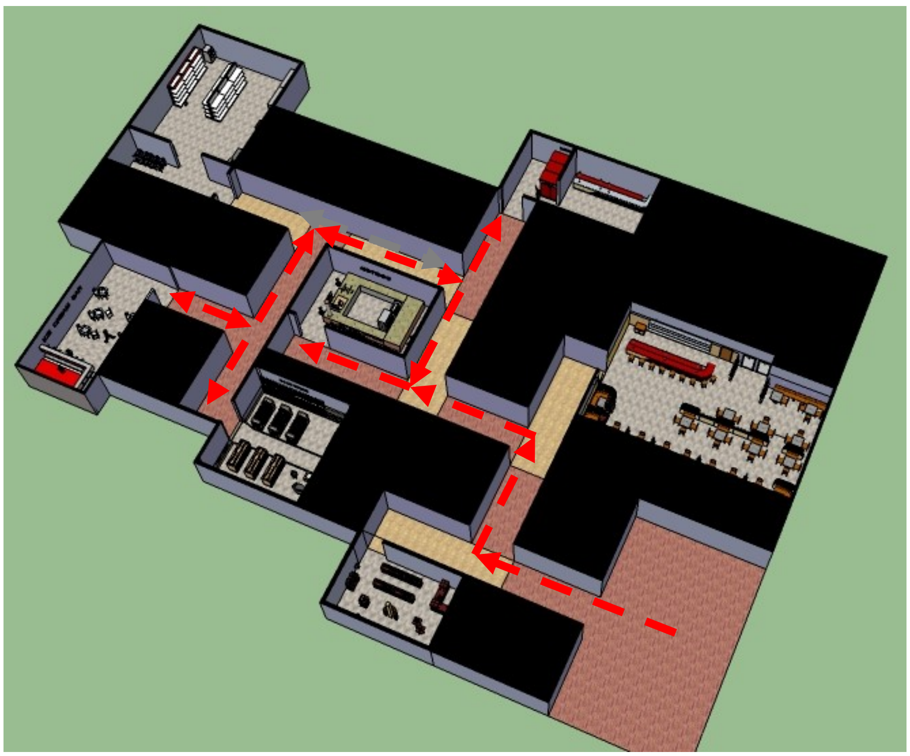
Figure 3.3 An example of V.E. with different landmarks



3.1.2.3 Environment with Horizontal Differentiation (Path Surfacing):

For *horizontal differentiation*, the environments differed according to the presence of path surface, which was varied to create path hierarchy. The most efficient paths between start and destination had different surfacing from other paths (see Figure 3.4).

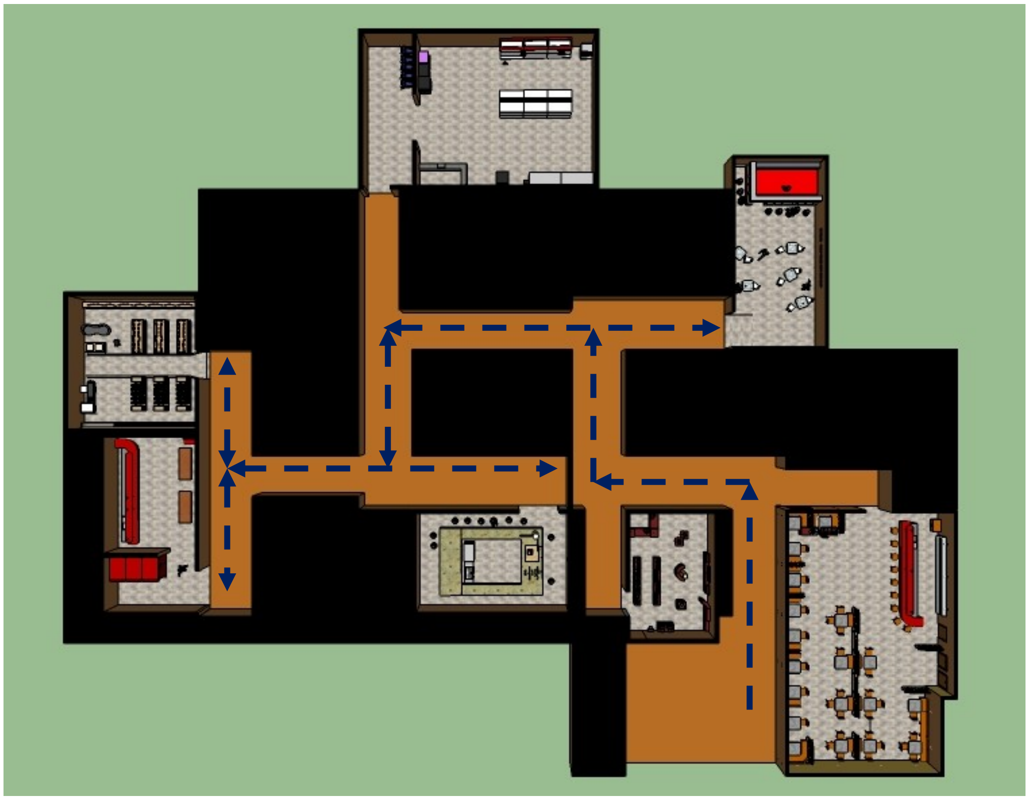
Figure 3.4 An example of V.E. with different path surfacing



3.1.2.4 Environment with Vertical and Horizontal Differentiation (Corridor Width):

For *Vertical and horizontal differentiation*, the environments differed according to the presence of corridor width, which was varied to create path hierarchy. The most efficient corridors between start and destination were wider compare to the other corridors (see Figure 3.5).

Figure 3.5 An example of V.E. with different corridor width viewed from above



3.2. Participants

Sixty volunteers (37 males, 23 females) were recruited to participate in this experiment. Most of them are graduate students from various departments at Concordia University. They are young adults with the age from 22 to 30, which was a quite narrow range.

Before taking the test, they were asked to answer a questionnaire to gather their personal information, including 3d computer game playing frequency and self-estimated wayfinding ability.

After calculating, computer game playing frequency ranged from 0 (never) to 4 (two or more times per week) with a mean of 1.283 (between 1-3 times one quarter and once every other week). Self-estimated wayfinding ability ranged from 0 (very poor) to 4 (very good) with a mean of 2.567 (between Fair and good)

All participants were divided into four groups in random: 15 participants for the original group, 15 participants for the landmark group, 15 participants for the path surfacing group, 15 participants for the corridor width group. They were asked to explore the designed V.E. according to the instruction provided by the experimenter.

3.3 Experimental Task Design

The itinerary and the design of the virtual environment were fixed after a pilot study. The purpose was to judge whether the V.E.'s complexity of layout and itinerary was suitable for this experiment in order to establish the final design of V.E..

Through the experiment description, the participants considered the virtual environment as a shopping mall and started from the entrance into the mall to find several designated stores. They were also required to return to a designated location before searching for the next store. The aim was to increase the opportunity of the participants to learn the environment and form a more complete cognitive map.

Task 1: Spatial Knowledge Acquisition Phase

1. Start from Entrance, Go to Bank to withdraw money

2. Start From Bank, Go to Ice Cream Bar to buy a cool drink, Return to Bank

3. Start from Bank, Go to Book Store to buy a birthday card, Return to Bank

4. Start from Bank, Go to Hotdog Stand to buy a hotdog, Return to Bank, task finished.

Task 2: Spatial Knowledge Application Phase

Start from Entrance -- Go to Bank to withdraw money -- Go to Ice Cream Bar to buy a cool drink -- Go to Book Store to buy a birthday card -- Go to Hotdog Stand to buy a hotdog -- Return to Bank -- task finished.

3.4 Experiment Procedures

The experiment contained a learning phase and a test phase.

3.4.1 Learning Phase

In the learning phase, participants were allowed to explore another virtual environment freely just to familiarize them with the scale and dimension of V.E. and the experience of traveling in V.E.. They were allowed to stop exploring if they said they were ready to take the test.

3.4.2 Wayfinding Task Execution Phase：

Before the execution of the task, all the participants were told that they would take a spatial knowledge test about the environment they traveled after the wayfinding task, so that they should try their best to explore each area of the environment and note the relative location of each store during the exploration.

After reading the description of the scene and the rules of the task, the participants started to execute Task 1. Task 1 contained: first, the participants started from the entrance, arrived at the bank to withdraw some money, and then looking for the ice cream bar to buy a cool drink, and went back to the bank again to withdraw money. In the following, the participants had to find the bookstore to buy a birthday card then returned to the bank again. Next, went to the hotdog stand to buy a hotdog and returned to the bank in the end. When Task 1 was completed, the total time spent at this part of task was recorded and the participants were asked to execute Task 2.

In Task 2, participants were asked to finish the wayfinding task as fast as they could, according to the previous memory in Task 1. In Task 2, they started from the entrance to the bank, then went to the ice cream bar, then went to the book store, then went to the hotdog stand and then back to the bank as soon as possible. The time spent in Task 2 was also recorded.

After finishing the entire navigating task, the participants could have a short break.

3.4.3 Spatial Knowledge Test Phase

Part 1 was Route Knowledge Test. Participants were asked to describe the route from the hotdog stand to the bank by word, sentence or sketching. It is the last part in their navigating.

Part 2 was Survey Knowledge Test. Participants saw a floor plan, illustrating the layout, the paths and the rooms of the environment they explored. Participants were then asked to place the name of the store in the correct location.

4. Analysis and Results

The whole experiment included two phases ---Wayfinding Task Execution Phase and Spatial Knowledge Test Phase, and these two phases provided three distinct types of data: navigation time for task 1 and task 2, route knowledge score (the participants' attempts to reconstitute the itinerary from the hotdog stand to the bank) and survey knowledge score (the participants' attempts to correctly locate the name of each store on the layout).

This section will present a summary of findings on effect of each factor (physical factors and personal factors) on each test (Navigation Test, Route Knowledge Test and Survey Knowledge Test). Because participants' performance for each environment model was tested and scored in multiple ways, the effect of physical factors and personal characters were analyzed separately by each test.

First, the results for the physical factors (landmarks, path surfacing and corridor width) by each test were reported, starting with the time spent in navigation task 1 and task 2, followed by route knowledge scores, and survey knowledge scores. Then they were considered overall and correlations between them are tested.

The results of each test are reported following the same procedure. First the mean scores across conditions were presented, and then statistic analysis was used to discuss the significance of their difference across conditions. Then all the scores of the three test phases were standardized and aggregated to calculate a composite score, “an overall spatial performance measure”. The same procedure was used above to analyze the composite test score.

Secondly, the results for the personal factors (sex, computer game playing frequency and self-estimated wayfinding ability) which were collected by questionnaires before the experiment were reported following the same procedure above.

For the statistical analysis, Non-parametric (or distribution-free) tests were chosen due to the sample size and the non-normal population distribution. *Kruskal-Wallis Test* was used to determine the statistical significance between treatments of all dependent measures; the measures for sex were analyzed by the *Mann-Whitney Test*. Finally, *Pearson’s Correlation* was employed to display the intercorrelations between all dependent measures of the three tests, and between the measures and some personal characters.

Recall that each environment group included three equivalent models and each of the 60 participants has navigated three models. Therefore, 15 participants for each group produced 45 independent results and 60 participants produce 180 independent results in total. Hence the total data sample size for statistic is 180, and 45 for each environment group.

4.1 The Effect of Physical Factors on Wayfinding Performance

For physical environmental characteristics, the hypothesis that environments with Physical Differentiation would produce better wayfinding performance than environments with No Vertical or Horizontal differentiation was proposed. Secondly, if it was found that this hypothesis is supported, then it is needed to test which kind of differentiation is more effective, the horizontal differentiation or the vertical differentiation.

4.1.1 Navigation Test

In Navigation Test, participants were asked to perform two wayfinding tasks which produced two time measures—Time for Task 1 and Time for Task 2. Figure 4.1 summarizes the data of the time participants spent in task 1 and task 2, by different environment group.

Figures 4.1 and 4.2 show that participants for the environment with landmarks spent shortest time in both two wayfinding task. The *Kruskal-Wallis Test* result revealed that the difference for time 1 (x^2=8.334, p=0.040), time 2 (x^2=19.206, p=0.000) and the total time (x^2=16.023, p=0.001) between four environment groups is statistically significant. That is to say the effect of vertical differentiations (landmarks) is more significant than others on actual navigation performance.

Figure 4.1 The mean time spent in Task 1 and Task 2 for each environment group

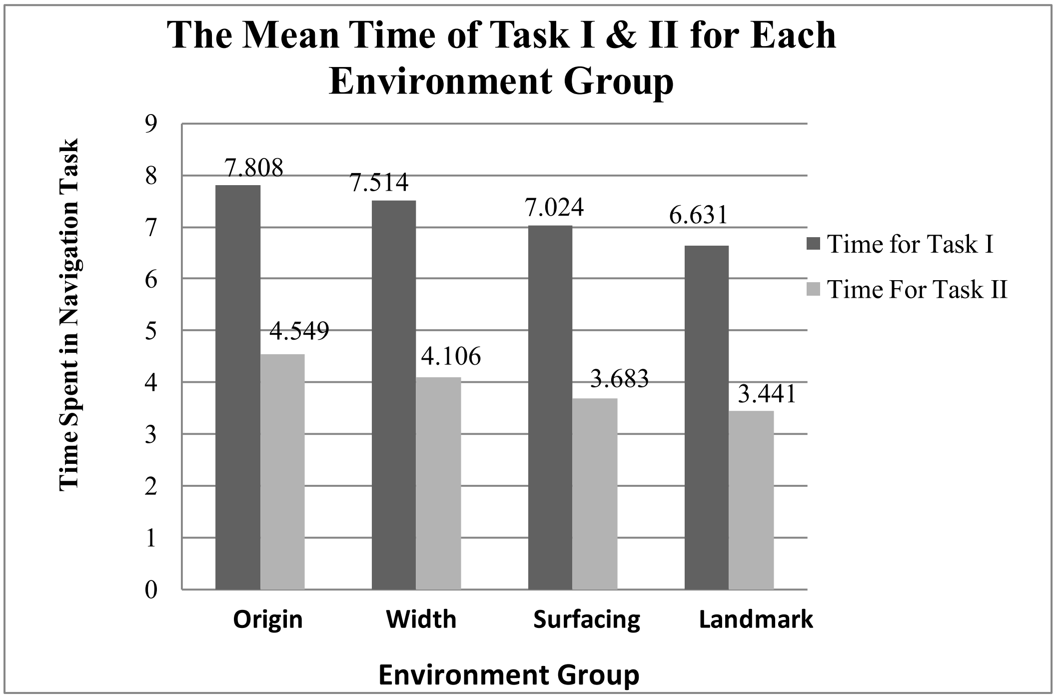


Figure 4.2 The mean of total time spent in navigation test for each environment group

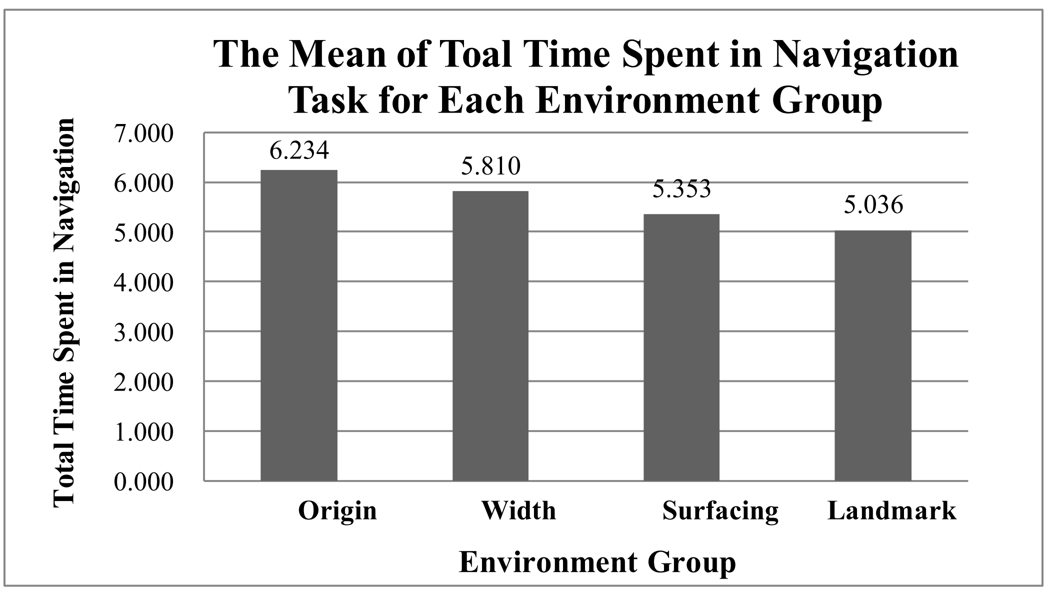


Table 4.1 Kruskal-Wallis Test for Navigation Time of each environment group

Kruskal-Wallis Test

Ranks

	group	N	Mean Rank
time1	1	45	101.17
	2	45	100.99
	3	45	85.18
	4	45	74.67
	Total	180	
time2	1	45	112.62
	2	45	101.10
	3	45	77.42
	4	45	70.86
	Total	180	
time	1	45	108.42
	2	45	102.12
	3	45	81.86
	4	45	69.60
	Total	180	

Test Statistics[a,b]

	time1	time2	time
Chi-Square	8.334	19.206	16.042
df	3	3	3
Asymp. Sig.	.040	.000	.001

a. Kruskal Wallis Test

b. Grouping Variable: group

Group: 1-Origin 2-Width 3-Surfacing 4-Landmark

4.1.2 Route Knowledge Test

Following the two navigating tasks of a given environment model, each participant was asked to recall the last section of their navigation, describe the itinerary from the hotdog stand to the bank by word, sentence or sketching on a piece of paper. In the result of this study, 99% of participants chose to describe the itinerary by sketching. According to previous research, it's difficult to devise a quantitative measure of the drawings. For this study, a qualitative and quantitative mixed approach was chosen to classify the hand drawn maps into three levels. In order to employ the power of statistical analysis, all analyzed maps are credited with the following three specific scores:

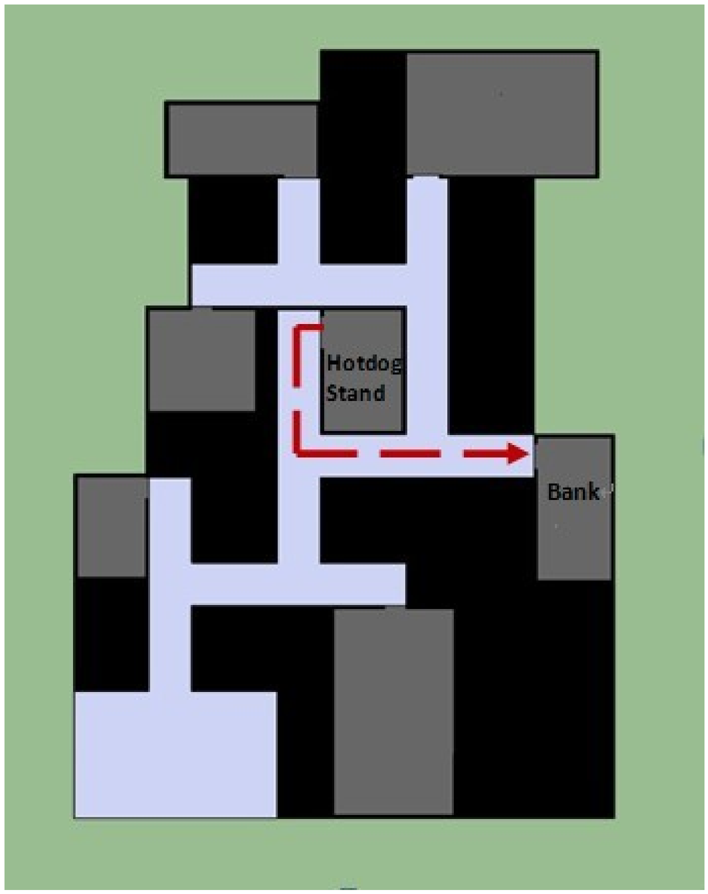
Level 0: The direction, the sequence and the number of route turns are wrong (Score 0).

Level 1: Either the direction, the sequence or the number of the route turns is correct (Score 1).

Level 2: All the direction, the sequence and the number of route turns are correct (Score 2).

Figure 4.3 to Figure 4.5 illustrate the actual three models with the accurate required itinerary, associated the scoring standards. A series of typical sketches by different participants in various styles is also attached to explain the sketching score.

Figure 4.3 Model 1



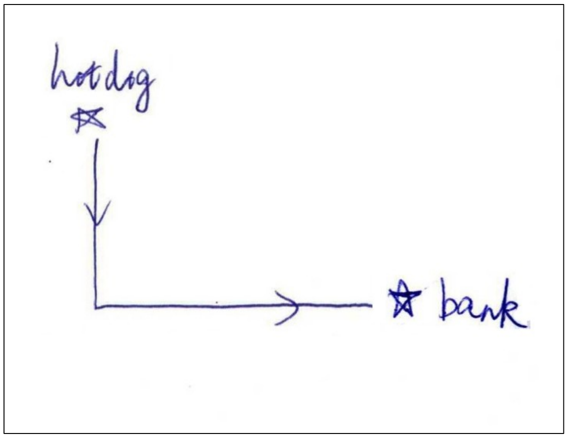
Itinerary from Hotdog Stand to Bank:

a. Go out and turn left,

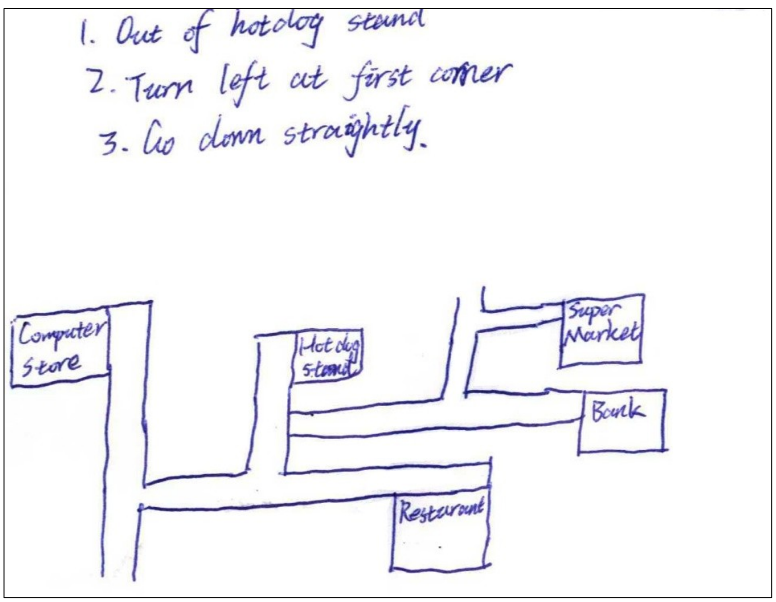
b. Go straight and turn left at the first T-junction, **(1 point)**

c. Go straight and the bank will be found at the end of the corridor. **(1 point)**

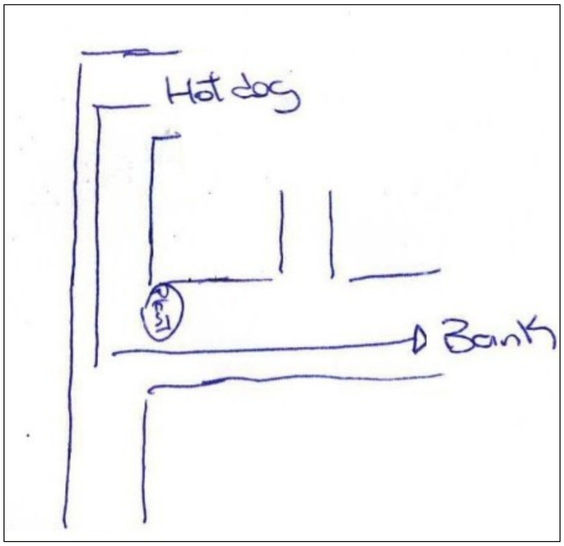
Samples of Route Sketching Result for Model 1:



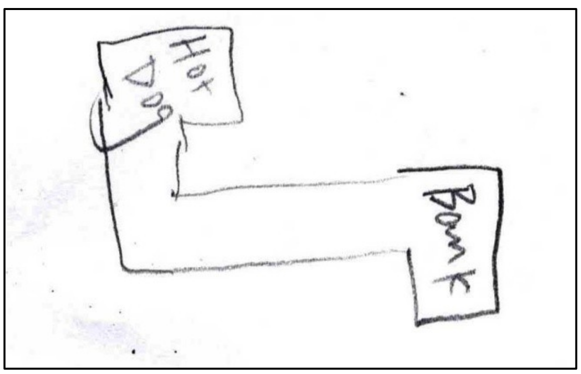
Drawing by Subject #2 in the Original Group (Score 2)



Drawing by Subject #12 in the Landmark Group (Score 2).

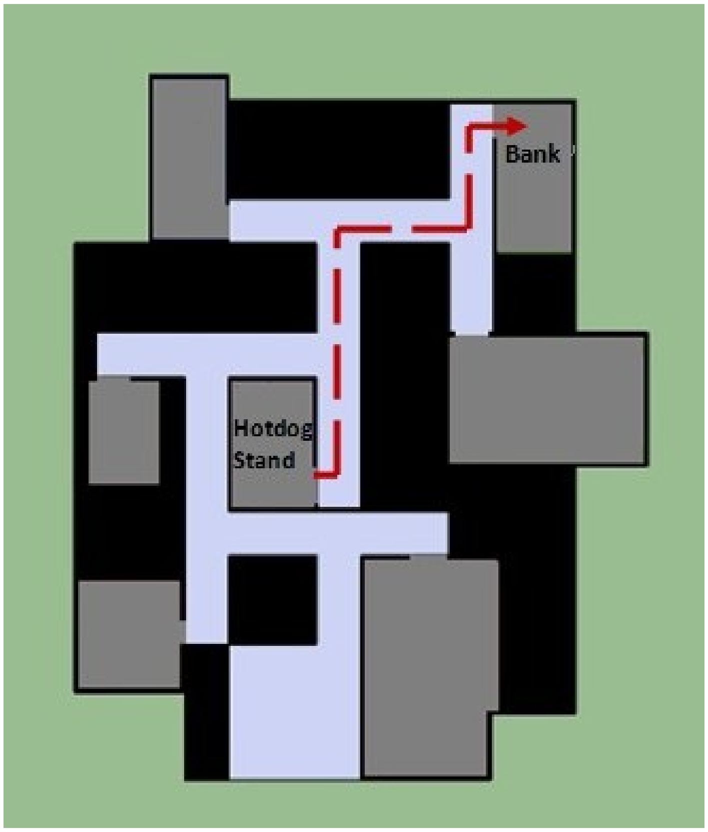


Drawing by Subject #10 in the Landmark Group (Score 2).



Drawing by Subject #9 in the Original Group (Score 2).

Figure 4.4 Model 2



Itinerary from Hotdog Stand to Bank:

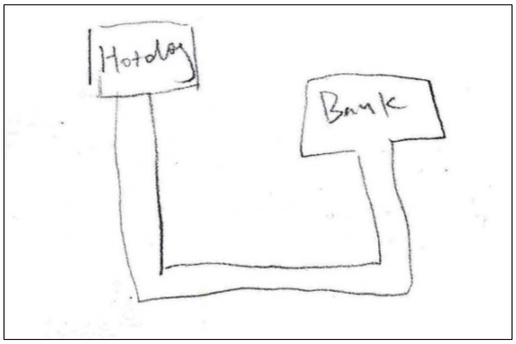
a. Go out and turn left,

b. Go straight and turn right at the second T-junction, **(1 point)**

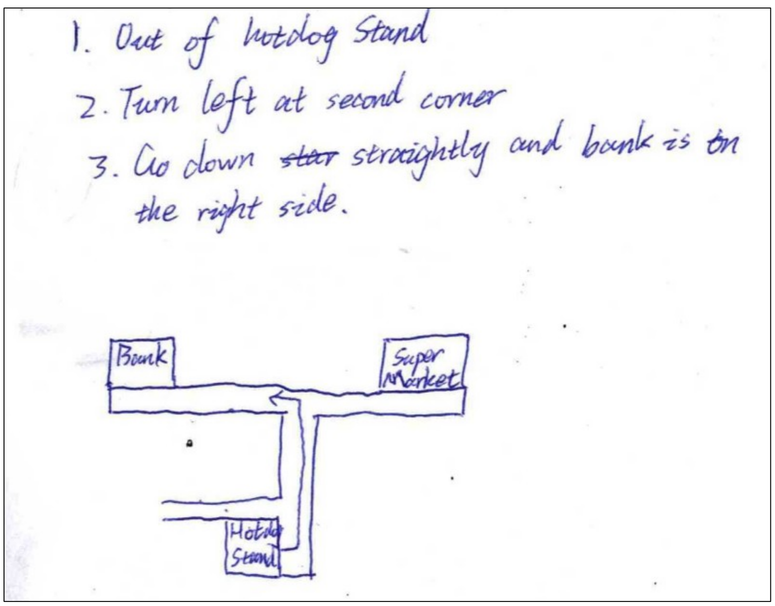
c. Go straight and turn left at the third T-junction **(1 point)**

d. Go straight until the end of the corridor and the bank will be found on the right side.

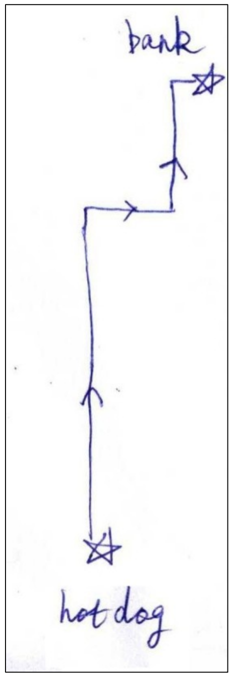
Samples of Route Sketching Result for Model 2:



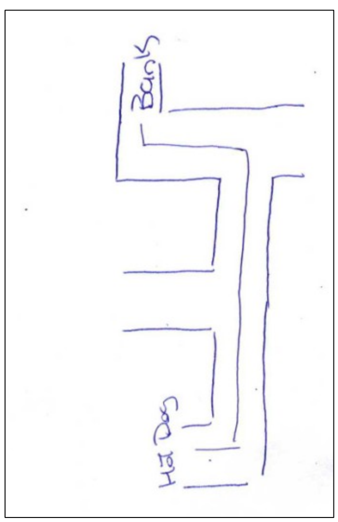
Drawing by Subject #9 in the Original Group (Score 0).



Drawing by Subject #12 in the Landmark Group (Score 1).

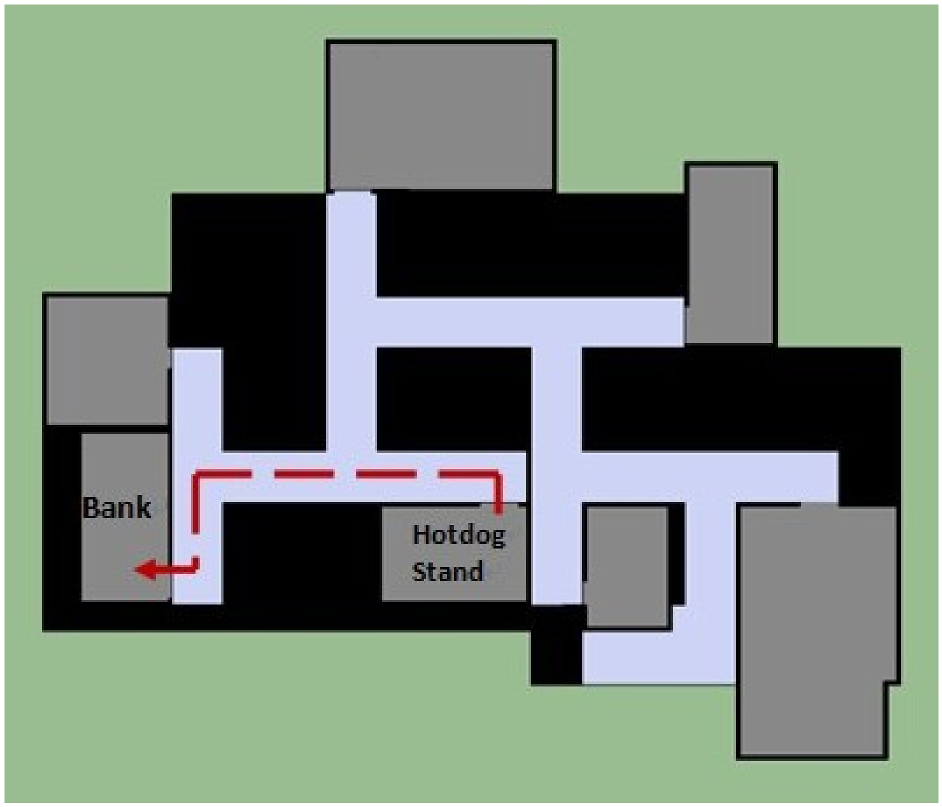


Drawing by Subject #3 in the Original Group (Score 2).



Drawing by Subject #10 in the Landmark Group (Score 1).

Figure 4.5 Model 3



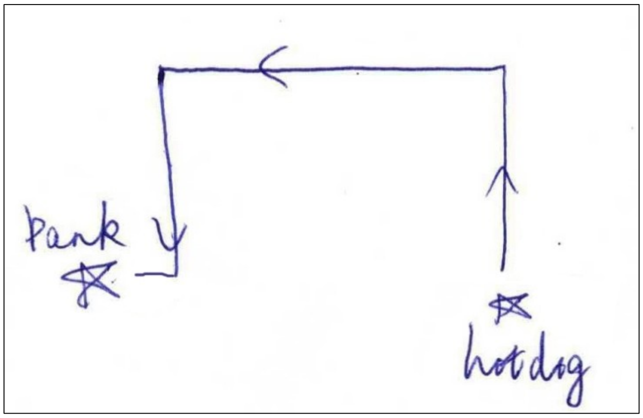
Itinerary from Hotdog Stand to Bank:

a. Go out and turn left,

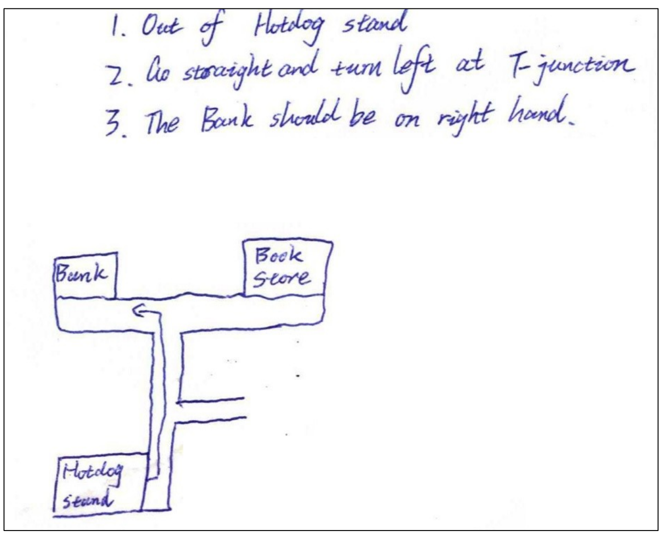
b. Go straight and turn left at the second T-junction, **(1 point)**

c. Go straight until the end of the corridor and the bank will be found on the right side. **(1 point)**

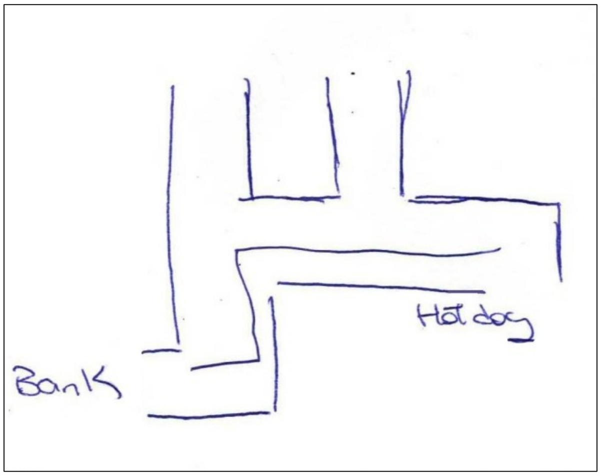
Samples of Route Sketching Result for Model 3:



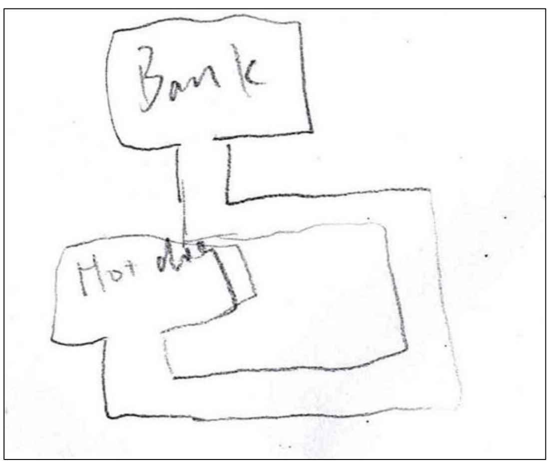
Drawing by Subject #2 in the Original Group (Score 2).



Drawing by Subject #12 in the Landmark Group (Score 2).



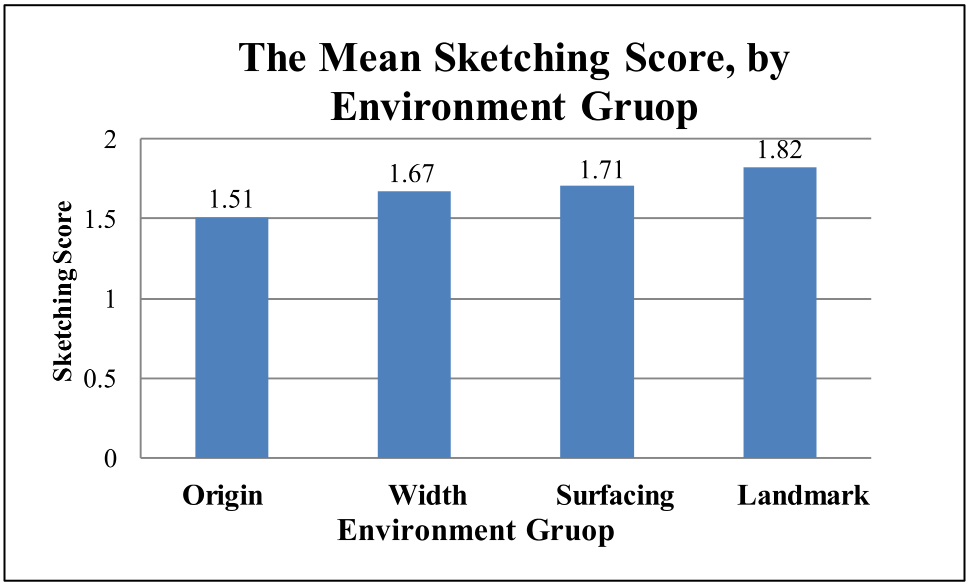
Drawing by Subject #10 in the Landmark Group (Score 2).



Drawing by Subject #9 in the Original Group (Score 2).

Figure 4.6 shows the mean score of each environment group on the route sketching test. It shows that participants of the landmark group obtain the highest score in the route knowledge test.

Figure 4.6 The mean sketching score of route knowledge test for each environment group



The *Kruskal-Wallis Test* result revealed no significant difference on sketching score between the four environment groups (x^2=3.453, p=0.327). And the *Mann-Whitney Test* also showed that the difference between the original group and the other three physical differentiation groups is also not statistically significant ($p>0.05$).

That is to say, landmark group performed better than other group but the gap is not so obvious. The scores among four groups are close and overall high perhaps because the test is kind of simple for most participants.

Table 4.2 The Kruskal-Wallis Test for sketching score of each environment group.

Kruskal-Wallis Test

Ranks

	group	N	Mean Rank
route	1	45	83.10
	2	45	88.92
	3	45	92.52
	4	45	97.46
	Total	180	

Test Statistics[a,b]

	route
Chi-Square	3.453
df	3
Asymp. Sig.	.327

a. Kruskal Wallis Test

b. Grouping Variable: group

Group: 1-Origin 2-Width 3-Surfacing 4-Landmark

Table 4.3 The Mann-Whitney Test for sketching score between Origin-Group and one of the Differentiation-Groups.

Mann-Whitney Test

Ranks

	group	N	Mean Rank	Sum of Ranks
route	1	45	43.98	1979.00
	2	45	47.02	2116.00
	Total	90		

Group: 1- Origin 2-Width

Test Statistics[a]

	route
Mann-Whitney U	944.000
Wilcoxon W	1.979E3
Z	-.713
Asymp. Sig. (2-tailed)	.476

a. Grouping Variable: group

Ranks

	group	N	Mean Rank	Sum of Ranks
route	1	45	43.18	1943.00
	3	45	47.82	2152.00
	Total	90		

Group: 1-Origin 3-Surfacing

Test Statistics[a]

	route
Mann-Whitney U	908.000
Wilcoxon W	1.943E3
Z	-1.122
Asymp. Sig. (2-tailed)	.262

a. Grouping Variable: group

Ranks

	group	N	Mean Rank	Sum of Ranks
route	1	45	41.94	1887.50
	4	45	49.06	2207.50
	Total	90		

Group: 1-Origin 4-Landmark

Test Statistics[a]

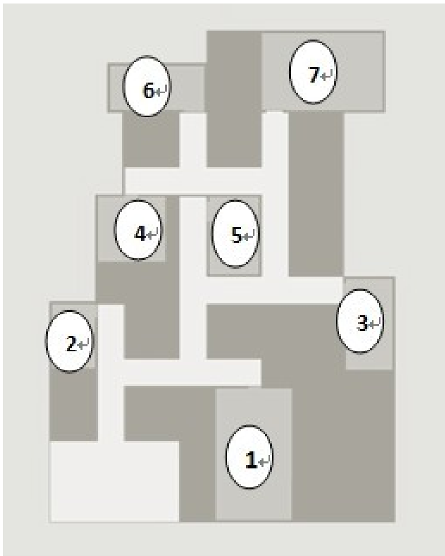
	route
Mann-Whitney U	852.500
Wilcoxon W	1.888E3
Z	-1.779
Asymp. Sig. (2-tailed)	.075

a. Grouping Variable: group

4.1.3 Survey Knowledge Test

Figure 4.7 shows the location of the store, within which the name placement on the layout is considered correct. Each time placing the correct name of store on the correct location, participants were credited 1 score. There are seven stores on the layout and so the score ranges from 0-7.

Figure 4.7 The location of each store for three virtual environments



Model 1

① restaurant

② computer store

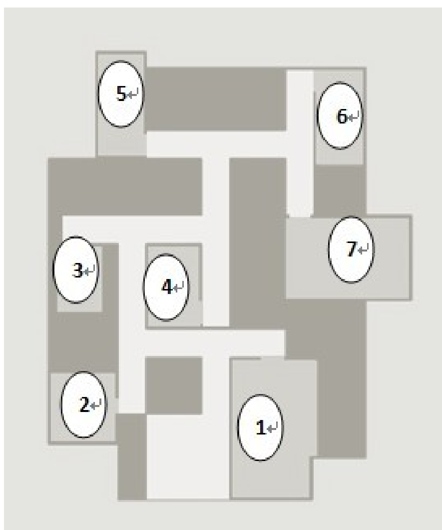
③ bank

④ bookstore

⑤ hotdog stand

⑥ ice cream bar

⑦ supermarket



Model 2

① restaurant

② bookstore

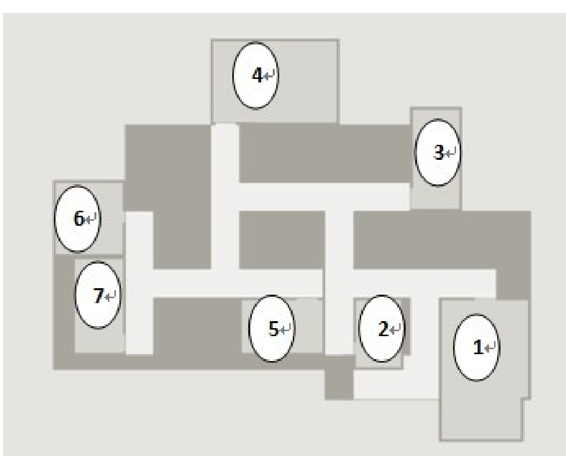
③ computer store

④ hotdog stand

⑤ ice cream bar

⑥ bank

⑦ supermarket



Model 3

① restaurant

② computer store

③ ice cream bar

④ supermarket

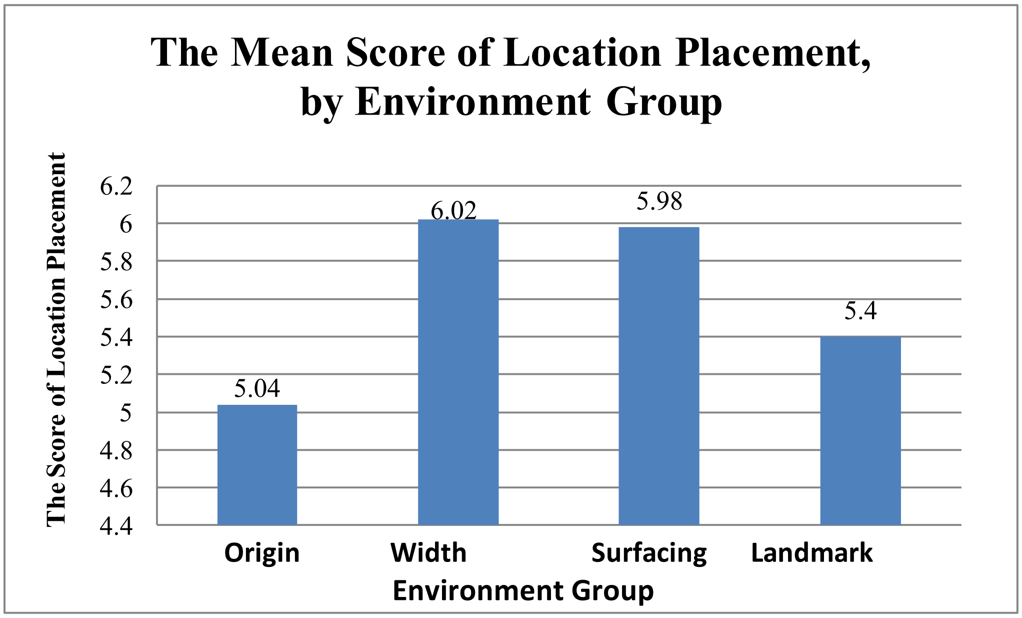
⑤ hotdog stand

⑥ bookstore

⑦ bank

Figure 4.8 shows the performance comparison among the four different environment group in the survey knowledge test. It shows that participants of the width group and surfacing group locate more accurate store than participants of the other groups.

Figure 4.8 The mean score of location placement for each environment group



The *Kruskal-Wallis Test* result revealed no significant difference of location placement scores between the four environment groups (x^2=7.059, p=0.70>0.05). The *Mann-Whitney Test* indicated that only the presence of width differentiation was found to be marginally significant on the location placement score (z=-1.957, p=0.05).

That is to say, the effect of width variation on survey knowledge acquisition is significant compared to no physical differentiation. However, the difference across three differentiated groups is not so obvious.

Table 4.4 The Kruskal-Wallis Test for location placement score of each environment group.

Kruskal Wallis Test

Ranks

	group	N	Mean Rank
location	1	45	80.23
	2	45	100.12
	3	45	99.27
	4	45	82.38
	Total	180	

Test Statistics[a,b]

	location
Chi-Square	7.059
df	3
Asymp. Sig.	.070

a. Kruskal Wallis Test

b. Grouping Variable: group

Group: 1- Origin 2-Width 3-Surfacing 4-Landmark

Table 4.5 The Mann-Whitney Test for location placement score between the Origin-Group and one of the Differentiation-Groups.

Ranks

	group	N	Mean Rank	Sum of Ranks
location	1	45	40.71	1832.00
	2	45	50.29	2263.00
	Total	90		

Group: 1-Origin 2-Width

Test Statistics[a]

	location
Mann-Whitney U	797.000
Wilcoxon W	1.832E3
Z	-1.957
Asymp. Sig. (2-tailed)	.050

a. Grouping Variable: group

Ranks

	group	N	Mean Rank	Sum of Ranks
location	1	45	40.91	1841.00
	3	45	50.09	2254.00
	Total	90		

Group: 1-Origin 3-Surfacing

Test Statistics[a]

	location
Mann-Whitney U	806.000
Wilcoxon W	1.841E3
Z	-1.873
Asymp. Sig. (2-tailed)	.061

a. Grouping Variable: group

Ranks

	group	N	Mean Rank	Sum of Ranks
location	1	45	44.61	2007.50
	4	45	46.39	2087.50
	Total	90		

Group: 1-Origin 4-Landmark

Test Statistics[a]

	location
Mann-Whitney U	972.500
Wilcoxon W	2.008E3
Z	-.345
Asymp. Sig. (2-tailed)	.730

a. Grouping Variable: group

4.1.4 Overall Spatial Performance Measure

A composite measure, "an overall spatial performance measure," was calculated using the responses to three tests (navigation, route sketching and location placement). To do this, the scores for each test (navigation, route knowledge and survey knowledge) were standardized.

Then the navigation time scores were standardized with the following equation (I also used the same equation to standardize any score for the remainder measures):

$$Standardized\ Score = \frac{(Actual\ Score - Minimum\ Score)}{(Maximum\ Score - Minimum\ Score)}$$

Standardized scores ranged from 0 to 1. Subtracting the standardized navigating time scores from "1" turned time scores into "speed" scores.

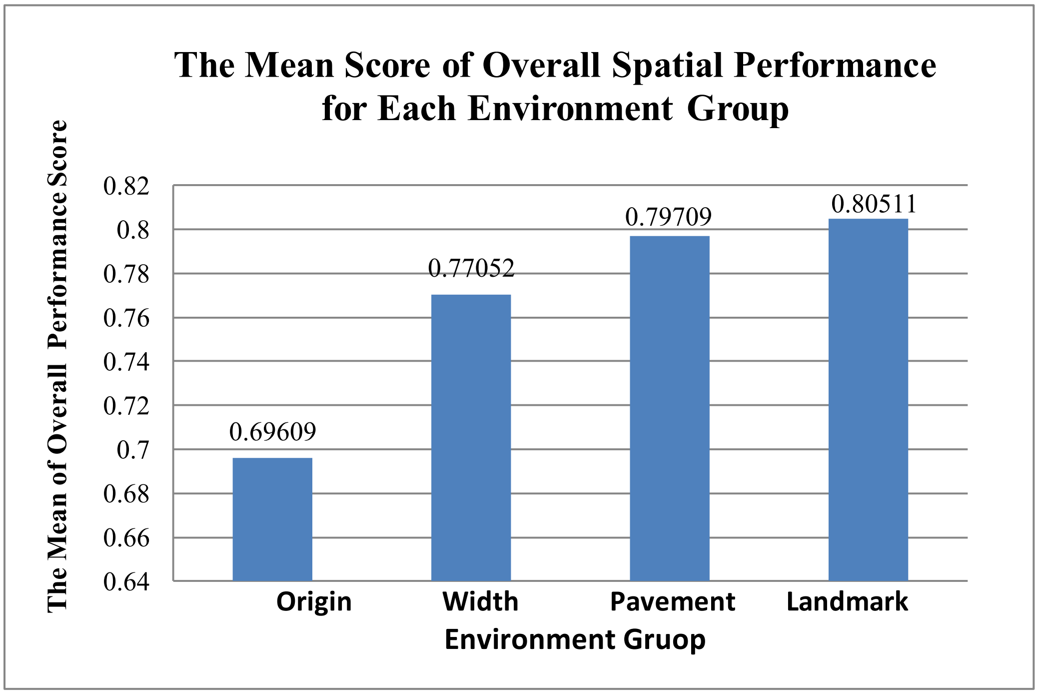
Then an overall spatial performance score was calculated with the following equation:

Overall Spatial Performance Score = Standardized Scores (Navigation Speed Score^1 + Navigation Speed Score^2 + Route Knowledge Score + Survey knowledge Score)/4

The *overall spatial awareness error* score ranged between 0 and 1.

Figure 4.9 indicates the mean score of overall spatial performance for the four environment groups. Participants for environment with landmark differentiation obtained the highest score during overall test, closely followed by environment with surfacing differentiation, and then environment with width differentiation.

Figure 4.9 The mean score of overall spatial performance for each environment group.



The overall spatial performance scores were also analyzed using a *Kruskal-Wallis Tes*t, which indicated that there was a significant difference between the four environment groups (x^2=8.012, p=0.046) but the rank differs from the Mean Compare in Figure 4.11. The Mean Rank of Group 3 – surfacing is highest so the participants' overall performance in Surfacing Group is better than the other groups.

Table 4.6 The Kruskal-Wallis Test for overall performance score of each environment group.

Kruskal-Wallis Test

Ranks

	group	N	Mean Rank
Overall Score	1	45	74.73
	2	45	86.18
	3	45	103.22
	4	45	97.87
	Total	180	

Group: 1- Origin 2-Width 3-Surfacing 4-Landmark

Test Statistics[a,b]

	Overall Score
Chi-Square	8.012
df	3
Asymp. Sig.	.046

a. Kruskal Wallis Test

b. Grouping Variable: group

4.2 The Effect of Personal Characteristics on Wayfinding Performance

For personal characteristics, it was hypothesized that males, people who play 3D games more often and people whose wayfinding ability is higher would show better performance than females, people who play 3D Games rarely and people who estimate their wayfinding ability is poorer. Because the sample had a narrow age range of young adults (20-32), the differences in performance associated with age were not analyzed.

4.2.1 Navigation Task

The analysis also looked at personal characteristics. For sex, as expected in Navigation test males spent fewer time than females in both Task 1 and Task 2 (see Figure 4.10 and Figure 4.11).

Figure 4.10 The mean time spent in Task 1 and Task 2 for sex

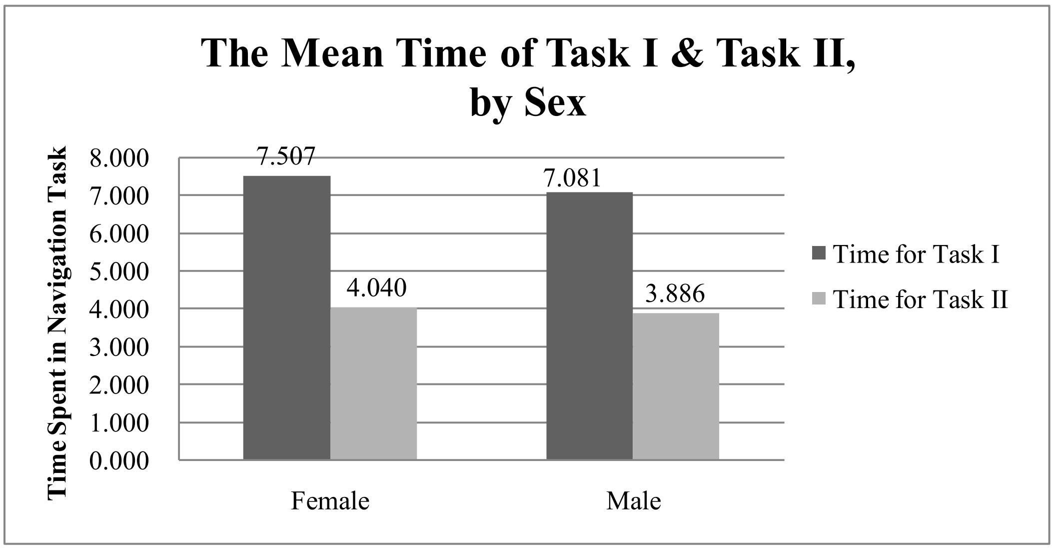
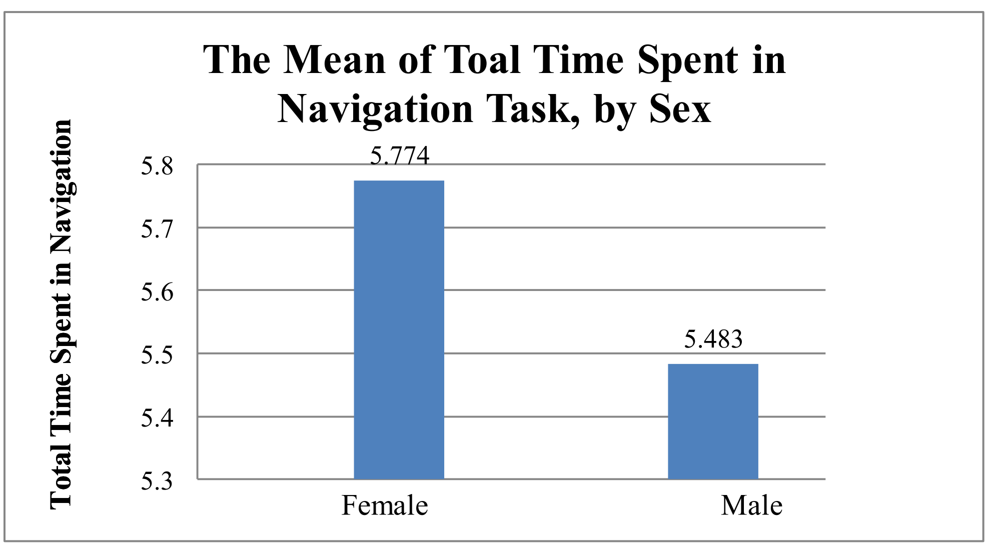


Figure 4.11 The mean of total time spent in Task 1 & 2 for sex



However, after analyzed by the *Mann-Whitney Test*, this difference was not significant (see Table 4.7).

Table 4.7 Mann-Whitney Test for Navigation Time of each sex

Mann-Whitney Test

Ranks

	sex	N	Mean Rank	Sum of Ranks
time1	0	69	94.14	6496.00
	1	111	88.23	9794.00
	Total	180		
time2	0	69	94.74	6537.00
	1	111	87.86	9753.00
	Total	180		
time	0	69	93.80	6472.00
	1	111	88.45	9818.00
	Total	180		

Sex: 0-female 1-male

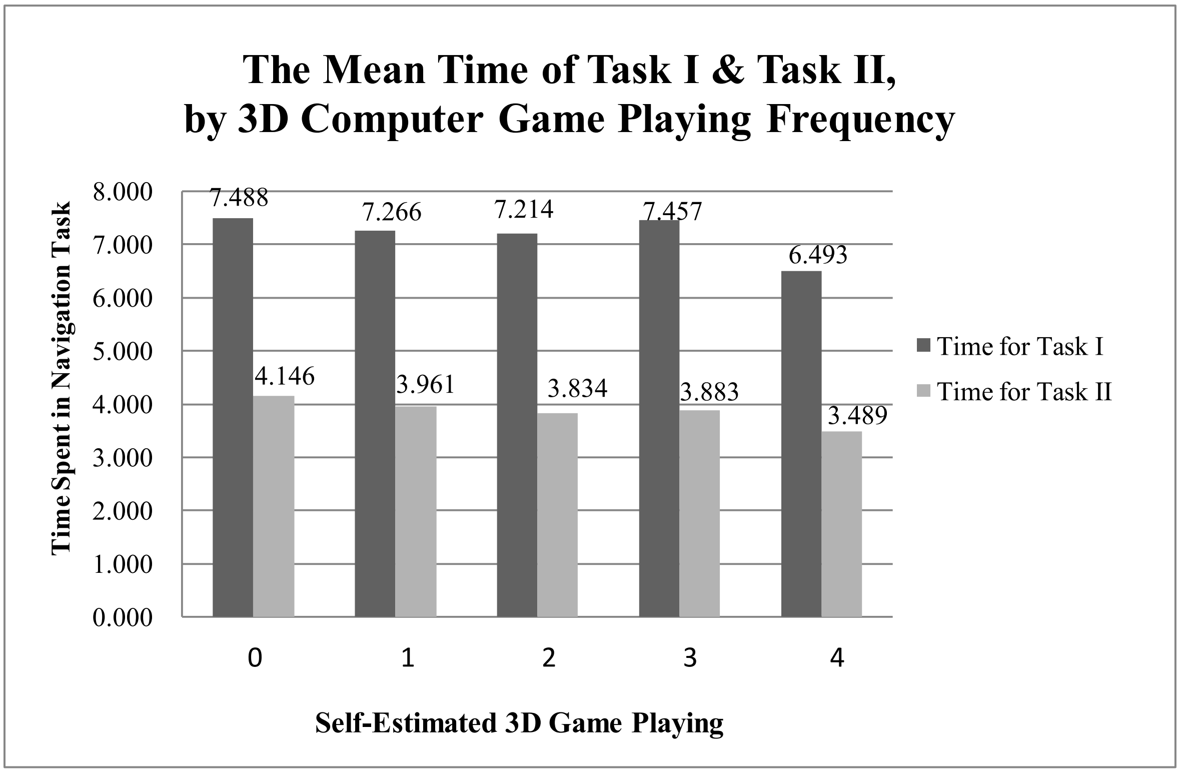
Test Statistics[a]

	time1	time2	time
Mann-Whitney U	3.578E3	3.537E3	3.602E3
Wilcoxon W	9.794E3	9.753E3	9.818E3
Z	-.740	-.861	-.669
Asymp. Sig. (2-tailed)	.459	.389	.503

a. Grouping Variable: sex

For 3D game playing frequency, the pattern is not quite clear but in general as frequencies of game playing increased navigation time spent decreased (see Figure 4.12 and Figure 4.13).

Figure 4.12 The mean time spent in Task 1 and Task 2 for 3d computer game playing frequency

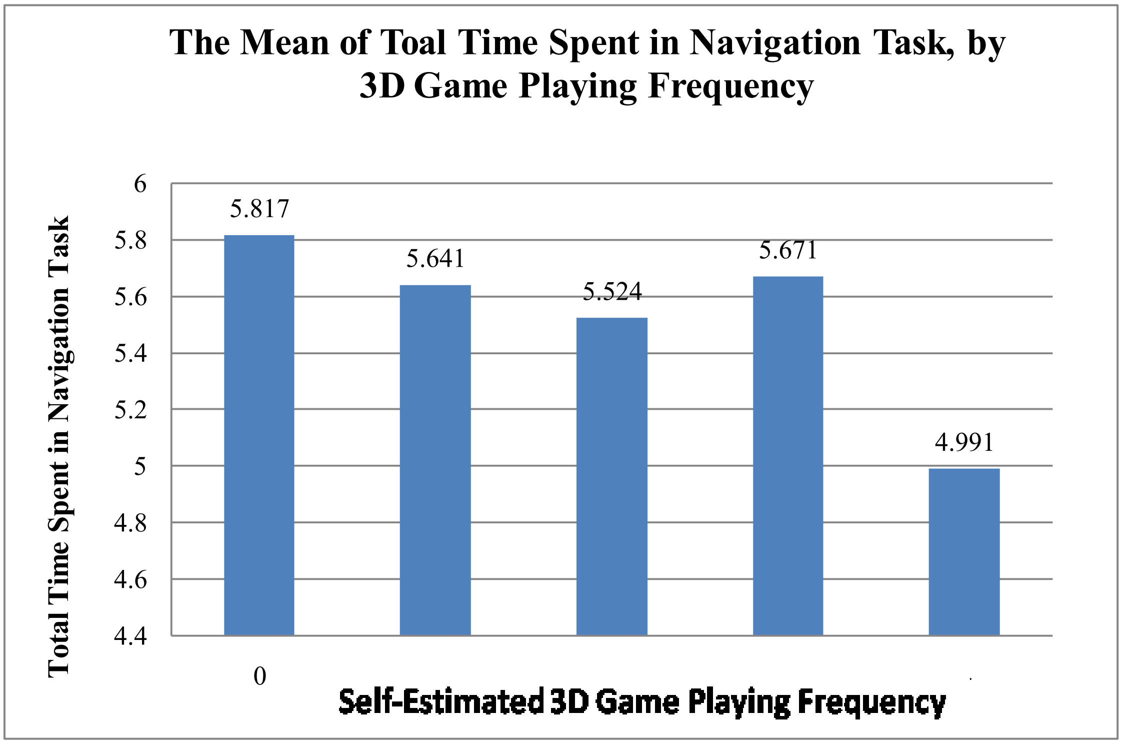


Self-Estimated 3D Game Playing Frequency:

0— Never; **1**— 1-3 times; **2**— about every other week;

3— about once per week; **4**— 2 or more times per week

Figure 4.13 The mean of total time spent in Task 1 & 2 for 3d computer game playing frequency



Self-Estimated 3D Game Playing Frequency:

0— Never; **1**— 1-3 times; **2**— about every other week;

3— about once per week; **4**— 2 or more times per week

Table 4.8 Kruskal-Wallis Test for Navigation Time of different 3d computer game playing frequency

Kruskal-Wallis Test

Ranks

	game	N	Mean Rank
time	0	75	99.19
	1	42	87.83
	2	27	87.13
	3	9	100.78
	4	27	70.44
	Total	180	
time1	0	75	96.33
	1	42	87.36
	2	27	93.74
	3	9	97.39
	4	27	73.65
	Total	180	
time2	0	75	99.05
	1	42	90.65
	2	27	83.02
	3	9	90.00
	4	27	74.15
	Total	180	

Test Statistics[a,b]

	time	time1	time2
Chi-Square	6.661	4.179	5.238
df	4	4	4
Asymp. Sig.	.155	.382	.264

a. Kruskal Wallis Test

b. Grouping Variable: game

3D Game Playing Frequency：

0— Never;

1— 1-3 times;

2— about every other week;

3— about once per week;

4— 2 or more times per week

As shown in Table 4.8, the difference of time spent in navigation test did not achieve significance for different game playing frequency by *Kruskal-Wallis Test*. However, the *Pearson's Correlation* indicated that there are significant correlations between game playing frequency and time spent in Navigation Test (Table 4.9). That is to say, the more frequent the participants played 3d games, the better they performed in Navigation Test although the difference is not so much.

Table 4.9 The Pearson's Correlation for game playing frequency and time spent in Navigation Test.

Pearson's Correlation

Correlations

		time1	time2	time	game
time1	Pearson Correlation	1	.412**	.902**	-.150*
	Sig. (2-tailed)		.000	.000	.044
	N	180	180	180	180
time2	Pearson Correlation	.412**	1	.766**	-.165*
	Sig. (2-tailed)	.000		.000	.027
	N	180	180	180	180
time	Pearson Correlation	.902**	.766**	1	-.184*
	Sig. (2-tailed)	.000	.000		.013
	N	180	180	180	180
game	Pearson Correlation	-.150*	-.165*	-.184*	1
	Sig. (2-tailed)	.044	.027	.013	
	N	180	180	180	180

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

I also analyzed the relation between the self-estimated wayfinding ability and time spent in navigation test. Figure 4.14 and Figure 4.15 shows that less time spent is associated with higher scores in wayfinding ability. That is also verified by the *Kruskal-Wallis Test* and *Pearson's Correlation,* which shows that the difference of time spent by each wayfinding score and the correlation between time spent and wayfinding score are both statistically significant (Table 4.10 and 4.11).

Figure 4.14 The mean time spent in Task 1 and Task 2 for different wayfinding ability score

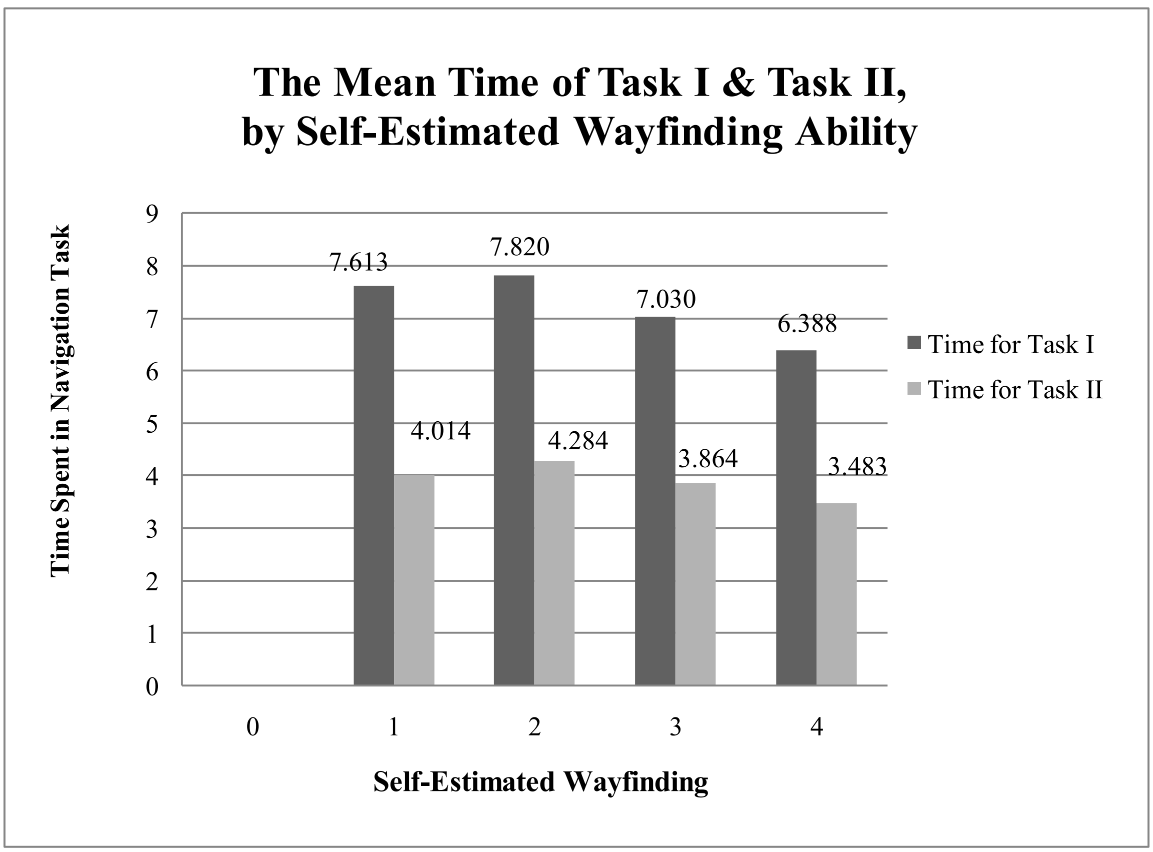
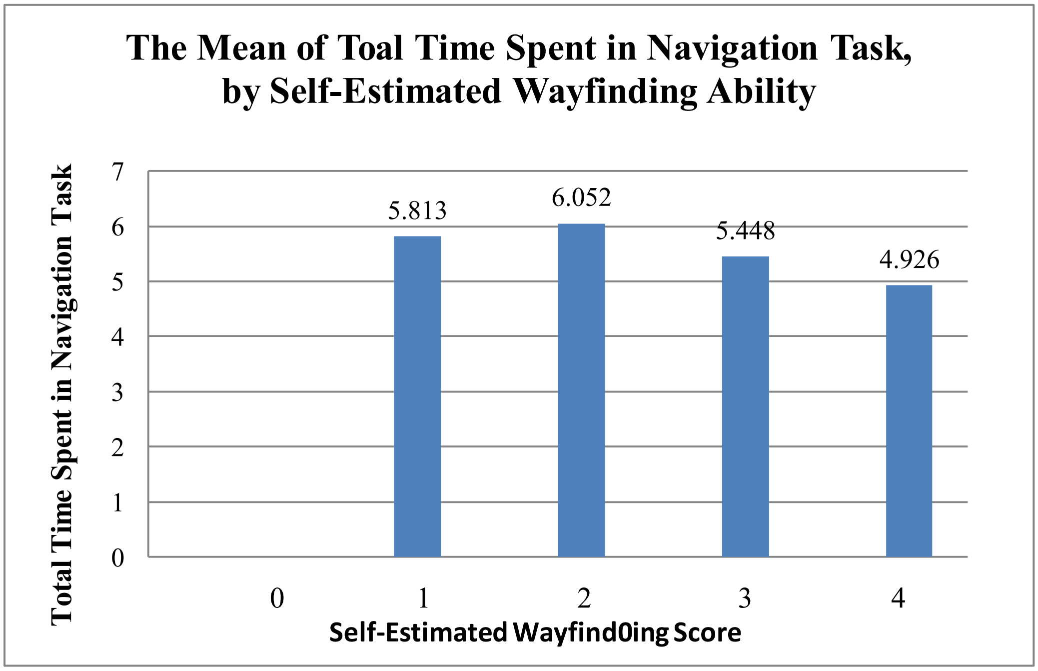


Figure 4.15 The mean of total time spent in Task 1 & 2 for different wayfinding ability score



Self-Estimated Wayfinding Score:

0—Very Poor **1**—Poor **2**—Fair **3**—Good **4**—Very Good

Table 4.10 The Kruskal-Wallis Test for Navigation Time of different wayfinding ability score

Kruskal-Wallis Test

Ranks

	wayfinding	N	Mean Rank
time	1	27	102.39
	2	63	104.45
	3	48	87.89
	4	42	64.92
	Total	180	
time1	1	27	102.52
	2	63	102.29
	3	48	85.41
	4	42	70.90
	Total	180	
time2	1	27	96.83
	2	63	100.72
	3	48	90.30
	4	42	71.32
	Total	180	

Test Statistics[a,b]

	time	time1	time2
Chi-Square	16.169	11.063	8.515
df	3	3	3
Asymp. Sig.	.001	.011	.036

a. Kruskal Wallis Test

b. Grouping Variable: wayfinding

Self-Estimated Wayfinding Ability Score:
- 0—Very Poor
- 1—Poor
- 2—Fair
- 3—Good
- 4—Very Good

Table 4.11 The Pearson's Correlation for wayfinding ability score and time spent in Navigation Test.

Pearson's Correlation

Correlations

		time1	time2	time	wayfinding
time1	Pearson Correlation	1	.412**	.902**	-.259**
	Sig. (2-tailed)		.000	.000	.000
	N	180	180	180	180
time2	Pearson Correlation	.412**	1	.766**	-.186*
	Sig. (2-tailed)	.000		.000	.013
	N	180	180	180	180
time	Pearson Correlation	.902**	.766**	1	-.271**
	Sig. (2-tailed)	.000	.000		.000
	N	180	180	180	180
wayfinding	Pearson Correlation	-.259**	-.186*	-.271**	1
	Sig. (2-tailed)	.000	.013	.000	
	N	180	180	180	180

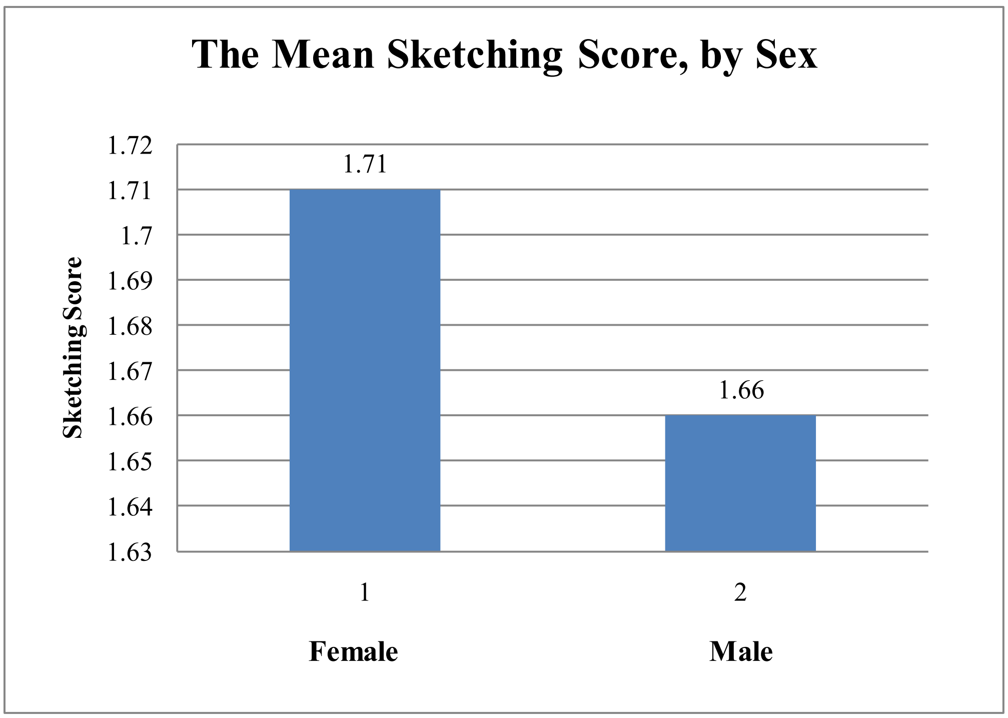
**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

4.2.2 Route Knowledge Test

This section considers the effect of personal characteristics on itinerary sketching score. Sex produces opposite effect on Route Knowledge Test to Navigation Test. Females showed higher level scores (M = 1.71, SD = 0.621, n = 69) than males (M = 1.66, SD = 0.667, n = 111) on sketching itinerary (see Figure 4.16).

Figure 4.16 The mean sketching score for each sex



However, after analyzed by *Mann-Whitney Test*, the sketching score difference between male and female doesn't achieve statistical significant (Z=-0.511, p=0.609) (Table 4.12).

Table 4.12 Mann-Whitney Test for Sketching Score of each sex

Mann-Whitney Test

Ranks

	sex	N	Mean Rank	Sum of Ranks
route	0	69	92.33	6370.50
	1	111	89.36	9919.50
	Total	180		

sex: 0-female 1-male

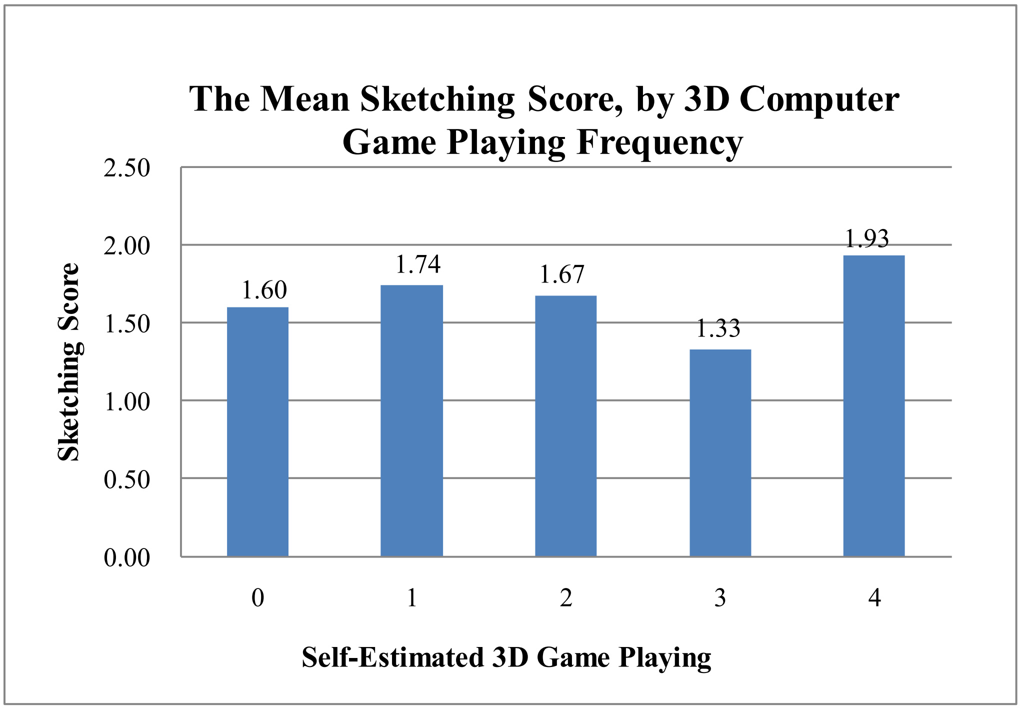
Test Statistics[a]

	route
Mann-Whitney U	3.704E3
Wilcoxon W	9.920E3
Z	-.511
Asymp. Sig. (2-tailed)	.609

a. Grouping Variable: sex

As expected, more frequent game players suppose to have higher scores on route knowledge test than less frequent game players. However, the pattern is not clear on Figure 4.17 (there is an outlier in Frequency Score 3 and the participants within this range is much fewer than others) and neither the *Kruskal-Wallis Test* (x^2 =7.363, p=0.118) nor the *Pearson's Correlation* (r=0.117, p=0.118) shows statistical significance (Table 4.13 and Table 4.14).

Figure 4.17 The mean sketching score for different 3d game playing frequency



Self-Estimated 3D Game Playing Frequency:

0— Never; **1**— 1-3 times; **2**— about every other week;

3— about once per week; **4**— 2 or more times per week

Table 4.13 The Kruskal-Wallis Test for sketching score of different 3d game playing frequency

Kruskal-Wallis Test

Ranks

	game	N	Mean Rank
route	0	75	87.05
	1	42	93.64
	2	27	88.02
	3	9	70.06
	4	27	104.50
	Total	180	

Test Statistics[a,b]

	route
Chi-Square	7.363
df	4
Asymp. Sig.	.118

a. Kruskal Wallis Test

b. Grouping Variable: game frequency

Table 4.14 The Pearson's Correlation for sketching score and 3d game playing frequency

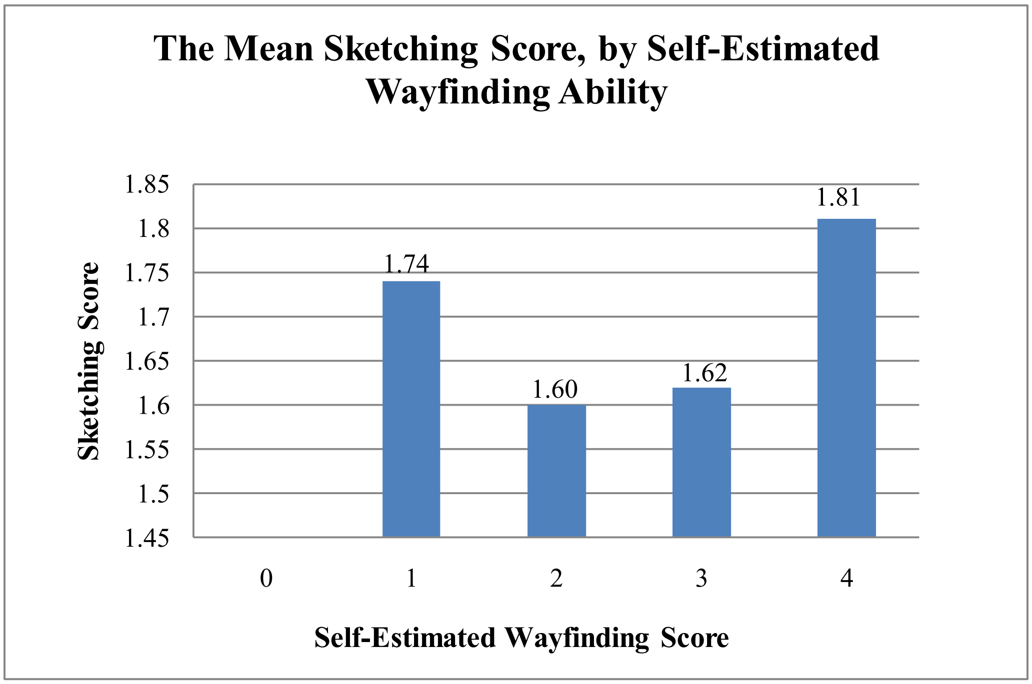
Pearson's Correlation

Correlations

		route	game
route	Pearson Correlation	1	.117
	Sig. (2-tailed)		.118
	N	180	180
game	Pearson Correlation	.117	1
	Sig. (2-tailed)	.118	
	N	180	180

Self-estimated wayfinding ability also doesn't yield expected effect on Route Knowledge Test (see Figure 4.18). The difference of sketching scores doesn't achieve significance by *Kruskal-Wallis Test* (x^2 =7.363, p=0.118) and by *Pearson's Correlation* (r=0.117, p=0.118) (Table 4.15 and Table 4.16).

Figure 4.18 The mean sketching score for different wayfinding ability score



Self-Estimated Wayfinding Ability in Daily Life：

0—Very Poor **1**—Poor **2**—Fair **3**—Good **4**—Very Good

Table 4.15 The Kruskal-Wallis Test for sketching score of different wayfinding ability score

Kruskal-Wallis Test

Ranks

	wayfinding	N	Mean Rank
route	1	27	94.02
	2	63	87.07
	3	48	86.48
	4	42	97.98
	Total	180	

Test Statistics[a,b]

	route
Chi-Square	2.936
df	3
Asymp. Sig.	.402

a. Kruskal Wallis Test

b. Grouping Variable: wayfinding ability

Self-Estimated Wayfinding Ability Score:

0—Very Poor 1—Poor 2—Fair

3—Good 4—Very Good

Table 4.16 The Pearson's Correlation for sketching score and self-estimated wayfinding ability score

Pearson's Correlation

		route	wayfinding
route	Pearson Correlation	1	.058
	Sig. (2-tailed)		.436
	N	180	180
wayfinding	Pearson Correlation	.058	1
	Sig. (2-tailed)	.436	
	N	180	180

4.2.3 Survey Knowledge Test

As expected, males (M = 5.73, SD = 1.824, n = 111) performed better than female (M = 5.42, SD = 2.047, n = 69) in Survey knowledge Test (see Figure 4.19).

Figure 4.19 The mean location placement score for each sex

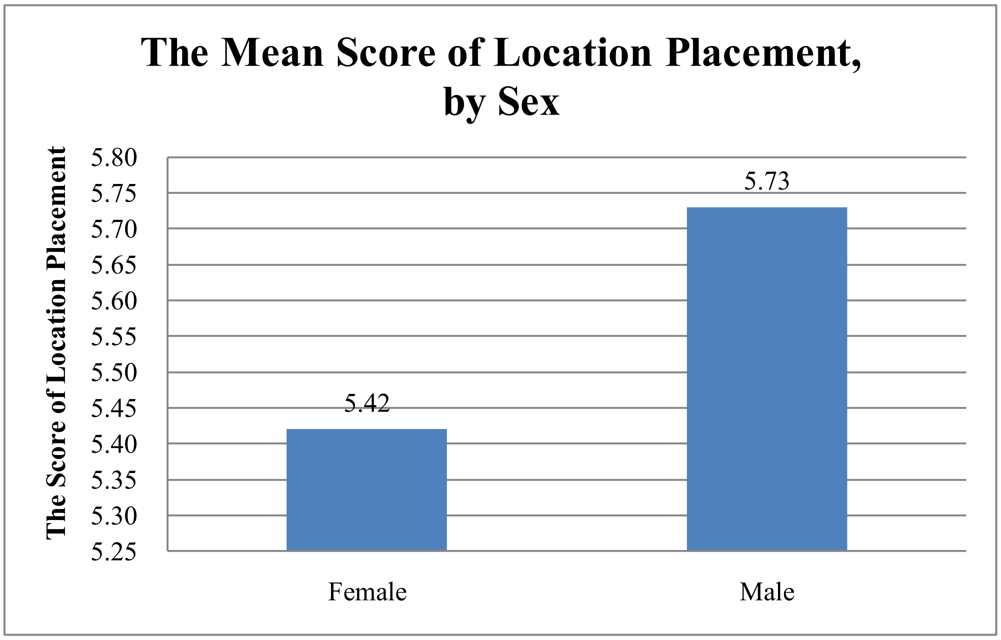


Table 4.17 indicated the results analyzed by *Mann-Whitney Test*, the score difference of location placement by sex isn't statistically significant (Z=-0.957, p=0.339).

Table 4.17 Mann-Whitney Test for location placement score of each sex

Mann-Whitney Test

Ranks

	sex	N	Mean Rank	Sum of Ranks
location	0	69	86.28	5953.50
	1	111	93.12	10336.50
	Total	180		

Sex: 0-female 1-male

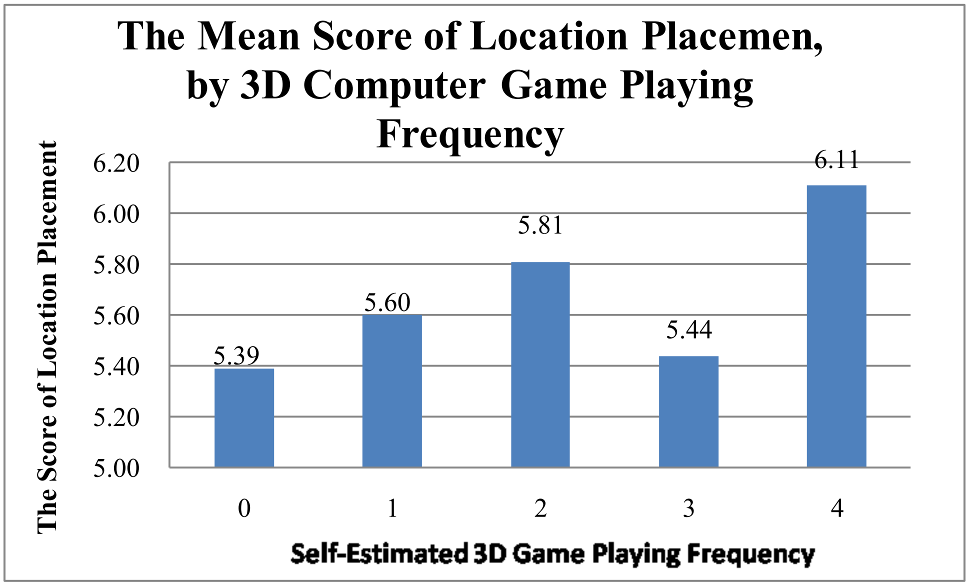
Test Statistics[a]

	location
Mann-Whitney U	3.538E3
Wilcoxon W	5.954E3
Z	-.957
Asymp. Sig. (2-tailed)	.339

a. Grouping Variable: sex

For game playing frequency, the pattern is not clear but in general as frequencies of game playing increased location placement score increased (Figure 4.20). However this difference doesn't achieve significance by *Kruskal-Wallis Test* (x^2=2.982, p=0.561) and the correlation between them doesn't achieve significance by *Pearson's Correlation* (r=0.122, p=0.102) (Table 4.18 and Table 4.19).

Figure 4.20 The mean location placement score for different game playing frequency



Self-Estimated 3D Game Playing Frequency:

0— Never; **1**— 1-3 times; **2**— about every other week;

3— about once per week; **4**— 2 or more times per week

Table 4.18 The Kruskal-Wallis Test for location placement score of different game 3d playing frequency

Kruskal-Wallis Test

Ranks

	game	N	Mean Rank
location	0	75	85.35
	1	42	89.17
	2	27	96.87
	3	9	87.67
	4	27	101.46
	Total	180	

Test Statistics[a,b]

	location
Chi-Square	2.982
df	4
Asymp. Sig.	.561

a. Kruskal Wallis Test

b. Grouping Variable: game

Table 4.19 The Pearson's Correlation for location placement score and 3d game playing frequency

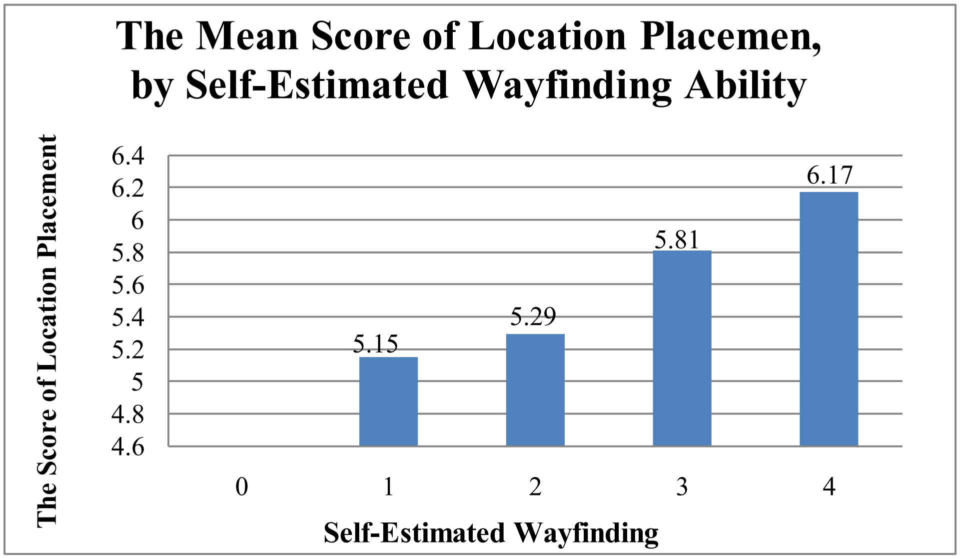
Pearson's Correlation

Correlations

		location	game
location	Pearson Correlation	1	.122
	Sig. (2-tailed)		.102
	N	180	180
game	Pearson Correlation	.122	1
	Sig. (2-tailed)	.102	
	N	180	180

As Figure 4.21 and Table 4.21 shown, The Location Placement Score increased as the score of participants' self-estimated wayfinding ability increased (r = 0.2, p = 0.002). This effect doesn't achieve statistical significance by Kruskal-Wallis Test, but it is pretty close to the margin (x^2 =7.748, p=0.052) (see Table 4.20). That is to say, the one who described themselves with higher wayfinding ability performed better in Survey Knowledge Acqusition.

Figure 4.21 The mean location placement score for different wayfinding ability score



Self-Estimated Wayfinding Ability in Daily Life：

0—Very Poor **1**—Poor **2**—Fair **3**—Good **4**—Very Good

Table 4.20 The Kruskal-Wallis Test for location placement score of different wayfinding ability score

Kruskal-Wallis Test

Ranks

	wayfinding	N	Mean Rank
location	1	27	75.87
	2	63	83.65
	3	48	97.46
	4	42	102.23
	Total	180	

Test Statistics[a,b]

	location
Chi-Square	7.748
df	3
Asymp. Sig.	.052

a. Kruskal Wallis Test

b. Grouping Variable: wayfinding ability

Table 4.21 The Pearson's Correlation for wayfinding ability score and location placement score

Pearson's Correlation

Correlations

		location	wayfinding
location	Pearson Correlation	1	.200**
	Sig. (2-tailed)		.007
	N	180	180
wayfinding	Pearson Correlation	.200**	1
	Sig. (2-tailed)	.007	
	N	180	180

**. Correlation is significant at the 0.01 level (2-tailed).

4.2.4 Overall Spatial Performance Score

On the Overall Wayfinding Performance Measure (Figure 4.22), males' score (M = 0.774, SD = 0.148, n = 111) is slightly higher than females' (M = 0.757, SD = 0.163, n = 69). However, the difference is not statistically significant by *Mann-Whitney Test* (Table 4.22).

Figure 4.22 The mean of overall performance score for each sex

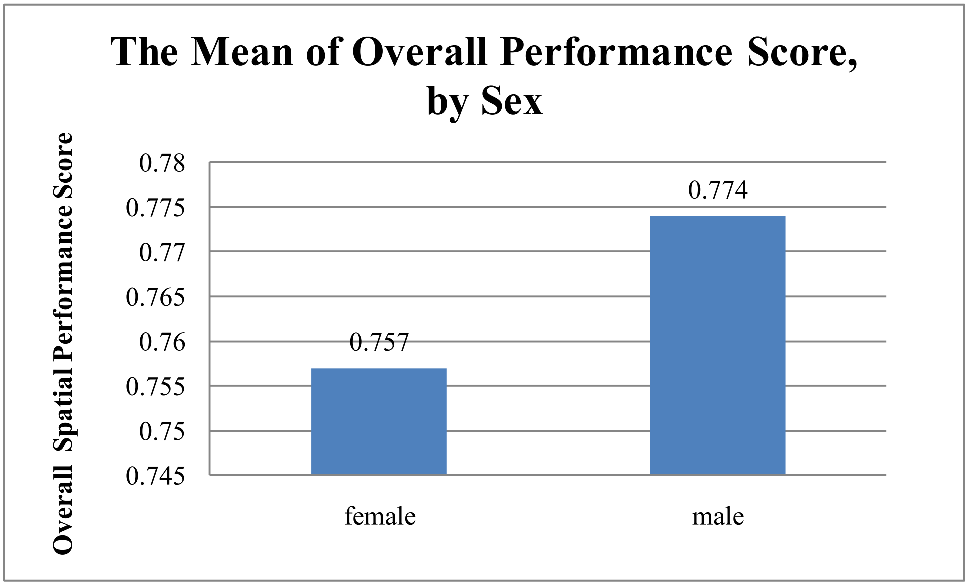


Table 4.22 Mann-Whitney Test for overall performance score of each sex

Mann-Whitney Test

Ranks

	sex	N	Mean Rank	Sum of Ranks
Overall Score	0	69	87.65	6048.00
	1	111	92.27	10242.00
	Total	180		

Sex: 0- female 1- male

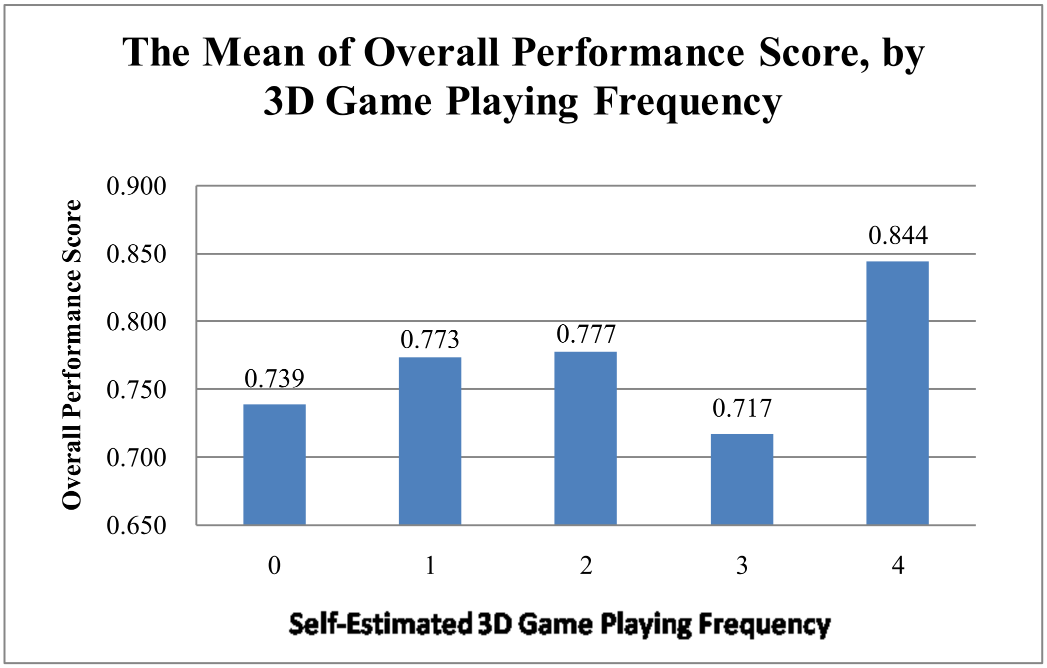
Test Statistics[a]

	OverallScore
Mann-Whitney U	3633.000
Wilcoxon W	6048.000
Z	-.578
Asymp. Sig. (2-tailed)	.563

a. Grouping Variable: sex

For 3d game playing, in general more frequent game players have higher overall performance scores than less frequent game players (Figure 4.23).

Figure 4.23 The mean of overall performance score for different 3d game playing frequency.



Self-Estimated 3D Game Playing Frequency：

0— Never; **1**— 1-3 times; **2**— about every other week;

3— about once per week; **4**— 2 or more times per week

As shown from Table 4.23 and Table 4.24, the effect of game playing frequency on overall wayfinding performance doesn't achieve statistical significance (x^2=9.243, p=0.055) but the correlation between them is significantly strong (r=0.197, p=0.008).

Table 4.23 The Kruskal-Wallis Test for overall performance score of different 3d game playing frequency.

Kruskal-Wallis Test

Ranks

	game	N	Mean Rank
OverallScore	0	75	81.80
	1	42	89.50
	2	27	94.33
	3	9	79.11
	4	27	116.19
	Total	180	

Test Statistics[a,b]

	OverallScore
Chi-Square	9.243
df	4
Asymp. Sig.	.055

a. Kruskal Wallis Test

b. Grouping Variable: game

Table 4.24 The Pearson's Correlation for overall performance score and 3d game playing frequency.

Pearson's Correlation

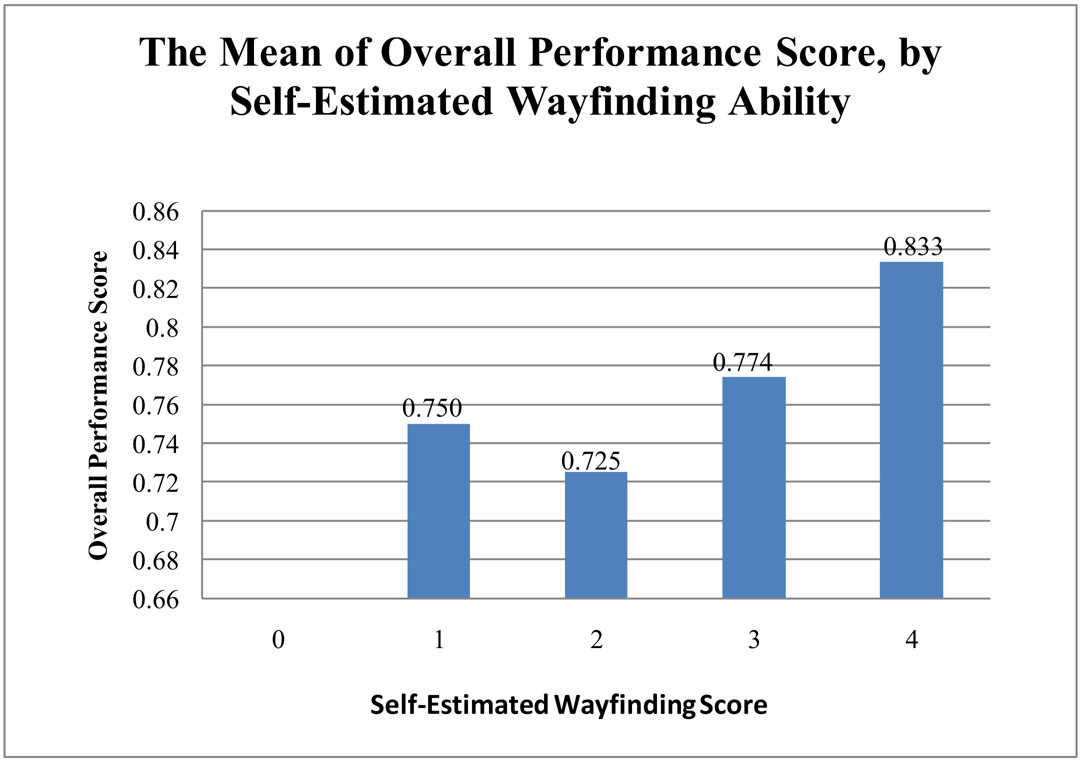
correlations

		OverallScore	game
OverallScore	Pearson Correlation	1	.197**
	Sig. (2-tailed)		.008
	N	180	180
game	Pearson Correlation	.197**	1
	Sig. (2-tailed)	.008	
	N	180	180

**. Correlation is significant at the 0.01 level (2-tailed).

For wayfinding ability, in general participants with higher wayfinding ability are associated with higher overall performance scores than those with lower wayfinding ability (Figure 4.24).

Figure 4.24 The mean of overall performance score for different wayfinding ability score



Self-Estimated Wayfinding Ability in Daily Life：

0—Very Poor **1**—Poor **2**—Fair **3**—Good **4**—Very Good

In addition, the *Kruskal-Wallis Test* shows that the difference of overall performance by different wayfinding ability is statistically significant (x^2=14.697, p=0.002). The *Pearson's Correlation* indicates the overall performance and wayfinding ability are strongly correlated (r=0.229, p=0.002).

Table 4.25 The Kruskal-Wallis Test for overall performance score of different wayfinding ability score

Kruskal-Wallis Test

Ranks

	wayfinding	N	Mean Rank
OverallScore	1	27	78.59
	2	63	78.29
	3	48	91.19
	4	42	115.69
	Total	180	

Test Statistics[a,b]

	OverallScore
Chi-Square	14.697
df	3
Asymp. Sig.	.002

a. Kruskal Wallis Test

b. Grouping Variable: wayfinding ability

Table 4.26 The Pearson's Correlation for wayfinding ability score and overall performance score

Pearson's Correlation

correlations

		OverallScore	wayfinding
OverallScore	Pearson Correlation	1	.229**
	Sig. (2-tailed)		.002
	N	180	180
wayfinding	Pearson Correlation	.229**	1
	Sig. (2-tailed)	.002	
	N	180	180

**. Correlation is significant at the 0.01 level (2-tailed).

4.3 Relation between Different Measures of Wayfinding Performance

Multi-measures of wayfinding performance was used and people were asked to find the shortest route to a destination (Navigation Test), to mark the traveled location on corresponding layout (Survey knowledge Test) and to draw the route between locations (Route Knowledge Test). Responses on each task, should relate to one another, because they all measure the same construct, wayfinding performance (spatial knowledge). *Pearson's Correlation* supported the expectation (Table 4.27).

Table 4.27 Navigation Time, Route Sketching and Location Placement scores have a statistically significant correlation with one another

Pearson's Correlation

		time	route	location
time	Pearson Correlation	1	-.176*	-.176*
	Sig. (2-tailed)		.018	.018
	N	180	180	180
route	Pearson Correlation	-.176*	1	.376**
	Sig. (2-tailed)	.018		.000
	N	180	180	180
location	Pearson Correlation	-.176*	.376**	1
	Sig. (2-tailed)	.018	.000	
	N	180	180	180

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Navigation Time is negatively correlated with Route Sketching Scores (r= -0.176, p<0.05) and Location Placement Scores (r= -0.176, p<0.05). That is to say, participants who spent less time in navigating test also did well on spatial knowledge tests.

Route knowledge Score and Survey Knowledge Score has a quite strong positive correlation with each outer (r=0.376, p<0.001). Participants, who were more successful to reconstitute the route, were also successful to place store names in the correct location.

4.4 Correlation between Test Times and Wayfinding Performance

In this study, each participant had been tested three times. The test sequence for each person was Model 1----Model 2----Model 3 among the four environment groups. It seems to have a relation between the performance and test times, either better or poorer as the test time increased.

As expected, the Pearson's Correlation shows there is some significant correlations between tested times and several wayfinding performance scores.

As the test times increase, the Navigation time for Task 1 and Total Navigation time decreases, the Location Placement Score increases.

The correlation between test times and Overall Score is not significant but it also shows a trend that the performance is improved as the number of test time increase.

Table 4.28 Correlation between Test Times and Wayfinding Performance

Pearson's Correlation

		test times	time1	time2	total time	route	location	Overall score
test times	Pearson Correlation	1	-.298**	.018	-.202**	-.042	.150*	.101
	Sig. (2-tailed)		.000	.806	.007	.575	.045	.175
	N	180	180	180	180	180	180	180

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

It may be due to that participants are more familiar and adapted with the operation of virtual environment during navigating from Model 1 to Model 3. Therefore, familiarity produced significant effects on several tests. Wayfinding performance is enhanced associate with the increase of test times.

5. Conclusion

The main objective of this research is to explore the spatial factors (e.g., landmark, path surfacing, and corridor width) that may influence wayfinding performance. It is expected that wayfinding performance should be enhanced if these factors are considered and designed optimally. It is hoped that people will navigate more easily and efficiently in the environment with more spatial differentiations, and individual differentiations will also influence the result.

Based on the previous studies, two sets of hypotheses were proposed. The first set of hypotheses was designed to investigate the effect of physical factors. Three spatial differentiations were studied: *horizontal differentiation* (path surfacing), *vertical differentiation* (landmark) and *both horizontal and vertical differentiations* (corridor width). The second set of hypotheses was aimed at evaluating the effect of the personal factors of sex, declared wayfinding ability and game-playing frequency. Both hypotheses were empirically tested.

This experiment was undertaken to explore the differences in navigation time and spatial knowledge acquisition. Spatial knowledge was evaluated through the completion of two tests: itinerary replication and location placement on a layout of the virtual environment. The results were then analyzed to determine if there was a significant difference between the performances of Original Group, Width Group, Surfacing Group and Landmark

Group. Group scores were analyzed by *Kruskal-Wallis Test, Mann-Whitney Test* and *Pearson's Correlation*.

The experimental results showed that the two hypotheses were both supported. The experimental results are summarized in the next section.

5.1 The Effect of Spatial Differentiations on Wayfinding Performance

For physical environmental characteristics, the results for the overall measure of spatial awareness supported the hypothesis that lack of differentiation led to poor wayfinding performance. Results showed that people who navigated in Environment with Horizontal Differentiation (different path surface) did better than Environment with Vertical Differentiation (landmarks) and Environment without differentiation (origin) for the overall spatial performance.

The Navigation Time measure differed significantly for the four environment groups but the result didn't parallel the Overall Performance Measure. People in Landmark Group spent less time than other groups, which indicated that Vertical Differentiation imposed the most positive influence on the actual navigation performance.

Sketching scores paralleled the results of the Navigation Time but the difference didn't achieve statistical significance. For the Location Placement Test, the environment with both Horizontal and Vertical Differentiation (different corridor width) yielded the best performance. The difference was only significant for Width Group and Original Group. It didn't differ significantly among other groups.

This may suggest that Vertical Differentiation (landmarks) is more effective than Horizontal Differentiation (road surfacing and width) for the real navigating performance and the route knowledge acquisition, but the Horizontal Differentiation (road surfacing) is more effective than Vertical Differentiation (landmarks) in the survey knowledge acquisition.

These results supported the existing literature suggesting that vertical differentiations (landmarks) are the memorable cues that are selected along a path, particularly in learning and recalling turning points along the path (Sorrows and Hirtle, 1999) so is more effective for route knowledge acquisition. Horizontal differentiations (path variation) enable pedestrians to encode spatial relations between objects and paths, enhancing the development of a cognitive map of a region so is more effective on survey knowledge acquisition (Sorrows and Hirtle, 1999, Golledge, 1999).

Physical differentiations provide key information about the relationships of locations, objects and paths (Sorrows and Hirtle, 1999). The use of physical differentiations to build survey knowledge of the environment enables one to orient oneself in space, to develop new routes, and to discriminate features of a region.

Table 5.1 The results of the effects of spatial differentiations on various tests of wayfinding performance.

The Test	The Performance*	Statistic Significance**
Navigation Test	Origin < Width < Surfacing < Landmark	S
Route Knowledge Test	Origin < Width < Surfacing < Landmark	
Survey Knowledge Test	Origin < Landmark < Surfacing < Width	S^w
Overall Performance	Origin < Width < Landmark < Surfacing	S

* Poor performance < good performance
** S - Significant. S^w - significance only between Width and Origin Group

5.2 The Effect of Personal Factors on Wayfinding Performance

For individual characteristics, as expected, on the overall measure Males performed better than Females but the difference was not significant (*Mann-Whitney Test*), Performance improved with Game Playing Frequency and Self-Estimated Wayfinding Ability (*Pearson's Correlation*). On specific measures, Males did better than Females on Navigation Test and Survey Knowledge Test, but Females were more successful than Males on Route Knowledge Test.

As Self- Estimated Wayfinding Ability Score increased, Navigation Time reduced and Location Placement Scores improved. Increases in Game Playing Frequency were associated with decreases in Navigation Time (*Pearson's Correlation*). However, there was not a clear effect of Game Playing and Wayfinding Ability on Route Sketching Test.

The failure to verify statistical significance on Route Sketching Test may be related to the confounding effect between game playing, wayfinding ability and sex. The data showed that males tended to play computer games more often than females and males estimated their wayfinding ability higher than females. The significant effect of game playing and wayfinding ability on sketching test might have masked the effect of gender on sketching test. And also, the scores are overall high perhaps because the question is kind of simple for most participants.

Table 5.2 The results of the effects of personal characteristics on various tests of wayfinding performance.

The Test	The Performance*		
	Sex	Game Playing Frequency	Wayfinding Ability
Navigation Test	Male > Female	Less frequent < More frequent	Low ability < high ability
Route Knowledge Test	Female > Male	No Significant Correlation	No Significant Correlation
Survey Knowledge Test	Male > Female	No Significant Correlation	Low ability < high ability
Overall Performance	Male > Female	Less frequent < More frequent	Low ability < high ability

* Poor performance < good performance

5.3 Correlation among three Wayfinding Measures (Time Spent, Route Knowledge and Survey Knowledge Acquisition) and Tested Times

Calculating *Pearson's Correlation* revealed a number of significant correlations between various measures adopted in the tests.

1. Participants who performed better on the Navigation Test (spent less time) also performed well on spatial knowledge tests. There are negative correlations between time participants spent in the V.E. and their Route Sketching Scores ($r= -0.176$, $p<0.05$) and Location Placement Scores ($r= -0.176$, $p<0.05$).

2. Predictably strong positive correlation was also found between Route knowledge Score and Survey Knowledge Score ($r=0.376$, $p<0.001$). Participants, who were better able to reconstitute the route, are also better able to place store names in the correct location.

3. All results from the three tests are strongly correlated, although these tests are designed to measure different aspects of wayfinding performance (time spent, route knowledge, and survey knowledge). The strong correlation among these measures suggests that different wayfinding performance measures cannot be exclusively tested and analyzed.

5.4 Correlation between Tested Times and Wayfinding Performance

Pearson's Correlation also shows there is some significant correlations between tested times and several wayfinding performance scores. As the test times increase, the

Navigation time for Task 1 and Total Navigation time decreases, the Location Placement Score increases. The correlation between test times and Overall Score is not significant but it also shows a trend that the performance is improved as the number of test times increases. It may be due to participants being more familiar and adapted to the operation of the virtual environment having progressed from Model 1 to Model 3. Therefore, familiarity and experience positively influence performance.

6. Recommendation and Implication

6.1 Recommendations for Future Research

Future research on physical factors should test for other physical factors, such as floor plan, visibility and colours, all of which may affect wayfinding. Even for landmarks this study only tested *local* landmarks; future research should also look at the *global* landmarks.

In addition, the measures of navigation time include a confounding effect. When people travel in the differentiated environments, even though they know the route and the direction, they may stop to observe the differentiation. When calculating the navigation time, future research should control the difference between stopping to look at the differentiation and stopping due to the confusion about the route to follow.

During the process of Navigation Test, I also found that some participants preferred to just explore some specific locations required by the instruction and some preferred to explore everywhere to learn the whole environment. The adoption of different wayfinding strategy can also affect the navigating time.

Furthermore, there may also exist confounding effects between game playing, wayfinding ability and sex. Therefore, future work needs to test males and females with similar levels of game playing experience, wayfinding ability and wayfinding strategy.

6.2 Implications for Environmental Design and Planning

For planners and designers, understanding the effect of physical factors is more important than understanding the effect of personal factors, as the effect size for personal characteristics is relatively smaller.

There are many different devices in environmental design to aid wayfinding. Some devices are used consciously like signs or maps. But many other devices are used more subconsciously, such as prominent landmarks, distinct road pavement or other architectural differentiations. These more subtle devices can be an effective solution to guiding pedestrians along preferred routes within an indoor environment if they are designed with wayfinding in mind.

My research demonstrated that physical differentiations enhance pedestrians' wayfinding performance and spatial knowledge acquisition. Furthermore, Abu-Ghazzeh (1996) also described the unusual appearance of the University, which contains a set of buildings with nearly identical external architecture and internal floor plans. His research showed that the uniform visual nature of the space made the environment extremely difficult and frustrating to learn and navigate (Abu-Ghazzeh, T. M., 1996).

Therefore, the environment should be shaped with clear differentiation rather than neutral and monotonous, so that pedestrians can get oriented easily and will spend less time in navigation and acquire more useful spatial knowledge.

For vertical differentiation, put landmarks at important decision points to help pedestrians to verify their choice or remind them of a desired destination nearby.

For the horizontal differentiation, add the hierarchy of route and highlight the main route. The main route should have the wider corridor, higher ceiling and distinct surfacing; it should traverse or lead to the minor routes and connect the important locations and landmarks.

Designers and planners can use the V.E. technology to test and refine designs. It allows researcher to easily control physical factors. Although the real underground environments are more complex than the virtual environments used in this experiment, they are composed by a series of simple unit. Therefore, we can understand a complex entirety from the details of each component part.

As to the entire design of underground space, the district, edge, path, node and landmark should compose an organic and well cognized system. The interior layout should produce one, even series of distinctive images to reinforce the cognitive map in people's mind. That is to say, physical space is considered as a hierarchical systems composed by different units and each unit should have a trait that can be identified by the majority of people. It should reach a level where one can clearly describe a place to wayfinders using only a few words and following a logical sequence.

In all types of environments, whether open terrain or networked space, physical differentiations provide key information about the relationships of locations, objects and paths, and are used in active navigation and in orientation tasks. The use of physical differentiations to build survey knowledge of the environment enables one to orient oneself in space, to develop new routes, and to discriminate features of a region.

Landmarks are cues along a path to a goal and provide global understanding of the environment. Clearly defined and well-lit pathways will control the flow of people much more intuitively than a directional sign. But signs are needed at key decision points for reassurance and confirmation. The success of an environment relies on all environmental features working together to give the same wayfinding message, through an integrated design approach and holistic strategy.

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8. Appendices

8.1 Appendix A: Experiment Introduction NO.________

1. Experiment Procedure Introduction

This experiment includes three parts. The first one is the Learning Phase about the virtual exploration scene. The second part is Wayfinding Task Execution Phase which includes Task 1 and Task 2. The third part is Spatial Knowledge Test phase, including route, store or landmark identification.

You will take the whole experiment under the condition of three different but equivalent virtual environments separately.

All the information collected is ONLY used for an academic dissertation. It will not be released to the public without your permission.

2. Experiment Scene Introduction

In the following virtual scene, please execute the designated task in turns according to the instruction and watch out the spatial layout of the virtual environment.

Basic operation of the movement in the experiment:

Key	Function
left arrow	turn left
right arrow	turn right
up arrow	forward
down arrow	backward

3. Experiment Scene Practice

Please use the direction arrows (left, right, up and down arrow) to explore the environment for practice and familiarize yourself with the mode of operation.

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4. **Wayfinding Task Execution Phase – Task 1**

Task Instruction

Now imagine that you are in a shopping mall on a weekend afternoon. There are many different kinds of stores in this mall, such as book store, computer store, and supermarket and so on, and you are supposed to meet your friends in front of the **bank.** When you get to the bank, you find that others are late and only Mike and you are punctual. As you feel a bit thirsty and hot, you go to the **ice cream bar** to buy some cool drinks and then return to the bank share it with Mike. When you two are enjoying the drink, you suddenly remember that today is Tom's Birthday. Therefore, you decide to go to the **book store** to buy a birthday card for Tom before he comes. After buying the card, you return to the bank and find others still not come. At this time, Mike feels hungry and asks you to buy him something to eat and he keeps waiting at the bank. Thus, you go to the **hotdog stand**, buy a hotdog and bring it back to Mike.

There is no time limit for this task and you must execute it in turns.

Note:

When you are executing the task, please explore each store of the mall as thoroughly as possible and remember the location of each store as you can because you will be required to describe the location of each store.

Task Procedure

1. Start from Entrance, Go to **Bank** to withdraw money

2. Start From Bank, Go to **Ice Cream** Bar to buy a cool drink, Return to **Bank**

3. Start from Bank, Go to **Book Store** to buy a birthday car, Return to **Bank**

4. Start from Bank, Go to **Hotdog Stand** to **buy** a hotdog, Return to **Bank**, task finished.

--- Please read the next page if finished ---

4. Wayfinding Task Execution Phase – Task 2

Task Instruction

When you finish all of the task above, your friend Kate call you that she is lost and will wait for you at the entrance of the mall. You soon get to the entrance and take Kate to the bank. Kate is so tired, thirsty and hungry so you immediately go to the ice cream bar to buy a cool drink, go to the book store to buy a birthday card, go to the hotdog stand to buy a hotdog and then take all of these back to the bank.

Kate is very hungry so please execute the task as fast as possible.

Task Procedure

Start from Entrance -- Go to Bank to withdraw money -- Go to Ice Cream Bar to buy a cool drink -- Go to Book Store to buy a birthday car -- Go to Hotdog Stand to buy a hotdog -- Return to Bank -- task finished.

Time spent for Task 1 ____________________

Time spent for Task 2 ____________________

--- Task Finished ---

Please continue the next step

8.2 Appendix B: Answer Sheet for Route Knowledge Test No.2_____

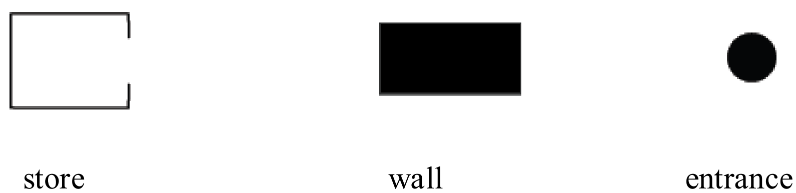
When you have managed to go back to the bank, you receive a call from Tom. He is at the Hotdog Stand and asks you how to get to the bank. Therefore, you need to tell Tom how to go from the Hotdog Stand to the bank to meet with other friends.

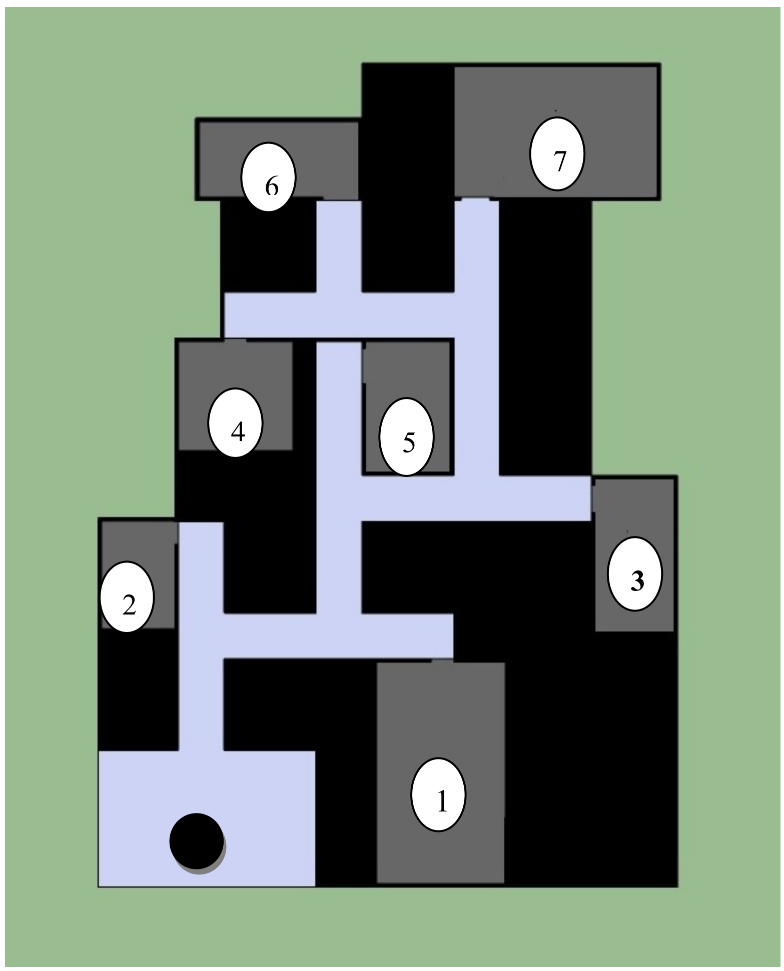
Now please recall the route from the hotdog stand to the bank and then describe it by word, sentence (for example, go out and turn left at the T-junction, then go straight…) or sketching.

8.3 Appendix C: Answer Sheet for Survey Knowledge Test

Appendix C-1 **NO.________**

Please illustrate the correct location of each store on the floor plan from your memory of the shopping mall. Just write the name of the store on its location



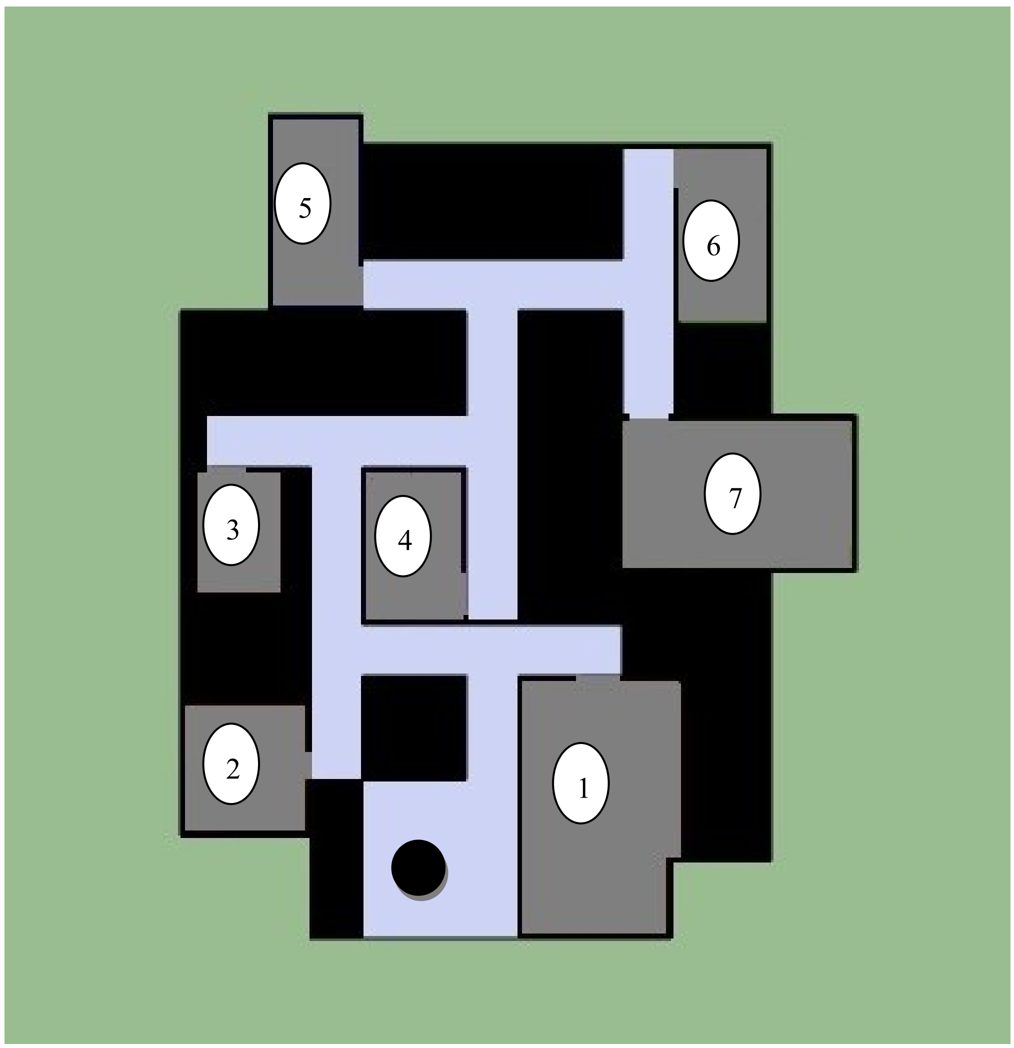


Model 1

Appendix C-2 NO.________

Please illustrate the correct location of each store on the floor plan from your memory of the shopping mall. Just write the name of the store on its location

store wall entrance

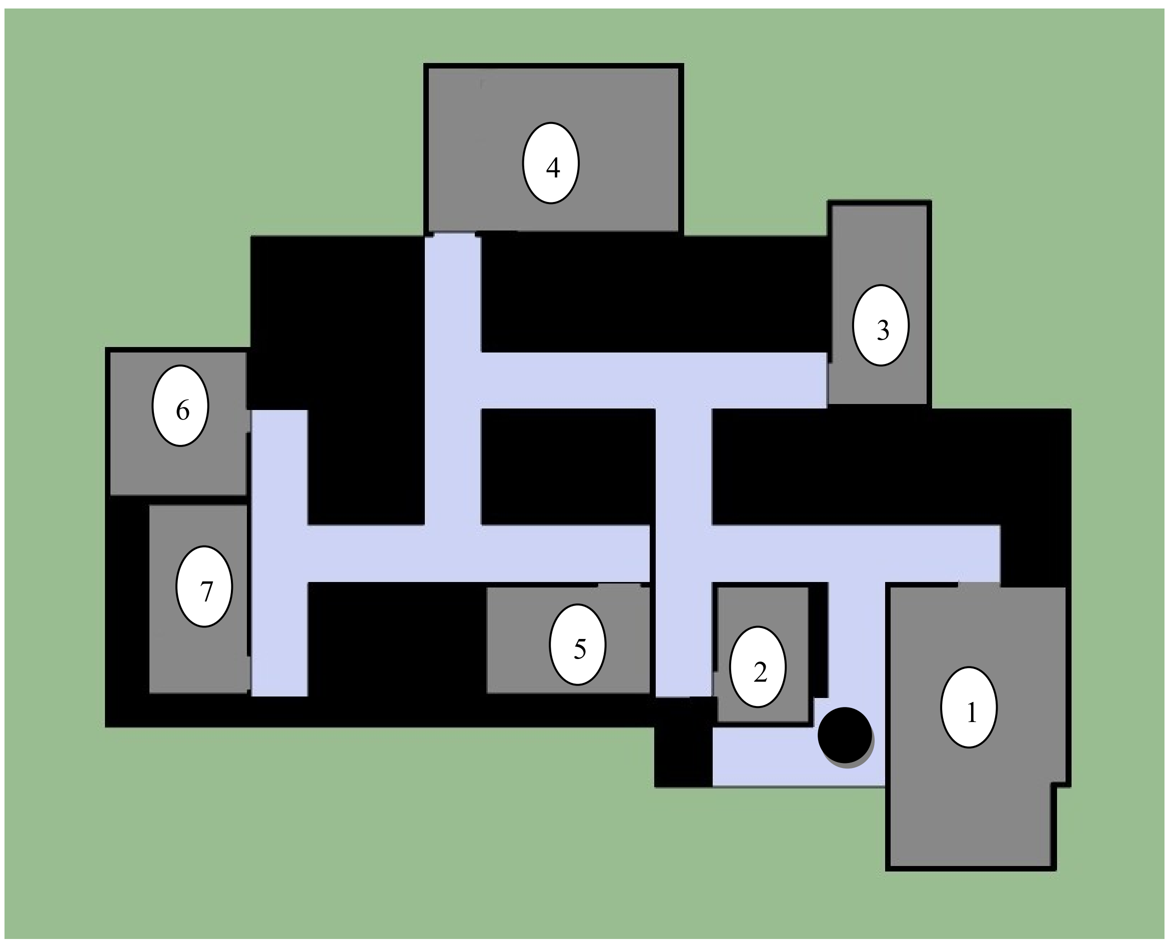


Model 2

Appendix C-3 **NO.________**

Please illustrate the correct location of each store on the floor plan from your memory of the shopping mall. Just write the name of the store on its location

store wall entrance



Model 3

8.4 Appendix D: Personal Information

1. Gender： □Male □Female

2. During a typical quarter, how many times do you play 3D computer games?

□Never □1-3 times □About every other week

□About once per week □2 or more times per week

3. How do you think of your wayfinding ability in daily life?

□Very Poor □Poor □Fair □Good □Very Good

Experiment is now completed. Thank you again for your participation.

8.5 Appendix E: The logging data of each test for each environment group

Group	time1	time2	time	sketch	location	sex	game	Wayfind	OverallScore
4	3.367	2.783	6.150	2	7	0	0	4	0.960
4	3.467	3.483	6.950	2	2	0	1	2	0.756
4	8.317	2.017	10.334	2	5	0	1	4	0.835
4	7.050	3.267	10.317	2	7	0	4	1	0.884
4	11.450	2.400	13.850	2	7	1	1	2	0.842
4	8.083	2.683	10.766	2	4	0	1	1	0.780
4	8.067	4.350	12.417	2	7	1	0	3	0.830
4	5.067	3.233	8.300	2	2	0	0	3	0.739
4	7.067	2.517	9.584	2	5	1	1	4	0.838
4	10.567	4.250	14.817	2	5	0	1	1	0.721
4	7.733	2.317	10.050	2	7	1	4	4	0.905
4	9.367	2.733	12.100	2	4	1	0	1	0.757
4	8.733	3.417	12.150	2	4	1	4	2	0.744
4	11.933	4.600	16.533	2	5	0	1	2	0.687
4	2.667	1.967	4.634	2	7	1	4	4	1.000
4	4.667	3.133	7.800	2	5	0	0	4	0.856
4	5.483	2.667	8.150	2	4	0	1	2	0.823
4	6.967	3.417	10.384	1	5	0	1	4	0.683
4	7.017	2.833	9.850	2	7	0	4	1	0.899
4	6.467	2.817	9.284	2	1	1	1	2	0.694
4	6.567	4.117	10.684	2	3	0	1	1	0.719
4	7.267	3.487	10.754	1	7	1	0	3	0.747
4	7.367	5.767	13.134	1	1	0	0	3	0.453
4	6.983	4.033	11.016	0	2	1	1	4	0.430
4	11.783	4.650	16.433	2	7	0	1	1	0.759
4	5.967	3.167	9.134	1	5	1	4	4	0.708
4	6.183	4.583	10.766	2	4	1	0	1	0.745
4	9.050	4.133	13.183	2	7	1	4	2	0.821
4	12.667	5.617	18.284	2	7	0	1	2	0.711
4	2.850	2.167	5.017	2	7	1	4	4	0.990
4	3.650	3.267	6.917	2	7	0	0	4	0.939
4	3.767	2.500	6.267	1	6	0	1	2	0.803
4	4.450	3.817	8.267	1	7	0	1	4	0.782
4	5.430	3.300	8.730	2	7	0	4	1	0.909
4	4.067	2.717	6.784	2	5	1	1	2	0.880

Group	time1	time2	time	sketch	location	sex	game	Wayfind	OverallScore
4	8.850	3.433	12.283	2	7	0	1	1	0.849
4	4.717	3.333	8.050	2	5	1	0	3	0.848
4	4.833	6.717	11.550	2	5	0	0	3	0.729
4	4.417	4.150	8.567	2	4	1	1	4	0.789
4	6.867	3.300	10.167	2	7	0	1	1	0.885
4	4.150	3.183	7.333	2	7	1	4	4	0.934
4	4.700	2.917	7.617	2	5	1	0	1	0.863
4	7.650	3.317	10.967	2	7	1	4	2	0.872
4	7.650	4.100	11.750	2	7	0	1	2	0.845
4	2.980	2.167	5.147	2	7	1	4	4	0.988
3	8.400	2.567	10.967	2	7	0	0	3	0.886
3	10.033	4.733	14.766	2	2	1	0	2	0.606
3	8.400	2.500	10.900	1	3	0	0	3	0.620
3	7.833	2.433	10.266	1	7	1	0	2	0.775
3	7.833	4.083	11.916	2	7	1	1	2	0.843
3	5.683	3.183	8.866	2	3	1	2	2	0.766
3	9.367	2.683	12.050	2	7	1	0	4	0.866
3	6.683	2.833	9.516	2	4	1	0	3	0.797
3	7.200	5.750	12.950	2	7	1	0	3	0.796
3	7.583	4.517	12.100	2	7	1	0	4	0.832
3	7.683	2.433	10.116	2	7	1	1	2	0.902
3	6.633	2.583	9.216	2	7	1	4	4	0.914
3	5.583	4.533	10.116	2	7	1	0	4	0.864
3	6.700	2.617	9.317	2	7	1	2	2	0.912
3	9.533	4.683	14.216	2	7	0	1	2	0.794
3	5.383	2.467	7.850	2	7	0	0	3	0.938
3	5.700	3.067	8.767	1	5	1	0	2	0.716
3	9.783	2.550	12.333	2	7	0	0	3	0.864
3	8.433	6.850	15.283	0	3	1	0	2	0.345
3	6.017	7.533	13.550	2	5	1	1	2	0.682
3	7.406	4.183	11.589	2	4	1	2	2	0.739
3	6.567	3.433	10.000	2	7	1	0	4	0.886
3	8.053	5.167	13.220	0	7	1	0	3	0.552
3	5.700	4.833	10.533	2	7	1	0	3	0.852
3	7.033	5.567	12.600	2	5	1	0	4	0.733
3	5.567	4.433	10.000	2	7	1	1	2	0.868
3	5.900	4.117	10.017	1	5	1	4	4	0.677

Group	time1	time2	time	sketch	location	sex	game	Wayfind	OverallScore
3	7.250	2.333	9.583	2	7	1	0	4	0.913
3	4.250	2.533	6.783	1	7	1	2	2	0.830
3	6.933	2.033	8.966	2	7	0	1	2	0.928
3	5.200	2.617	7.817	2	7	0	0	3	0.936
3	8.517	3.100	11.617	2	7	1	0	2	0.865
3	7.783	3.383	11.166	2	1	0	0	3	0.653
3	6.850	4.883	11.733	0	3	1	0	2	0.438
3	6.850	3.283	10.133	2	7	1	1	2	0.886
3	8.163	3.717	11.880	2	7	1	2	2	0.850
3	7.850	3.683	11.533	2	7	1	0	4	0.856
3	6.967	3.565	10.532	0	5	1	0	3	0.553
3	7.567	6.550	14.117	2	7	1	0	3	0.762
3	6.683	5.083	11.766	2	6	1	0	4	0.791
3	5.083	3.200	8.283	2	7	1	1	2	0.918
3	5.250	2.052	7.302	2	5	1	4	4	0.883
3	6.833	2.000	8.833	2	7	1	0	4	0.931
3	5.900	2.283	8.183	2	7	1	2	2	0.936
3	5.450	3.100	8.550	2	7	0	1	2	0.915
2	7.700	2.667	10.367	2	3	1	0	1	0.751
2	9.867	4.283	14.150	2	7	0	0	2	0.803
2	7.650	3.567	11.217	2	5	0	0	3	0.792
2	9.833	5.167	15.000	2	7	1	0	3	0.773
2	8.467	5.800	14.267	1	5	1	2	2	0.577
2	8.667	6.200	14.867	2	7	1	2	4	0.756
2	8.833	3.500	12.333	1	7	1	2	3	0.721
2	9.367	5.267	14.634	2	7	1	4	2	0.777
2	6.667	5.317	11.984	2	7	1	0	3	0.819
2	6.717	2.817	9.534	2	7	1	2	3	0.905
2	5.617	3.183	8.800	2	7	0	0	2	0.910
2	6.733	4.367	11.100	2	7	1	2	2	0.851
2	7.300	4.800	12.100	1	7	1	1	3	0.702
2	8.400	3.117	11.517	2	7	1	3	3	0.867
2	9.233	5.333	14.566	2	7	1	0	1	0.777
2	8.450	3.767	12.217	1	5	1	0	1	0.647
2	8.483	3.750	12.233	2	5	0	0	2	0.772
2	7.167	3.833	11.000	0	5	0	0	3	0.541
2	6.867	3.233	10.100	0	1	1	0	3	0.423

Group	time1	time2	time	sketch	location	sex	game	Wayfind	OverallScore
2	8.967	7.467	16.434	2	2	1	2	2	0.529
2	7.183	2.830	10.013	0	3	1	2	4	0.504
2	6.900	5.033	11.933	1	3	1	2	3	0.557
2	9.667	2.783	12.450	2	7	1	4	2	0.858
2	7.683	4.400	12.083	2	7	1	0	3	0.834
2	6.817	4.433	11.250	2	7	1	2	3	0.847
2	6.083	3.200	9.283	2	7	0	0	2	0.902
2	6.867	3.083	9.950	2	5	1	2	2	0.822
2	6.967	4.833	11.800	2	5	1	1	3	0.760
2	6.600	2.783	9.383	2	7	1	3	3	0.908
2	7.200	2.867	10.067	2	7	1	0	1	0.895
2	6.917	3.700	10.617	2	4	1	0	1	0.764
2	6.417	3.917	10.334	0	7	0	0	2	0.622
2	6.183	3.800	9.983	2	7	0	0	3	0.879
2	6.633	4.150	10.783	1	7	1	0	3	0.735
2	4.983	3.300	8.283	1	5	1	2	2	0.720
2	8.650	7.167	15.817	2	7	1	2	4	0.723
2	6.583	3.083	9.666	2	7	1	2	3	0.898
2	7.867	4.383	12.250	2	7	1	4	2	0.832
2	6.050	3.483	9.533	2	7	1	0	3	0.892
2	7.100	2.967	10.067	2	7	1	2	3	0.893
2	6.867	4.350	11.217	2	7	0	0	2	0.849
2	8.867	3.950	12.817	2	7	1	2	2	0.830
2	6.517	4.983	11.500	2	7	1	1	3	0.833
2	7.700	3.900	11.600	2	5	1	3	3	0.780
2	7.833	3.967	11.800	2	7	1	0	1	0.847
1	9.600	2.967	12.567	0	1	1	3	1	0.388
1	9.517	3.433	12.950	2	7	0	0	4	0.838
1	5.150	2.917	8.067	2	7	0	1	4	0.927
1	8.650	2.700	11.350	0	1	1	2	3	0.413
1	5.400	4.900	10.300	2	5	1	4	4	0.783
1	8.567	6.317	14.884	2	7	0	0	2	0.754
1	11.600	4.383	15.983	0	2	0	0	2	0.342
1	7.233	5.400	12.633	2	5	0	4	1	0.736
1	11.067	7.500	18.567	2	0	1	1	2	0.422
1	6.833	4.050	10.883	1	0	0	0	2	0.485
1	7.917	3.617	11.534	2	7	0	1	1	0.857

Group	time1	time2	time	sketch	location	sex	game	Wayfind	OverallScore
1	5.467	2.567	8.034	2	4	1	4	3	0.826
1	8.850	5.783	14.633	2	2	0	0	2	0.589
1	7.967	2.300	10.267	2	7	1	2	4	0.902
1	6.600	3.083	9.683	2	7	0	3	3	0.897
1	6.550	5.583	12.133	0	3	1	3	1	0.419
1	8.667	4.367	13.034	2	3	0	0	4	0.676
1	5.033	3.750	8.783	2	7	0	1	4	0.900
1	7.280	3.633	10.913	2	7	1	2	3	0.867
1	9.850	5.350	15.200	2	7	1	4	4	0.766
1	9.150	4.767	13.917	2	7	0	0	2	0.798
1	17.980	9.217	27.197	0	4	0	0	2	0.143
1	7.333	4.300	11.633	2	1	0	4	1	0.629
1	6.600	6.983	13.583	0	3	1	1	2	0.370
1	11.350	7.333	18.683	2	5	0	0	2	0.602
1	9.167	7.350	16.517	1	7	0	1	1	0.583
1	6.733	3.600	10.333	2	7	1	4	3	0.877
1	9.317	6.033	15.350	0	3	0	0	2	0.358
1	7.950	3.183	11.133	2	7	1	2	4	0.872
1	9.100	4.100	13.200	2	7	0	3	3	0.821
1	5.283	5.600	10.883	1	5	1	3	1	0.636
1	6.033	2.983	9.016	2	7	0	0	4	0.910
1	5.717	3.450	9.167	2	7	0	1	4	0.899
1	5.267	3.950	9.217	2	7	1	2	3	0.889
1	6.500	3.533	10.033	2	7	1	4	4	0.883
1	8.200	5.433	13.633	2	5	0	0	2	0.719
1	6.500	5.733	12.233	0	3	0	0	2	0.415
1	5.333	4.967	10.300	2	5	0	4	1	0.782
1	7.583	3.900	11.483	0	7	1	1	2	0.603
1	6.517	4.250	10.767	2	7	0	0	2	0.858
1	7.333	4.217	11.550	2	5	0	1	1	0.775
1	5.500	3.177	8.677	2	7	1	4	3	0.912
1	8.617	4.967	13.584	2	1	0	0	2	0.585
1	7.217	3.250	10.467	2	7	1	2	4	0.881
1	7.283	3.817	11.100	1	7	0	3	3	0.736

Group: 1- origin 2-width 3-surfacing 4-landmark