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Design Implications for an Indoor Navigation Map: Focusing on Vertical Movement

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Abstract

Recently, the importance of indoor positioning systems which are being developed to replace the global positioning system has increased. This is due to increases in the size of indoor space, which unlike outdoor space, is spatially limited by walls, ceilings and floors. Also, vertical movement occurs due to multi-level characteristics and this causes many people to easily lose their way indoors. Despite these differences found between indoor and outdoor environments, the number of studies on indoor navigation system was not studied far in extent. In addition, studies on indoor navigation systems have been largely technical, while consideration of map design, an important elements of an indoor navigation system, has not been a priority. This study investigated how indoor navigation maps should support users' indoor wayfinding.

In a preliminary study, a contextual inquiry, follow-up interview, and case study were conducted, resulting in six design implications: 1) design the map representation considering the essential elements of the wayfinding task 2) use appropriate criteria and the number of chunks 3) give feedback in the middle of a long straight path 4) consider giving distance information as a secondary source 5) consider individual's use of different strategies depending on the ceiling height 6) give the direction to move the floor level first. The main study considered the optimal timing for vertical movement, based on the design implications from the preliminary study. Experiments were conducted to determine whether there is a difference in people's spatial knowledge acquisition performance when a route direction is provided in an indoor navigation map by differentiating the timing for vertical movement (condition1: at the beginning, condition2: in the middle, condition3: at the end of the route). Findings indicated that the number of transitions between two maps (maps before and after floor level movement) and the difficulty to mentally connect the route between two maps were lower in condition 1 (vertical movement at the beginning) than condition2 (vertical movement in the middle). Results suggests that when designing a route, the floor should be moved at the beginning close to the starting point in indoor navigation maps.

Keywords: indoor navigation map, indoor navigation system, vertical movement, spatial knowledge, cognitive strategy,

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1. Introduction

Most people will have experienced getting lost in an unfamiliar environment at least once. For example, if you have to arrive at the boarding gate on time for a tightly scheduled flight at an airport you have never been to before, you will most likely have a very stressful experience in finding the route within a limited time. The ability to navigate is essential in human life because we frequently face situations in which we have to go to new places, such as shops, classrooms and hospitals (Prestopnik & Roskos-Ewoldsen, 2000). Wayfinding, or navigation, has been defined as the process of using the given cues in the environment to find a way to familiar or unfamiliar destinations (Lynch, 1960). Passini (1984) also described wayfinding as both a cognitive and behavioral ability to identify one's location and reach the planned destination.

For a long time, people have used maps which provide spatial information as a navigational aid to make the wayfinding process easier. As technology has developed, many kinds of navigational aids have been developed. In particular, global positioning system (GPS) technology, which uses satellite signals to provide location information, has greatly influenced navigation system research (Ishikawa, Fujiwara, Imai, & Okabe, 2008). Vehicle navigation systems, one of the most commonly-used navigation systems today, are associated with research conducted mainly to minimize driver's cognitive load while providing road guidance because even short distractions can be lead to accidents (Mashimo, Daimon, & Kawashima, 1993; Lee, Forlizzi, & Hudson, 2008) As a result, most of today's vehicles are equipped with an in-vehicle navigation system. Interests has shifted gradually to the study of navigation systems for pedestrians (Puikkonen, Sarjanoja, Haveri, Huhtala, & Häkkilä, 2009). There are several differences in wayfinding between cars and pedestrians. Most notably, pedestrians are relatively free to move compared to drivers. For example, pedestrians can stop when they want to and move at the speed they want. In addition, pedestrians can have more flexible paths than cars because they do not have to follow a road network (Delikostidis, Elzakker, & Kraak, 2016). In addition, there will be a wider range of pedestrians using sidewalks than drivers who require certain qualifications in order to legally drive.

However, most pedestrian navigation system studies are limited to the outdoor environment. The main reason for this is that GPS technology does not work indoors (Ohm, Müller, & Ludwig, 2015). However, recently, as the demand for large indoor facilities such as shopping malls, stations, and airports has increased, interest in wayfinding in indoor environments has also increased. According to a study by Moeser(1988), people easily lose their orientation and have difficulty remembering their route in complexly structured indoor space, even if their experience in the building has accumulated over a long period of time (Fellner, Huang, & Gartner, 2017). Therefore, there is a critical need for an indoor navigation system to support the wayfinding in indoor environments. Recently, indoor positioning system technology such as RFID, Wifi, NFC, Bluetooth and geomagnetic field-based technology has been developed and commercialized with the aim of replacing GPS. Accordingly, companies providing outdoor pedestrian navigation systems are expanding coverage to indoor areas, and there is an increasing number of indoor navigation systems developed and provided for visitors in various indoor facilities such as airports and shopping malls.

As noted above, research on indoor navigation systems, which is relatively small compared to outdoor, has focused mainly on indoor positioning systems, the IPSs, in other words, the technical aspect. Knowing the user's location through IPS in wayfinding is important because it helps people identify the departure and arrival points and ensures that they are following the defined route correctly. In addition, it can be used for promotional purposes by providing sales information or coupons from nearby shops through the user's location information. However, the identification of user location alone does not solve all the difficulties involved in wayfinding indoors, which is the original purpose of the indoor navigation system.

The navigational aid can be evaluated according to whether the aid makes the user's spatial knowledge formation available and helps this spatial knowledge to make wayfinding decisions (Boumenir, Georges, Rebillard, Valentin, & Dresp-Langley, 2010). Therefore, in order to gain spatial knowledge through navigation system, not only the technical aspects but also the map design plays an important role (in providing the knowledge users need). Here, the map design covers a wide range of information on how to provide information effectively which users need without covering technical aspects in regards to gain spatial knowledge.

Map design studies on outdoor navigation systems can be applied to indoor navigation systems (Ohm et al., 2015), but they cannot be seen exactly the same (Puikkonen et al., 2009). There are many reasons, but most of all, indoor is more complex than outdoor. Various obstacles such as equipment and human beings exist in confined spaces (Gu, Lo, & Niemegeers, 2009), and it is determined by constraints of architectural components such as doors, corridors, floors, and walls (Li, 2008). In addition, most indoor spaces have three-dimensional structures with several layers. Therefore, it involves vertical movement, that is, inter-floor movement (Karimi, 2015).

Despite this importance, there is not much research on indoor navigation maps, and the discussion is still in its early stages. Therefore, it is necessary to study how people make wayfinding through navigation system in a specific space called "indoor." Based on this, studies on what kind of information should be provided and how it should be delivered are also needed. Therefore, this study was conducted to answer how indoor navigation system should be designed to support users' wayfinding in the indoor environment. In the following section, the cognitive process that people experience in wayfinding, the effect of the indoor environment on the wayfinding, and the previous research related to the indoor navigation system were reviewed. After that, contextual inquiry and a follow-up interview were conducted to understand the characteristics of people's wayfinding in indoor, and a case study was conducted to see if current indoor navigation systems match the results of contextual inquiry and interview. As a result, the design implications were derived based on this series of processes.

2. Related Work

2.1 Wayfinding

Wayfinding, in other words, navigation, is one of the most natural and essential everyday activities. Everyone can reach new or relatively familiar destinations through wayfinding. The term “wayfinding” was first coined in 1960 by Kevin Lynch, who described it as a process of reaching the destination using information from the outside world. Passini (1996) defined wayfinding as a multi-faceted spatial problem-solving process (Chebat, Gélinas-Chebat, & Therrien, 2005), and Golledge(1999) said that wayfinding is a motivated activity with a goal and a direction that determines or follows the path or route between origin and destination. Several authors have discussed what wayfinding is, but there is no fully agreed definition. However, what is commonly mentioned is that wayfinding has a purpose to reach its destination, and both cognitive and behavioral abilities are required (Prestopnik et al., 2000).

2.1.1 Wayfinding Tasks

Although there have been many studies on wayfinding, there are many different types of wayfinding tasks used in the literature. It is difficult to compare existing research results because the required resources may vary depending on the characteristics of each task. (Wiener, Büchner, & Hölscher, 2009). Therefore, classifying wayfinding tasks is important to understand how people solve wayfinding problems (Wiener et al., 2009).

Several studies have been conducted attempting to classify wayfinding tasks. First, Allen (1999) classified wayfinding tasks into three types: commute, explore and quest. A commute is a kind of task that moves between a familiar starting point and destination and has very low uncertainty. For example, daily commute activity between home and work is typically fairy routinized behavior and is often somewhat automated rather than requiring a high level of cognitive effort. Explore as a type of wayfinding refers to traveling in an unfamiliar area to acquire knowledge of the surrounding environment. This may require a low level of memory processing, but sometimes an intentional, strategic cognitive process is required. The third type of wayfinding is quest, which is travelling from a familiar starting point to an unfamiliar destination. The information about the destination is received symbolically through verbal descriptions or maps. In such cases, it is necessary to understand the symbolically transmitted information, and in addition, a high level of cognitive effort is required.

Montello (2005) classified wayfinding tasks into two types. He proposed that navigation consists of two components: locomotion and wayfinding. Locomotion is the movement of the body around the environment, where the senses and movement systems are directly accessible at that moment. Examples of locomotion activities include avoiding obstacles, moving toward a perceptible landmark, and following a path without bumping into walls on either sides. The other component, wayfinding, is knowing where to go and how to get there. Wayfinding usually has distant destinations from starting point. Therefore, internal memory and external navigational aids, such as maps, influence performance to a large extent. Examples of wayfinding activities include decision making, such as path selection, orienting towards a non-perceptible landmark, finding s shortcut.

Weiner et al. (2009) conducted more elaborative work with the highest category being navigation as classified by locomotion and wayfinding according to Montello's (2005) work. Locomotion is the motor response to sensory information such as obstacle avoidance, redirection, and so on. This requires hardly any cognitive effort. Therefore, Weiner focused on wayfinding and classified sub-items into unaided wayfinding and aided wayfinding. Aided wayfinding and unaided wayfinding are classified according to whether they receive external assistance such as maps, verbal descriptions, and signage. The two often require different cognitive resources, because decision making such as route planning is essential when navigating without external aids (Weiner, 2009). On the other hand, aided navigation may differ depending on the type of navigational aid, but some cognitive processes can be omitted through receiving information. However, other cognitive processes that are not needed in unaided wayfinding may be required. For example, understanding symbols and self-localization are required for map-reading (Lobben, 2004).

It would be difficult to classify wayfinding tasks into just one category according to this system. For example, most of the wayfinding tasks involve both wayfinding and locomotion as described by Montello (2005), although there may be differences in the proportion of each component in a given task. Therefore, a more detailed classification is needed. The wayfinding task that this study focuses on would be similar to the wayfinding as defined by Montello (2005), quest as defined by Allen (1999), and aided wayfinding as defined by Weiner et al. (2009). Thus, it can be specified as wayfinding with the help of a navigation system to reach an unfamiliar destination in indoor space. Since many people routinely undertake this type of wayfinding, it is likely to be of importance in the future as well.

Ross and Burnett (2001) proposed the drivers' navigation process. At the planning stage, people confirm destinations and plan routes, at which a spatial knowledge for the entire route is formed. When navigation starts, people go through the previewing stage picturing what to do next, comparing it with the information currently visible and thinking about the distance or time remaining before taking action. The Identifying stage includes pinpointing where they need to turn, what direction they should go, and conducting required movements. Finally, during the confirm step, people confirm that their planned and completed movements were successful.

In consideration of the Ross and Burnett's (2001) navigation process, the process of performing the wayfinding task used in this study was derived. First, people plan a route by entering the destination they want to go into the navigation system, and as a result, the navigation system will automatically generate a route to the destination. After acquiring information on the generated route, people will go through a preview stage in which they compare the acquired information with reality. The next step will be to identify the point where action is needed and also completing it, and finally, confirming whether the plan and action was correct.

There will be two ways in which the route is represented. The first is to keep switching the information on where to go at the top of the screen, and the second is to give all the spatial information on a fixed map. The former representation is usually applied in systems which move with users (such as navigation systems on mobile phone). The latter representation is usually applied in fixed navigation systems. In both cases, the planning and previewing steps are essential, but in the former case, locomotion takes up a large part because it involves immediate action after confirming the information given. In the latter, the process of planning and acquiring information needs to be more detailed, so the rate of locomotion is low and the cognitive processes of planning the route and acquiring spatial knowledge are important. In a complex indoor space that people have never visited before, they usually navigate by using the map on a display installed at the entrance, and it is rare to navigate by downloading a navigation app onto their mobile phone. Therefore, it is necessary to focus on the aspect of navigating routes by interacting with fixed navigation systems.

2.1.2 Wayfinding and Cognition

In wayfinding processes, people use a wide range of cognitive abilities (Spiers & Maguire, 2008). Lidwell, Holden and Butler (2010) propose that wayfinding consists of four cognitive processes: orientation, route decisions, route monitoring, and destination recognition. Orientation is the relative determination of current location using destination information and nearby objects. The second step, route decision is the process of selecting a route to reach the anticipated destination. If space is large, complex, or unfamiliar, using a map as a tool can help make a mental representation of the space easier, thus making it easier to plan a route. However, this step can be omitted if you use a navigation system that automatically provides a route. The third step, route monitoring, is the process of ensuring that the chosen route leads to the destination. By identifying locations connecting the entire route, you can verify that you are traveling in the correct way. Finally, destination recognition refers to the step of recognizing the destination when one has arrived. In order to make this step more effective, it is important to clarify the identity of the destination from the beginning.

People use various cognitive strategies in the route decision process to facilitate effective wayfinding. In the distance minimization strategy, the aim is to select the shortest route with the purpose of minimizing the total distance (Garling & Garling, 1988). In the least-angle strategy, the aim is to minimize the angle deviation from the starting point to the destination and select the path as close as possible to the straight line (Dalton, 2003). This can be interpreted as an attempt to reduce the cognitive burden by choosing a straight route with a lower complexity than a meandering or indirect one (Tolman, 1938). Often people take the least-decision load strategy to select a route that minimizes the number of turns because this reduces uncertainty. This also can be seen as a way to reduce the cognitive burden by delaying or reducing the number of turning decisions (Wiener, Schnee, & Mallot, 2004).

Navigational aids have been used to make the various cognitive processes of wayfinding easier. Maps which visualizes spatial information are the most representative navigational aid. The form of maps has changed from paper to electronic in line with the development of technology. In recent years, GPS-supported electronic maps are the most common navigational aid. People often use maps when they go to unfamiliar places. Wayfinding using a map requires additional cognitive abilities. People first have to understand symbols that are visually presented on the map (Wiener et al., 2009), then memorize the important information needed to get to the destination. While moving through the environment, they need to match the map's view (mostly bird-eye view) with the ego-centric view of reality (Lobben, 2004). After they perceive and comprehend the surrounding environment, they then compare and integrate it with their existing knowledge.

2.1.2.1 Spatial Knowledge

One of the most basic cognitive processes in wayfinding is spatial knowledge acquisition. Spatial knowledge is the information that people acquire about space. The most common example of space is the environment in which we live (Thorndyke & Hayes-Roth, 1982). The spatial knowledge is acquired at the planning stage of the route（Ross & Burnett, 2001). As more spatial knowledge is acquired and well-constructed, the wayfinding performance increases and consequently, wayfinding can be effectively completed (Darken & Sibert, 1996). Spatial knowledge can be acquired through various sources. The most common method is to obtain information about space through the environment itself, and the other is to obtain information through navigational aids, such as a map. The former is termed environmental mapping and the latter is termed survey mapping (Lobben, 2004).

There are five elements that make up spatial knowledge (Lynch, 1960): paths, edges, districts, nodes, and landmarks. Paths are the channels along which people move such as a sidewalk or a road, and districts are the broad regions such as a neighborhood. Edges are the boundaries between the regions, and nodes are the focal points that are determined as strategic points. The nodes are strategic points that require people to make decisions. Finally, landmarks are physical objects which have prominent features that are easily recognized or memorized, that serves as a reference point. People mentally represent the information obtained through the external environment or maps through these five elements.

Spatial knowledge is roughly divided into three hierarchical levels: landmark knowledge, route knowledge, and survey knowledge (Thorndyke & Hayes-Roth, 1982; Darken & Sibert, 1996; Werner, Krieg-Brückner, Mallot, Schweizer, & Freksa, 1997; May, Ross, Bayer, & Tarkiainen, 2003). Landmark knowledge is the representation of the surrounding environment consisting of prominent landmarks such as parks, café, school, and so on. Route knowledge is the procedural knowledge of the path that connects locations, for example, knowing where to turn to go to another location. Lastly, survey knowledge is knowledge of the relationship between different locations as a whole. It is acquired through repeated experience or map-reading. In other words, it is an integrated knowledge of the complex environment, drawn like a map in the head. These three levels of spatial knowledge tend to be acquired as experience accumulates. However, the knowledge primarily used by each individual can differ, and knowledge may be acquired in parallel ways (Lawton, 1996; Pazzaglia & De Me, 2001).

2.1.2.2 Cognitive Map

The process of acquiring and forming spatial knowledge from an external environment or a map, and then storing it in the human mind is called cognitive mapping (Chebat et al., 2005). Tolman (1938) coined the mental representation as a result of this cognitive mapping of the individual as a “cognitive map” (Golledge, 1999; Levine, Jankovic, & Palij, 1982). Acquisition of a cognitive map takes place either independently or combined with survey mapping through maps and environmental mapping through the actual pathfinding process. For example, if you start wayfinding in a real environment based on a cognitive map obtained from a map, you will relate the knowledge gained from the map to the actual environment, and conversely, relate the actual environment to the map. Therefore, the cognitive map is refined due to updated external stimuli, and consequently, the survey mapping and environmental mapping together form a cognitive map (Lobben, 2004).

However, a cognitive map is not a veridical representation. Prioritization occurs for certain features and objects in a way that facilitates wayfinding (Carlson, Hölscher, Shipley, & Dalton, 2010). This prioritization is particularly focused on salient and relevant content. For example, if there is a junction at which needs a turn in the route is required, a cognitive map will be formed to make salient and close landmarks more prominent. Simplification of cognitive maps, such as regularization of distance, angle, and structure, also occurs (Carlson et al., 2010). For example, people will form a cognitive map by simplifying the turn to left or right, rather than remembering the specific angle of the turn. This prioritization and simplification can be interpreted as one of the strategies in making pathfinding more effective by minimizing cognitive effort.

Therefore, we cannot fully understand people's wayfinding process with physical information of the environment alone. People use a variety of cognitive strategies, such as selection and transformation of information, in a way that is cognitively convenient. Therefore, in order to understand how people actually complete wayfinding, it is necessary to use various methodologies, such as observation, interviewing, and experimentation.

2.2 Indoor Wayfinding

2.2.1 Environmental Factor in Wayfinding

Wayfinding always occurs in a specific environment, and the visual and structural characteristics of that environment influence the difficulty of wayfinding (Carpman

& Grant, 2002). The three most important factors affecting this difficulty are the differentiation, visual access, and layout complexity (Montello & Sas, 2006). Differentiation refers to how similar or different the environment is. Differentiation involves various aspects such as size, shape, color, and the higher the differentiation, the more distinct and memorable it will be and therefore easier to navigate (Montello & Sas, 2006). Consider a maze-it is easy to get lost in a maze because the pathways are all alike and as such, differentiation is low. However, if the degree of differentiation in the environment becomes too high, it becomes rather difficult to find the way, because there is too much information to process.

Visual access refers to the amount of space that is visible from various viewpoints. The higher the visual access, the less people will depend upon cognitive maps and will directly rely on the information they immediately see (Hölscher, Meilinger, Vrachliotis, Brösamle, & Knauff, 2006). Finally, layout complexity is composed of various elements, and thus difficult to define. However, the more complex the layout of the environment, the more difficult it is for people to navigate. For example, more articulated space, or space that is broken up into many parts, are complex (Montello & Sas, 2006). How the parts of the environment are arranged is also important. In a path network, an oblique turn is more disorienting than an orthogonal turn (Montello & Sas, 2006) and the layout is less complex when the overall pattern is easy to understand as a simple shape, or verbal form. For example, a square has a less complex layout than a parallelogram (Montello, 2007).

2.2.2 Indoor Environments in Wayfinding

The indoor environment has physical characteristics which are fundamentally different from the outdoor environment. It is a space determined by constraints of architectural elements such as walls, floors, stairs, and so on. (Li, 2008). Unlike outdoors, it is characterized by fragmented, enclosed, and is multileveled (Fellner et al., 2017). Therefore, in general, the indoor environment has lower differentiation and visual access than outdoor, and the layout complexity is higher (Montello, 2007). For this reason, many people find it difficult to identify or maintain their orientation indoors, and thus get lost easily (Brunner-Friedrich & Radoczky, 2005).

One of the biggest causes of difficulty in indoor wayfinding is the three-dimensional structure, which causes vertical movement, that is, the floor movement. There are several explanations for why wayfinding involving vertical movement is more difficult. Holscher et al. (2006) concluded that integrating spatial knowledge by connecting floors at transition points such as stairs, escalators, and elevators, is cognitively difficult. This is because it is not easy to retain information about the direction of a previous floor when floor movement occurs through vertical transportations. Montello and Pick (1993) also observed in their experiments that it is difficult for people to align vertical spaces correctly within a building. In addition, Soeda, Kushiyama, and Ohno (1997) (as cited in Hölscher et al., 2006) found that since people usually assume that the structure of each floor is the same, serious wayfinding difficulties occur when this assumption is violated. As a result, it is important to design an indoor navigation system to reduce the cognitive effort caused by vertical movement.

2.3 Indoor Navigation Systems

Research on indoor navigation systems has been conducted later than that on outdoor navigation systems. One of the main reasons for this is that it was impossible to apply GPS positioning technology indoors (Nossum, Li, & Giudice, 2013). The GPS system is a satellite-based positioning system that is widely used because it has a very large coverage and can be applied to various devices. However, since there are various obstacles indoors such as ceilings, walls, and crowds unlike outdoors, the line of sight transmission between the GPS satellite and the receiver was not possible (Gu et al., 2009). Therefore, in order to overcome these limitations, studies on indoor positioning systems (IPS) to replace GPS have been conducted. As a result, the topic of indoor navigation system research has mainly focused on positioning technology.

2.3.1 Indoor Positioning Systems

Various IPSs have been developed to identify users' locations indoors, such as Wifi, Bluetooth, RFID, and infrared (IR) (Gu et al., 2009). IPSs can be classified into two categories: network-based approaches and non-network-based approaches (Alarifi et al., 2016). The former uses the network infrastructure already in a building, including Wifi and Bluetooth. Since it does not require any additional hardware infrastructure, the cost is low. However, there is the disadvantage of low accuracy. A non-network-based approach requires a dedicated infrastructure for positioning. RFID, and IR fall into this category, which is costly because of the need for additional hardware infrastructure but has the advantage of relatively high accuracy. There are also dead reckoning and geomagnetic field technologies that work independently of buildings. Due to the variety of IPS technologies, evaluation criteria for IPS technologies are needed. The criteria for evaluating IPSs are generally security, cost, coverage area, and accuracy. However, no IPS technology available yet has all these advantages, and each one has limitations. Therefore, further research on IPS is needed (Chen et al., 2015; Alarifi et al., 2016).

Various technology-based studies on IPSs have been completed to inform improvements. However, obtaining location information through IPS does not solve all the difficulties people encounter in the wayfinding process. In order to design a better navigation system, several perspectives of the system, as well as technical support, need to be considered. The navigation system usually provides information about the space in visual format. Therefore, map design is also very important in considering what information to select and how to display that information. However, the design principles applied in outdoor navigation systems have been applied to indoor navigation systems as they were, despite the differences in the two environments. Since both related to pedestrian wayfinding, there are many design principles that can be applied in common. However, as we have seen in the previous literature, outdoor and indoor differs in several points, and it is possible that these differences can affect people's wayfinding.

2.3.2 Indoor Map Design

There have been some studies on the map design of indoor navigation systems, although this is a small amount compared to IPS studies. Puikkonen et al. (2009) conducted a user study on the use of indoor navigation systems on mobile devices in an indoor shopping mall. Several design applications have been derived from this. First, vertical navigation should be designed with more care than it has been previously because many users have struggled with floor movements. In addition, because it is difficult to identify compass directions indoors, users mainly use the eye-catching landmarks. Therefore it is necessary to design maps that emphasize landmarks. Finally, outdoor locations are relatively intuitive than indoor ones because the consistency between real-life and the map is straightforward. For example, there is a universally agreed graphical style such as gray for roads, and sky blue for rivers. However, because the colors and shapes of buildings vary from building to building, they should be designed to maintain consistency between real life and maps.

There are also studies on how many landmarks should be emphasized in a navigation system (Bauer, Müller, & Ludwig, 2016). As a result, it is more effective to provide one landmark than to provide multiple landmarks because it reduces the cognitive effort. Ohm et al. (2015) studied which landmarks are most commonly used by people for wayfinding according to different buildings such as universities, shopping malls, and train stations. It was found people in a shopping mall or train station mostly used store and restaurant landmarks for wayfinding, while function landmarks such as elevators, stairs, and doors were most used in a university. Therefore, when designing an indoor navigation map, it is necessary to emphasize the landmarks that are often used by people according to the purpose of the building. Also, there is an indoor map design study related to vertical movement comparing 2D maps and stereoscopic 3D maps. Unlike the conventional 2D map, which gives each floor's information on the side by side horizontally or vertically, in this study, a stereoscopic 3D floor map was used. It was found that people performed the wayfinding task more quickly when using stereoscopic 3D maps than 2D representation maps (Rantakari, Väyrynen, Colley, & Häkkilä, 2017).

As mentioned earlier, map design is important because it conveys information directly to people. However, despite this importance, research on indoor navigation map design is still at an early stage. A good navigational aid helps users to effectively make spatial knowledge available and help them to make better decisions while wayfinding (Boumenir et al., 2010). Therefore, it is necessary to understand the acquisition of the user's spatial knowledge in indoors and determine how users make decisions based on that spatial knowledge before designing a map. This will enable people to understand which information is important and how that information should be conveyed from the design point of view. Therefore, this study sought to answer the following research question.

RQ1. How should indoor navigation maps be designed to support users' wayfinding in indoor environments?

To answer this research question, this study started by exploring how people conduct wayfinding in indoor space. In order to do this, a contextual inquiry was conducted by giving people wayfinding tasks in the field, and then a follow-up interview. In addition, before deriving the design implications of this, we examined the indoor navigation systems currently used through a case study based on the findings of the previous stage.

3. Preliminary Study

In preliminary study, contextual inquiry and follow-up interview were conducted to explore how people navigate in the indoor environment using navigation system. The findings were derived through the process. Also, a case study was conducted to see how the previous findings are present in currently used indoor navigation systems. As a result, the design implication of the indoor navigation system was derived through this series of processes.

3.1 Contextual Inquiry and Interview

Before deriving the indoor navigation system design implication, contextual inquiry and a flow-up semi-structured interview were conducted to explore the wayfinding characteristics indoors. The reason for using contextual inquiry is that it is possible to obtain more detailed and vivid information by observing and interviewing the performance of the task in the field than to obtain information based on memory (Beyer & Holtzblatt, 1997).

3.1.1 Methods

Participants

Contextual inquiry and follow-up semi-structured interviews were conducted to explore how people navigate using indoor navigation systems indoors. A total of 4 participants (2 female, 2 male) who were recruited through the Word of Mouth participated in the study. Their average age was 25.5 years, ranging from 24 to 29. The participants were compensated with 10,000 KRW.

Procedures

A Study was conducted at two famous indoor shopping mall in Seoul: Coex mall, Time Square Mall. The place was chosen to be large enough for people to require cognitive effort and where vertical movement occurred. The reason for proceeding in two different places was to prevent the wayfinding from being biased by specific features of a particular indoor location. The study was divided into two sub-sections. 1) In order to carry out contextual inquiry, we gave participants wayfinding assignment by specifying starting point and destination. During the wayfinding, questions were asked immediately to participants to make sure any ambiguous words or actions were understood correctly, and the whole process was recorded. 2) After the wayfinding, the participant was given a follow-up semi-structured interview on the previous task. 2) After the wayfinding, the participants were given a follow-up semi-structured interview on the preceding task.

Two participants (p1, p2) participated wayfinding task at Coex mall and two others (p3, p4) at time square mall. They all proceeded with a total of two tasks: 1) wayfinding on the same floor and 2) wayfinding including vertical (floor) movement. After the first task was completed, the follow-up interview was conducted, and then the next task with the follow-up interview was conducted again as before. Since the purpose of the study was to collect exploratory data, we did not have much control over the way they do wayfinding or the way they use the navigation system. Therefore, the participants were allowed to perform the task using the navigation system as usual freely.

The study was conducted for about an hour. In the first section, contextual inquiry, questions according to their actions, or words were asked such as what information they are acquiring from a map, and why they are hesitating and stopped walking. At the interview section, we looked back at the process of their wayfinding task and talked about it. Also, we asked about the clues they used that were important during wayfinding such as landmarks that were noticeable. We also asked what was convenient or inconvenient about the indoor navigation system, the indoor environment’s characteristics that affected their wayfinding performance, and strategies they used for vertical movement. Additional questions were asked depending on the participants' answers.

Data collection and analysis

All procedures throughout the study were recorded under consent, and all of the data was transcribed for analysis. The transcript data obtained through the interview process was analyzed using the qualitative research methodology Critical Incident Technique (CIT) and thematic analysis (Flanagan, 1954). In order to extract meaningful contents from transcripts using CIT, we have selected criteria for negative and positive incidents that people experience during the task (Bitner, Booms, & Tatreault, 1990; Metcalfe & Matharu, 1995). Negative incident criteria were: 1) repeating the same action several times 2) hesitating behavior 3) negative emotional expression while doing task. On the other hand, the criteria of positive incident are 1) positive emotional expression 2) say something is easy. After repeatedly reading the transcript, we extracted critical incidents that meet these criteria (Flanagan, 1954). Extracted "critical incidents" were recorded with the criteria and verbal and behavioral evidence that met those criteria.

In order to derive findings from the data, we conducted thematic analysis (Braun & Clarke, 2006). Thematic analysis consisted of a total of five steps: 1) in the first step, we had time to get used to the data by reading it repeatedly. 2) After getting used to it, initial code was written as a simple comment on each piece of data. 3) In the next step, we categorized the codes with similar ones using the code list 4) in the fourth stage, the theme was refined by merging or separating the themes through several reviews 5) finally, six themes were confirmed through this series of processes. As a result, the contents of the six themes derived from the data obtained from the preceding contextual inquiry and interview process are as follows.

3.1.2 Results

Table 1. Results of the contextual inquiry

No	Findings	participants
1	Matching user's viewpoint and map orientation	p2, p4
2	Chunking the route	p1, p2, p4
3	The Importance of Feedback	p1, p2, p3
4	Low importance of distance information	p1, p2, p3
5	Strategy according to ceiling height	p1, p3, p4
6	Vertical movement strategy	p1, p3, p4

Matching user's viewpoint and map orientation

All participants participated used the navigation systems of the kiosk in the building. The navigation systems used North-up maps that were fixed to the cardinal directions. Participants needed to check the stores on the right side and the left side to match them with map from navigation systems. Through this step, they could find out where they are and where to go. Also, when they needed to make turn and their perspective and the map alignment was not matched, they went through the mental rotation process to decide whether it is left turn or right turn. Participants said that information on the cardinal direction given on the North-up map is not very helpful. Thus, they said showing the direction which accords with user's viewpoint would reduce the additional cognitive effort to rotate the map mentally so that they could make a decision more easily.

"I cannot tell if my standing towards east or west in indoor, so if navigation system shows me a first-person viewpoint of which direction to go, I think unnecessary thinking will be reduced." –p2

"It's confusing because I need a process of matching the map and the way I need to go when using this(north-up map) map. It is easier when there is a shop on my left side is also on the left side of me on the map."–p4

Chunking the route

Rather than remembering the entire path as a single piece of connected information, people tended to remember the path in several parts. Notably, the chunks tended to be divided easily based on the intersection and between the floors where vertical movement occurred. Also, paths with no distinctive features such as a straight path tended to be easily tied into one large chunk. In fact, in the wayfinding process, people tended to complete the first chunk first, and then step-by-step processed the next chunks.

"After arriving at the intersection, I was going to think about the next direction. However, I spotted cosmetic stores in line, so I thought there would be the destination." –p1

"During the wayfinding, I had to think a lot especially in the intersection, and since I knew it was a straight line past that point, I did not have to think that much." –p2

"The routes are all connected anyway, so I thought I'd go 3rd floor by escalator first……" –p4

The Importance of Feedback

Participants showed a tendency to follow directions while confirming whether they were going well during the wayfinding process. The presence of these feedbacks seemed to be very important, because by receiving the feedback, the participant was assured that the location he was on was not wrong. At the same time, they also helped keep people on the road by giving them confidence that they could travel well in the future. In particular, the indoor environment is given a large number of visual cues within a limited space, which is why it is essential to get feedback in the appropriate section to get less distraction and complete the wayfinding.

“I think I was running out of information when I went from escalator 1 to 2. I think it would be nice if the information would be displayed as a sign in the interval between them. I think there is a side road in the middle and it would be nice if there is information” –p1

“If there is A land(clothing store) around here, it’s proof that I’m doing well. I also remembered another store as a backup just in case.” –p2

“I was a bit worried when I could not see Andong chicken restaurant from Giordano(clothing store). I got worried because new stores were kept showing up, but not the one I’m expecting.” –p2

“Space is limited, but on the other hand, there are too many visual cues around, so it’s easy to get lost.” –p3

Low importance of distance information

Distance information tended not to be significant in indoor wayfinding process. Most people mentioned that distance information was not very helpful, and they said that they were doing wayfinding mainly by landmarks. In the case of distance information, there was a prevailing opinion that it stays at an additional source level to confirm the route rather than the primary source.

“I do not think distance information will help much. If you do wayfinding indoor, there are many people around, many shops, so it is difficult to estimate the distance.” –p1

“I do not think I can find my way with only distance information. I think I can use it as a secondary source while doing wayfinding mainly with landmarks, the primary source.” –p2

“I do not think the distance information will help much because there is too much information around in indoor. If it says 300 meters, I think I can use it for just guessing if I walked too much.” –p3

Strategy according to ceiling height

The ceiling height varies according to the design purpose and interior characteristics of the building. Depending on the ceiling height, people tended to differ in the strategies they use in wayfinding. When the ceiling was low, people tended to use their nearby landmarks and signs to identify their relative coordinates and find their way. On the other hand, when the ceiling was high, people tended to use overall structure and form of the building, or distant and large landmarks.

"This place has a low ceiling, so my view is blocked, so I'm confused where I should go." – p1

"The underground floor, which had a low ceiling, I saw more landmarks. In the case of third floor with a high ceiling, I saw more in overall building form." –p3

"the ceiling is high to the end, so you could see the overall structure of the building. It looks like a round droplet. Therefore, the directions are easy to identify based on this information" –p4

Vertical movement strategy

Most of the people preferred to move the floor first (3 out of 4) when the route included vertical movement in the indoor wayfinding. In other words, when the destination is on a different floor, it was preferred to first travel to the destination floor through the vertical transportation as close as possible to the starting point, and then navigate the rest of the way. People said that they would make a clear choice for now to reduce future options. Only one participant preferred to go to destination floor at the end after finding the route from the departure floor mostly. She explained that since departure floor is more familiar, she wanted to get more directions in that space.

"Rather than calculating route to destination in advance, choosing what I can choose right now(moving the floor) is easier, because it reduces the choice." –p1

"Anyway, If I go up to the third floor, I have to find my way again. So, I want to minimize my thinking until I get to the third floor." –p4

"Now that this floor is relatively familiar, it would be easier to find and move on this floor than destination floor." –p3

A case study was conducted to confirm how the six findings are presented in the currently implemented indoor navigation system. In the case study, we focused on checking whether the indoor navigation system is designed according to the previous findings.

3.2 Case Study

We conducted a case study on six indoor navigation systems to see if the design of the indoor navigation system currently used matches the findings derived in the previous step.

3.2.1 Methods

To collect the indoor navigation system, we searched for famous indoor facilities located in Seoul that supports its own navigation system, and also searched for apps and websites that support indoor navigation. We also examined whether there are any outdoor pedestrian navigation systems which support indoor navigation too. We excluded cases where route guidance was not supported among the searched systems. A total of six indoor navigation systems were selected, and kiosks, applications and web platforms were all considered. Basic information for selected indoor navigation systems are shown in Table1.

Table 2. Information on indoor navigation systems for case study

S#	Name	Platform
S1	Coex mall[1)]	kiosk
S2	Coex mall	mobile app
S3	Time square mall[2)]	kiosk
S4	Lotte world mall[3)]	kiosk
S5	Lotte world mall	mobile app
S6	IFC mall[4)]	kiosk

Data Collection and Analysis

Each system was used to see if current indoor navigation systems match the findings from the previous step. Starting points and destinations were randomly selected, and route searching function was repeatedly used both with vertical movement and without vertical movement. In the course of using the system, we have summarized the facts related to the previous findings for each navigation system: 1) whether the user's viewpoint and map orientation can be matched 2) Whether the whole route is divided into several chunks 3) whether distance information is given 4) when is vertical movement timing. We excluded from the case study about feedback and ceiling height findings which are difficult to intuitively confirm whether it is reflected in design of indoor navigation system.

1) Coex mall consists of 4-floor levels, and most of the paths are radially shaped.
2) Time square mall consists of 7-floor levels, and the structure of the underground levels and ground levels are different. In the case of the ground floor, the center of the building is round and open to the ceiling.
3) Lotte world mall consists of 13-floor levels, and the structure of the underground levels and ground levels are different. In the case of the ground floor, the center of the building is round and open to the ceiling.
4) The IFC mall consists of 3-floor levels, and the building is a large triangular shape.

3.2.2 Results

The results of the case study on whether each navigation system conforms to the previous findings are as follows.

Table 3. Results of the case study

	S1	S2	S3	S4	S5	S6
Map	Fixed (North up)	Rotatable	Fixed (North up)	Fixed (North up)	Rotatable	Fixed (North up)
Chunking	X	O	X	X	O	X
Distance	X	X	X	X	O	X
Vertical movement	End	Middle	End	Middle	Middle	Beginning

First of all, all of the six systems were set up in the North-up direction as to whether the user's viewpoint and the map direction could be matched. Among them, the mobile apps S2 and S5 were able to rotate the screen by touch, and the remaining four systems were fixed in the North-up direction and could not be adjusted. Second, in the case of route chunking, as in the previous case, only the mobile apps S2 and S5 of the six systems were divided according to specific criteria, and the remaining four systems were shown as one continuous route. In the case of S2, every time the angle changes in the route, all the chunks are numbered. The S5 was divided in more detail in addition to angle changes, but it was difficult to understand the criteria intuitively. The chunk steps are listed in the lower part of the map. In both systems, the number of chunks is usually more than about 10, which may vary depending on the length of the route, but seemed too many to remember. Thirdly, distance information was provided by S5, one of the six systems. In S5, information about how many meters to go for each divided chunk is shown below (ex. Turn left in 8m). However, information on how many meters the total route was displayed at the top

(S5) and the right (S1) of the map in S5 and S1. The other four systems did not provide any distance information at all. Finally, only one (S6) of the six indoor navigation systems coincided with the previous finding regarding the floor movement timing. In other words, S6 provided routes suggesting vertical movement to be performed near the beginning. Two of the remaining five (S1, S3) suggested to do floor movement at the last minute, and three (S2, S4, S5) were proposed to make floor movements in the middle.

3.3 Design Implication

Based on the results obtained from the contextual inquiry, follow-up interview and case study, we propose six design implications which should be considered in the design of the indoor navigation system in accordance with the people's indoor wayfinding g process.

Table 4. Design Implications of indoor navigation system

No	Findings
1	Design the map representation considering the essential elements of the wayfinding task
2	Use appropriate criteria and the number of chunks
3	Give feedback in the middle of a long straight path,
4	Consider giving distance information as a secondary source
5	Consider individual's use of different strategy depending on the ceiling height
6	Give the direction to move the floor level first.

Design the map representation considering the essential elements of the wayfinding task.

The interviews showed that the users mentally rotated the map at the starting point or before turning to match the actual viewpoint. So, people explained that it would be better if maps were given as first-person viewpoints so that these mental rotations were not needed. Research on map representation variation has been around for a long time. One is the North-up method, with the north direction always on top, with maps fixed to cardinal directions (Montello & Sas, 2006). The other is a heading-up method, in which the map is continuously rotated so that the direction in which it moves forward is fixed at the top. Examples are navigation systems used in automobiles (Mashimo et al., 1993). We cannot say which representation is better, and each has its advantages and disadvantages. North-up has the disadvantage that it is difficult to identify the turning direction and also challenging to apply map to reality. However, because the map is fixed, it is less distracting and easier to form a cognitive map. Conversely, heading-up can be distracting and more difficult to form a cognitive map because the map keeps moving. However, it is easy to grasp the left and right directions and to apply the map to reality (Mashimo et al., 2013; Dingus & Hulse, 1993). Therefore, the map representation should be designed considering the characteristics of the specific navigation system and the advantages and disadvantages of representation mentioned above.

First, whether or not the navigation system moves with the user should be considered. Recently, there are many navigation systems used through mobile devices. In this way, heading-up should be applied. It is because it would be easier to match the map with the reality while navigating in real, and also easier to identify right or left directions. However, when using a fixed navigation systems such as by kiosk, people have to acquire the route information and form a cognitive map beforehand. Therefore it would be distracting to get information from heading-up representation, since it keeps moving which would be distracting. Therefore, a north-up that is easy to form a cognitive map would be more appropriate.

However, as the interview results show, the indoor is limited space, so harder to identify cardinal direction than the outside. Therefore, cardinal information provided by North-up map is not very useful, so those who used the North-up map had difficulty identifying directions. Therefore, when the north-up map is used in indoor, it will be helpful to provide the first-person view map as an option, because it will compensate for the difficulty the north-up map has. For example, the rotatable map representation we saw in the case study would be one way.

Use appropriate criteria and the number of chunks

The interviews showed that when people were looking for directions or reading maps, they tended to divide the entire pathway into several sub goals rather than one. These characteristics were also revealed in an in-vehicle navigation study by Lee et al. (2008). Drivers tend to divide the road into several steps, or sub goals, which can be very small units, or Might be a relatively large schematized route that the driver already knows. In a pedestrian wayfinding study in an outdoor environment, users were also shown to segment the route into a bundle of paths and nodes (May et al., 2003). This can be interpreted as a chunking strategy for people to reduce their cognitive effort. Anderson's 1993(as cited in Myers, 1992) study found that people use a variety of strategies to remember more efficiently with limited cognitive resources, especially chunking strategies that organize one long piece of information into several manageable units. According to the interview, the reference point of chunking in indoor wayfinding has occurred mainly in intersection similar to outdoors (May et al., 2003), and floor movement which is prominent feature of the indoors. Therefore, when designing an indoor navigation system, dividing chunks by considering these reference points will be suitable for people's cognitive process. As shown in the case study, only two of the six indoor navigation systems divide the route into chunks. However, the chunking criterion was a change in angle, so there were too many chunks. However, too much chunking can result in a complicated map, resulting in an increased cognitive load (Ohm et al., 2015). As a result, the route should be designed to have the proper number of chunks at appropriate points, such as at intersections or when floor movements occur.

Give feedback in the middle of a long straight path

According to the interviews, participants tended to check repeatedly if they are on the right track. Especially because indoors usually have a lot of visual cues coming in from a distance closer to the outdoors, they tend to get easily distracted and worried about whether they are going right or not. Therefore, feedback is critical in indoor navigation system, and it needs to be given relatively densely compared to outdoor (Radoczky, 2007). In the route, intersection is a crucial point, and people want to be careful to memorize it. This is because of high uncertainty and the need for decision making (May et al., 2003). On the other hand, in the case of a straight path, it tended to be tied into a single chunk regardless of length. However, May et al. (2003) found that 68% of the information mentioned by people during the outdoor wayfinding task occurred in the intersection, and the remaining 32% occurred in the path. This shows that even though it is not a decision point, there is a need for information in the path to get confirmation and confidence. Therefore, an appropriate number of feedbacks must be provided in proportion to the length of the path even in a straight one. One of the ways to do this is to emphasize the landmark at the middle of a long path, or use a prior chunking strategy to distribute chunks based on a visible landmark in the middle of the path.

Consider giving distance information as a secondary source

According to interviews, people said the importance of distance information in indoor wayfinding is low. People said they could use it as a secondary source and would not use it as a primary source in finding directions. The reason was that there are many people and obstacles in the indoor space, which makes it difficult to estimate the distance. These results are similar to the existing outdoor pedestrian wayfinding study. Unlike the outdoor pedestrian navigation system, distance information such as “turn left in 100m” is commonly used in vehicle navigation systems. In the latter, however, users tend to prefer to find a way based on landmark information rather than distance information. This is because pedestrians are weaker in the ability to measure distance than drivers, and this is complemented by using salient objects (Winter, Raubal, & Nothegger, 2005; Ohm et al., 2015). It can be inferred that it is easier for the driver to judge the distance information because he continually confirms his speed. Besides, in the case of indoor wayfinding, it can be expected that distance information is more difficult to estimate because there are unexpected people and obstacle variables in a limited space. Therefore, the design of the indoor navigation system should be guided by the landmark rather than the information about the distance information. If distance information is given, it should be displayed only to the extent that it can be referenced. If there is much information given in the navigation system, it is better to omit considering cognitive load.

Consider individual's use of different strategy depending on the ceiling height

Unlike outdoor, indoor is characterized as a limited space by structures such as ceilings and walls (Li, 2008). The height of the ceiling varies depending on the function of the space and the purpose of the interior design. Thus, the amount of visual information that can be obtained from an individual perspective, in other words, visual access varies (Gärling, Lindberg, & Mäntylä, 1983). In interviews, people used different navigation strategies depending on the height of the ceiling. If the ceiling is low, a landmark located at a short distance is used. It is because when the ceiling height is low, the visual access is lowered naturally and a small amount of visual information can be obtained. (Montello, 2007). On the other hand, when the ceiling was high, people showed a tendency to find a way of using the overall shape of the building or relatively large or distant landmarks. It is because when the ceiling is high, the visual access is increased and more information can be seen. Also, since more information can be seen, spatial information is more easily connected, which makes it easier to identify the structure of the building. (Holscher et al., 2006). Therefore, when designing an indoor navigation system, if the ceiling of the space is low, the chunk of the route should be divided smaller and more landmarks should be emphasized. On the other hand, if the ceiling is high, the chunks of the path should be relatively large and fewer landmarks should be emphasized.

Give the direction to move the floor level first.

According to the interviews, people preferred to move to the destination floor first through vertical transportation close to the starting point. Only one of the four said that she would prefer to move to the destination floor at the end after finding all the way from the floor of the starting point. Also, nobody preferred to move the floor in the middle. This result can be explained by the fact that it can remove the load caused by the hierarchical route planning heuristic by vertically moving the layers first or at the end (Holscher et al., 2006). In other words, there is no need to keep information on two layers at the same time, and only information about one layer needs to be memorized. Mainly, the reason why people prefer to move the floor first is that when reaching the target floor through the vertical movement, one layer is first removed (Holscher et al., 2006) and the problem space is reduced to two dimensions which makes wayfinding more cognitively efficient (Wiener et al., 2004). However, as a result of the case study, there were three navigation systems suggesting floor movement in the middle of the route, and two systems suggesting floor movement at the end, which are incompatible with the interview finding. However, there was only one route design that applied strategy people preferred most, moving the floor first. Therefore, when presenting the route in the indoor navigation system, it is necessary to design to reach the destination floor first by using vertical transportation close to the starting point as much as possible. This is because they can eliminate or reduce the difficulty that people have when vertically arranging the space (Montello & Pick, 1993).

3.4 Discussion

In the previous preliminary study, six design implications related to the indoor navigation system were derived through the contextual inquiry, the follow-up interview, and the case study. The results are: 1) design the map representation considering the essential elements of the wayfinding task 2) use appropriate criteria and the number of chunks 3) give feedback in the middle of a long straight path 4) consider giving distance information as a secondary source 5) consider individual's use of different strategy depending on the ceiling height 6) give the direction to move the floor level first. The first four out of six can be applied to the outdoor wayfinding as well as to the indoor wayfinding, due to the common characteristic of the pedestrian wayfinding. However, its importance may be more significant in indoor, because of its limited and complex characteristics. However, the latter two of the six were only applicable to the indoor navigation system because it is caused by indoor environments' characteristic of its own, limited space and vertical movement. Therefore, these two design implications are an important part of designing an indoor navigation system to distinguish it from an outdoor navigation system.

Among these two design implications, as mentioned in the related work, the vertical movement is one of the biggest cause of indoor wayfinding difficulty compared to outdoor. Therefore, it is important to complement the cognitive difficulties of people in the task of wayfinding including floor movement through indoor navigation systems. However, as a result of the case study, five of the six navigation systems were designed to be incompatible with people's vertical movement strategies. In this way, considering the importance of floor movement in indoor wayfinding, and the outstanding discord with the current navigation system, we decided to additionally confirm whether the design implication makes a difference in people's wayfinding performance. Therefore, in the main study, we decided to empirically verify whether there is a difference in people's wayfinding performance when the condition of floor movement timing is given differently.

4. Main Study

In the main study, we aimed to verify whether there is a difference in wayfinding performance according to the design of the indoor navigation system which is given a different route of floor movement timing. The independent variable's three conditions of the experiment are 1) floor movement at the beginning 2) floor movement in the middle 3) floor movement at the end.

Independent Variable(IV): when the vertical(floor) movement occurs		
Condition1	At the beginning of the route	
Condition2	In the middle of the route	
Condition3	At the end of the route	

Figure 1 Information of independent variable

The dependent variable, wayfinding performance, was limited to spatial knowledge acquisition through navigation system according to the characteristics of laboratory experiment. Both objective and subjective measures were used to measure the performance. Objective measures include 1) the time taken to acquire the route information, 2) the number of times the map was switched between two maps to acquire the route information, and 3) The number of times the necessary information was omitted in verbal explanation was measured. As a subjective measure, after the completion of each condition, following three questions were asked to answer with a five-point Likert scale: 1) How difficult it was to remember the route 2) how difficult it was to connect the route of the two maps mentally 3) how difficult it was to verbalize the route formed in the head.

Dependent Variable(DV): spatial knowledge acquisition performance		
Objective measures	Time	The time taken to acquire the route information
	The number of transition	The number of times the map was switched between two maps to acquire the route information
	The number of error	The number of times the necessary information was omitted in verbal explanation
Subjective measures	Difficult to memorize	5-point Likert scale survey on how difficult it was to remember the route
	Difficult to connect	5-point Likert scale survey on how difficult it was to connect the route of the two maps mentally
	Difficult to verbalize	5-point Likert scale survey on how difficult it was to verbalize the route formed in the head

Figure 2 Information of dependent variable

문항	매우 쉬웠다				매우 어려웠다
1. 출발지에서 목적지까지의 경로를 기억하는 것이	1	2	3	4	5
2. 층 이동 전과 층 이동 후의 경로를 머리 속으로 연결하는 것이	1	2	3	4	5
3. 머리 속에 형성된 경로를 말로 설명하는 것이	1	2	3	4	5

Figure 3 5-point Likert scale survey of task difficulty

In Preliminary study, people preferred to move floor first or last because it is cognitively difficult to integrate the route vertically. Mainly, it was most preferred to reduce the mental representation of space to two dimensions by performing floor movement first. There was no preference for floor movement in the middle of the route because the information about the previous floor and the next floor should be held simultaneously which needs more cognitive effort. Therefore in Main study, the following research questions are derived:

RQ2. The spatial knowledge acquisition performance will be highest in the condition that floor movement occurs at the beginning of the route.

RQ3. The spatial knowledge acquisition performance will be lowest in the condition that floor movement occurs in the middle of the route.

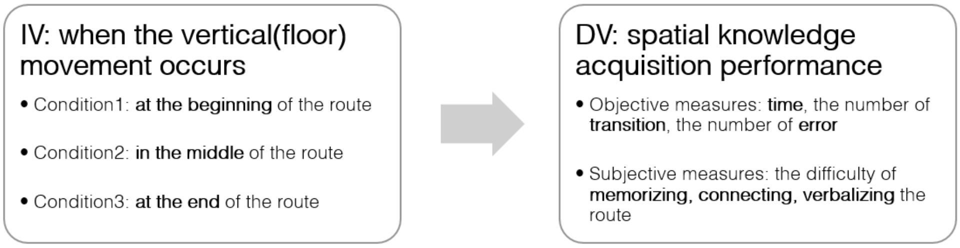

Figure 4 Diagram of the research question

4.1 Methods

Participants

In order to identify the research questions, 45 participants (22 female, 23 male) participated in the experiment. The mean age of participants was 25.89, ranged from 19 to 36. Recruitment flyers were posted on school community website, and on the campus experiment participant recruitment site (mozip.snu.ac.kr). The participants were compensated with 10,000 KRW.

Procedure

The experiment was carried out in a laboratory environment and the task was to memorize the route through the indoor navigation system prototype given in the laptop, and then explain the route verbally as if explaining it to a friend who has never been there (Thorndyke & Stasz, 1980). Many map-reading or wayfinding studies have used methods of verbalizing people's process of obtaining information about space or obtained information. (Gilhooly, Wood, Kinnear, & Green, 1988; Kato & Takeuchi, 2003; May et al., 2003). Go pro was used to record the whole process of the task, and the screen recording was performed simultaneously through the system built in the laptop's Windows 10.

We first gave a general instruction on the experiment, and conducted a survey on demographic information. Next, the laptop and mouse were placed on the desk in front of the participant to conduct the wayfinding task. To help them understand the task simple exercise task was performed before starting the actual one, and then checked if there was anything they did not understand. After the exercise task, participants completed tasks with following three different route conditions: 1) floor movement at the beginning of the route 2) floor movement in the middle of the route 3) floor movement at the end of the route. Total 2 maps were given in each condition. The first one was map of the starting point floor, and the second one was map of the destination floor after vertical movement occurred. The path was marked with a blue line, and in the process of acquiring the route information, they were free to move between the first and the second map by clicking a button with the mouse.

There was no time limit for acquiring path information, and three different maps (map A, map B, map C) were created to control the learning effect of using the same map under the three conditions. All three maps were designed to have four turns, but it was impossible to control the degree of difficulty between maps the same. Therefore, a random combination of three maps and three conditions was used. To do this, we used the sample function of the random module of python and randomized the order of the condition in the same way to control the learning effect according to the order.

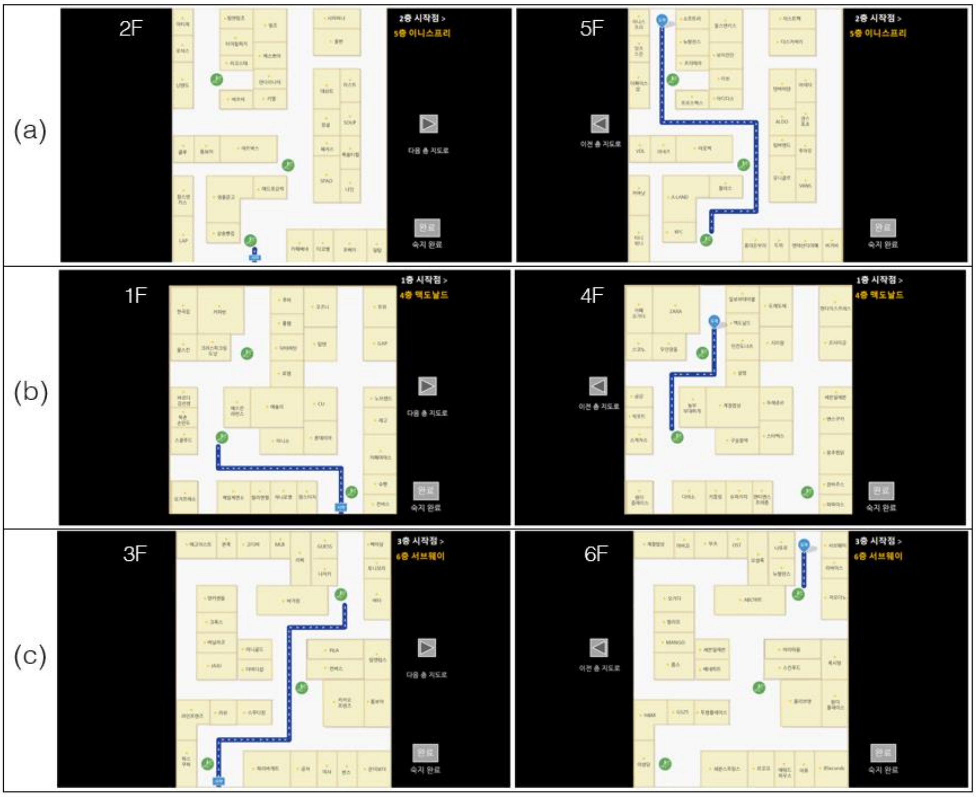

Figure 5 Example of map prototype used in experiment
(a) The floor movement at the beginning of the route (map A)
(b) The floor movement in the middle of the route (map B)
(c)The floor movement at the end of the route (map C)

In the course of performing three tasks, after each task was completed, the 5-point Likert scale questionnaire was asked about the difficulty of the following three items: 1) remembering the route 2) connecting the route of the two maps mentally 3) verbalizing the route formed in the head. After the completion of all the tasks, semi-structured interviews were conducted to ask whether there were any differences between the three tasks, which parts differed, and what factors influenced the difficulty of each task. The whole procedures took about one hour, and the interview was recorded under the consent of the participants.

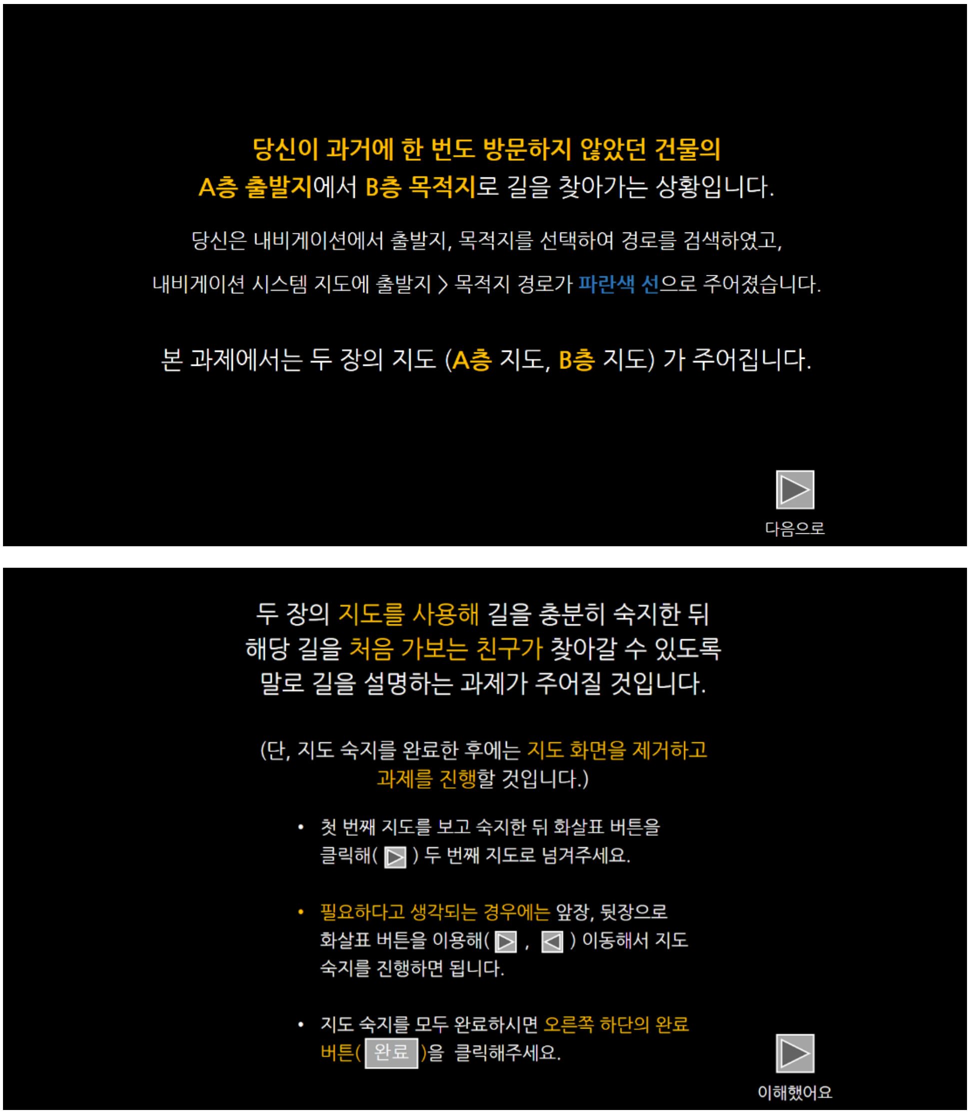

Figure 6 Instruction pages for wayfinding task

Screen1 (top) translated text: This is a situation where you go from A floor starting point to B floor destination of the building that you have never visited in the past. The route is given as a blue line on the navigation system map. In this assignment, two maps (A floor map, B floor map) are given.

Screen2 (bottom) translated text: You will be given a task to explain the route in words to a friend who is new to the building. However, once you have acquired the information from the map, the map will be removed from the screen. If necessary, use the arrow buttons to move the map back and forth (map A & map B). When you are finished with the maps, click a button in the bottom right corner.

Data Collection and Analysis

Through the recorded videos, we recorded the time it took for the participants to memorize the route, the number of times the two maps were switched, and the number of necessary information omitted from the verbal report. The necessary information in the third variable is whether the verbal report contains descriptions of all four turns that every map has, and counting the number of omissions in the four turns. Also, a score of 5 points for assessing difficulty was also recorded for the three items performed after each condition (remembering the route, connecting the route between the two maps mentally, and verbalizing the memorized route information). Since there are six dependent variables and all participants performed three conditions, 3 * 6 = 18 data values were recorded per person. The recorded data were analyzed using the statistical package SPSS and R, using the Friedman test, to see if there is a difference in each dependent variable according to the three conditions.

After completing the task, the interviews were all transcribed based on the recorded files and the data were analyzed by thematic analysis (Braun & Clarke, 2006). The analysis consisted of five steps: 1) Reading data repeatedly and get familiar with it 2) Writing initial code for the data fragments 3) categorizing the written code by grouping similar topics together 4) refining process to merge or separate the categories again by reviewing 5) finally confirming the four themes.

4.2 Results

A total of 45 study participants participated in the experiments and interviews to confirm the research questions for the main study, and the analysis results are as follows.

4.2.1 Wayfinding Task

In order to measure the spatial knowledge acquisition performance according to the three conditions, three objective measures 1) Time 2) the number of transition 3) Error counts and three subjective measures 1) route memory difficulty 2) connecting route difficulty 3) Verbalize difficulty, a total six dependent variables were analyzed using the Friedman test each. As a result of the statistical analysis, there were differences in the number of transition, which is the objective measure, and the difficulty of route connection, which is a subjective measure, according to the three conditions.

Table 5. Results of the Friedman test

	N	df	Chi square	P-value
Time	45	2	1.764	0.414
The number of transitions	45	2	26.684	0.000
The number of errors	45	2	0.299	0.861
Difficult to memorize	45	2	0.748	0.688
Difficult to connect	45	2	8.373	0.015
Difficult to verbalize	45	2	0.458	0.795

The number of transitions

As a result of the analysis, there were significant differences in the number of transition variables according to the three conditions (χ^2= 26.684, p <0.001). The average number of transition for the first, second, and third conditions were 4.29, 6.76, and 5.20, and the mean rank was 1.51, 2.51, 1.98 in order. The post hoc test was performed with wilcoxon signed-rank test to determine the difference between conditions according to the Friedman test results. The alpha value was divided by 3 (0.05 / 3 = 0.017) through bonferroni correction and the evaluation was performed. As a result of analysis, the mean rank of condition2 (mean rank=2.51) was significantly higher than the condition1 (mean rank=1.51). Also, the mean rank of condition2 was significantly higher than the condition3 (mean rank=1.98). However, the mean rank of the number of transition of condition 1 was lower than the condition 3, but there was no significant difference between the two (p = 0.082).

Table 6. Results of the Wilcoxon signed-rank test on the number of transitions

The number of transitions	N	Z	P-value
Condition2-condition1	45	-4.320	0.000*
Condition3-condition2	45	-3.054	0.002*
Condition3-condition1	45	-1.741	0.082

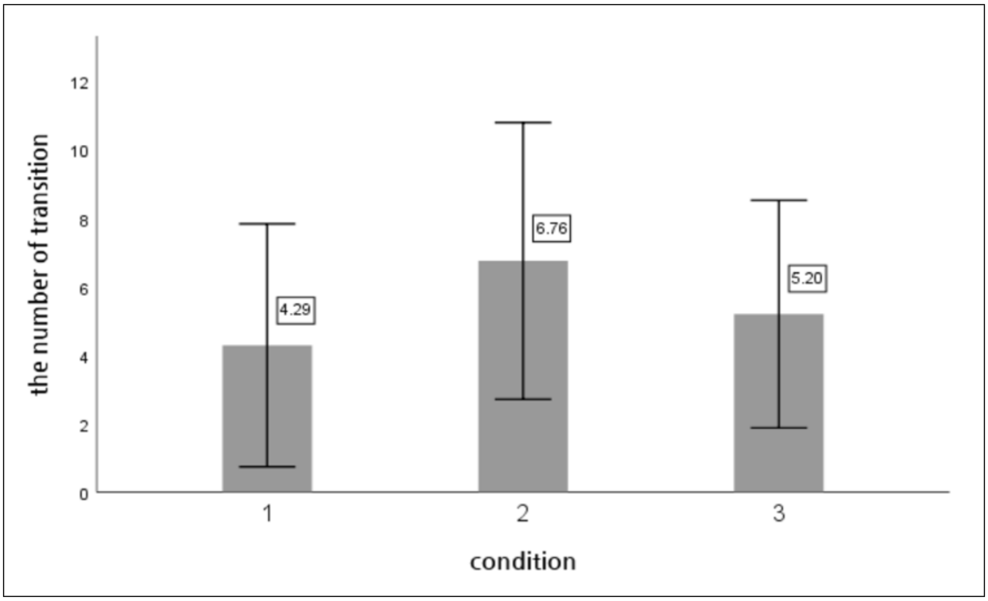

Figure 7 Mean difference among conditions of the number of transitions

Connection difficulty

As a result of the analysis, there was a significant difference between the three conditions in the connection difficulty variable (χ^2= 8.373, p = 0.015). The average number of transition for the first, second, and third conditions were 2.22, 2.76, and 2.49, and the mean rank was 1.74, 2.19, 2.07 in order. The post hoc test was performed with wilcoxon signed-rank test to determine the difference between conditions according to the Friedman test results. The alpha value was divided by 3 (0.05 / 3 = 0.017) through bonferroni correction. As a result, the mean rank of condition2 (mean rank=2.19) was significantly higher than condition1 (mean rank-1.74). Condition 3 (mean rank = 1.98) had higher mean rank than condition 1, but the difference was not significant (p = 0.026). Likewise, the mean rank was higher in condition 2 than in condition 3, but there was no significant difference between the two (p = 0.075).

Table 7. Results of the Wilcoxon signed-rank test on the connection difficulty

Difficult to connect	N	Z	P-value
Condition2-condition1	45	-3.046	0.002*
Condition3-condition2	45	-1.778	0.075
Condition3-condition1	45	-2.233	0.026

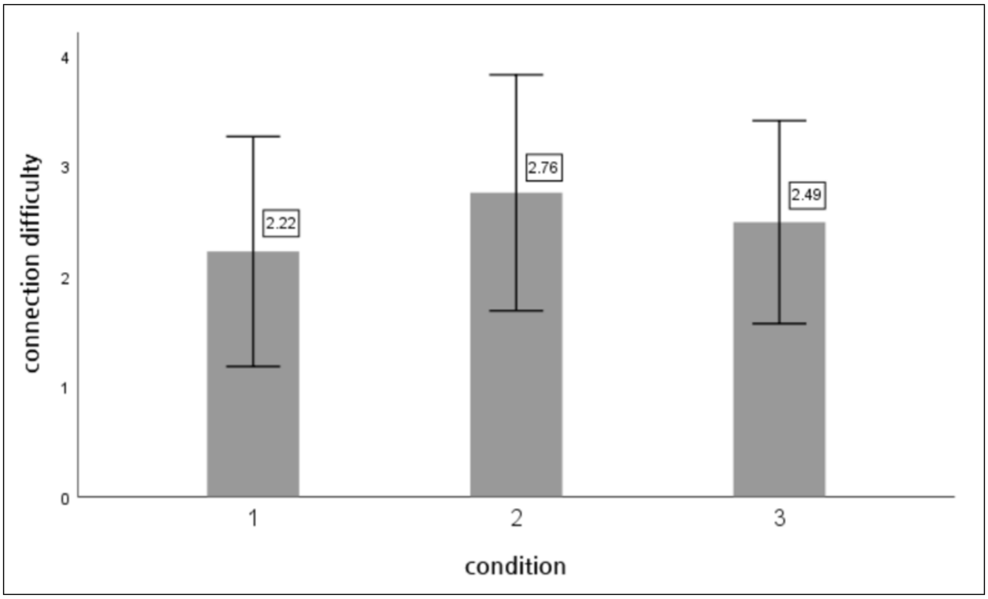

Figure 8 Mean difference among conditions of the connection difficulty

(5-point Likert scale survey on how difficult it was to connect the route)

4.2.2 Interview

Thematic analysis of interviews resulted in four themes. The first two of the four themes are about why the condition with floor movement in the middle of the route (condition2) makes it harder, and the other two are about why the condition with floor movement at the beginning of the route (condition1) makes it easier.

Information on both floors are needed

Participants replied that moving floors in the middle felt more difficult because they needed to know information about the space before and after the floor moved. On the other hand, moving floors at the beginning or at the end felt easier because they only needed to acquire spatial information on a single floor. Even though the overall length of the inter-conditional route is similar, participants explained that the condition2, in which the length of the route is roughly alike over two floors, felt like having difficulties twice because the task had to be resolved over two floors.

"Condition 2 was difficult because I had to know half about one floor and half about the other. Even if the path is long on one floor, such as condition 1 or condition 3, it is more convenient to know only one floor." –p1

"In condition 1 and 3, you only have to memorize one map, but condition 2 was harder because you had to represent both maps." –p2

"The condition2 was difficult because I had to explain both floors. Two separate floor information was in my head, which made me feel like doing the task twice." –p33

Difficult to connect floors mentally

Participants explained that when moving floors in the middle of the route, information about the space before and after the floor move was not smoothly connected, which makes it difficult. People were confused whether the information they remembered was about the previous floor or the back floor, and felt more difficult because they had to keep the previous floor's information in their head and acquire the latter one's information.

"I think condition2 was harder than condition1 or 3 because connecting the path between the two floors was difficult." -p31

"In condition2, the store on the previous map and the one on the back map got confused, because the route before and after the floor movement was not separated and overlapped. So, I was confused which floor the Mom's Touch (fast-food restaurant) was on." –p44

“Condition 2 was confused about which map came first because each map had similar length.” –p27

Easy to do the easy things first

Participants said that the condition1, moving the floor at the beginning was easier than the condition3, moving the floor at the end. People explained that it is because it is easier to do the easy things first and to postpone the difficult ones later than the opposite. They said if difficult information is given first, they get tired quickly, which made them feel more demanding about the task. For example, it was metaphorically compared to the way how people take the test: people tend to feel at ease when solving easier problems first before moving on to the difficult problems.

“I think it’s easier to do complicated things later. I think that’s why condition1 was easy.” –p8

“I don’t know why, but It’s easier to do the easy route first and the complicated route behind it. It’s like leaving a difficult question last on your test.” –p31

“If I get too much route information on the first map, no matter how simple the next one is, the task feels harder because I get tired from the beginning.” –p3

Easy to use general information first

Participants explained that the information on which floor to go is more general than the information about where the destination is located on the floor, so it is easier and more intuitive to use general information first. They also explained that if they solve the problem of floor movement first, they feel more comfortable because the fact that they are on the same plane as their destination is ensured.

“Which spot to go within the floor is more detailed information, and which floor to go is a bit general information. So, it seems easier to use general information first." –p45

"I think it's important to get closer to your destination psychologically. If you go up to that floor first, you'll be on the same plane as your destination. Also, I think it's more comfortable because the route is reduced from three dimensions to two dimensions." –p39

"When I move the floor, I feel comfortable that I have come to the same floor as my destination." –p10

"I feel like I should take an escalator once I see one, and get to the destination floor. So the conditions 2 and 3 that I had to pass through the escalator felt more difficult than Condition 1." –p8

4.3 Discussion

In the main study, experiments and interviews were carried out in the laboratory to check whether the spatial knowledge acquisition performance varied according to the vertical movement conditions. As a result, the two dependent variables significantly differed according to conditions: 1) the number of transitions 2) the difficulty of connecting the route between the two maps. For the number of transitions, condition2 was significantly higher than condition1 and condition3, and there was no statistically significant difference between condition1 and 3. For connection difficulty, condition 2 was significantly higher than condition 1 and there was no significant difference between the other conditions. The notable point was that condition 2 was significantly higher than condition 1 in both of the two dependent variables. These results indicate that people need more cognitive effort for the task of moving floors in the middle, and less effort for the task of moving floors at the beginning.

Although there were some differences between two dependent variables as to whether there were significant differences among the conditions, the performance order was the same. Both variables had the highest performance in condition1, followed by condition3, and the lowest in condition2. For the number of transitions, low performance is more switching back and forth between the two maps to obtain route information. The number of transitions in condition2 was the highest and the lowest number of transitions in condition1. For the connection difficulty, the higher the difficulty score, the lower the performance. Condition2 had the highest score and condition1 had the lowest score.

As a result of interviews, people felt it difficult to carry out the task of floor movements in the middle. It was because even if the total lengths of the routes are similar, they had to remember the information on the two floors together, and connecting the route between the floors smoothly was not easy too. Also, people said that it was easy to move the floor at the beginning, because it is easy to do the easy thing first, and which floor to go is more general information than which spot to go within the floor. The results of these interviews are consistent with the results of the experiments. As a result, when people acquire spatial knowledge from a map of an indoor navigation system, giving a route that moves the floor at the beginning will help the formation of spatial knowledge, which will lessen cognitive efforts. Also, the route that should be avoided in particular is the case where a route is given to move the floor in the middle, which increases the cognitive effort to memorize and connect information about the two floors together.

5. Conclusion

This study conducted a contextual inquiry, follow-up interview, and case study in a preliminary study to see how Indoor Navigation System should be designed to support users' wayfinding in indoor environments. As a result, a total of 6 Design Implications were derived: 1) design the map representation considering the essential elements of the wayfinding task 2) use appropriate criteria and the number of chunks, 3) give feedback in the middle of a long straight path 4) consider giving distance information as a secondary source 5) consider individual's use of different strategy depending on the ceiling height 6) give the direction to move the floor level first. In particular, the last two design implications are important points that should be distinguished from the outdoor navigation system, which derived from the inherent characteristics of the indoor environment: limited space and vertical movement.

In previous studies, vertical movement was mentioned as one of the leading causes of difficulty in the wayfinding of an indoor space. Nevertheless, the case study showed that only one of the six indoor navigation systems is compatible with people's preferred floor movement strategy. As a result of contextual inquiry, people preferred to move the floor at the beginning of the route as no one preferred to move the floor level in the middle of the route during wayfinding. Therefore, in the main study, we conducted the experiment with the research question that the spatial knowledge acquisition performance would be the highest in the condition that floor movement occurs at the beginning of the route and the spatial knowledge acquisition performance would be the lowest in the condition that floor movement occurs in the middle of the route. Experiments have suggested that there are differences in spatial knowledge acquisition performance from indoor navigation map according to three conditions: when the floor level movement happens at the beginning of the route (condition1), in the middle of the route (condition2), and at the end of the route (condition3).

As a result, among the variables of spatial knowledge acquisition performance, the number of map transition, and the difficulty in connecting routes of the two maps mentally were both significantly low in condition1 than condition2. This can be explained by the follow-up interview. People felt more comfortable by moving the floor level first, as the route is presented in two dimensions rather than three dimensions to place them on the same plane as they wish to travel. On the other hand, when a route that moves floor level in the middle of the route is given, the cognitive effort was high because people had to connect two layers of routes in three dimensions mentally. Therefore, when designing an indoor navigation system map, routes involving floor movements should be designed to reach the destination floor level first, through vertical transportation near the starting point.

It is easy to get lost in indoor environments compared to outdoor environments, but research on indoor navigation system has been focused mostly on Indoor Positioning System, the technology-oriented view. As little research has been done on the design of indoor navigation systems, the importance of map design has been raised to offer more user-friendly and instructive information to users. Through this study, an important finding was discovered on what kind of information should be transmitted in which way to support user's wayfinding in the indoor navigation system in comparison to the outdoor navigation system. Also, we could see what elements should be considered to design an indoor navigation system to support any difficulties when moving floor levels, which is considered to be one of the biggest causes of indoor wayfinding difficulties.

Although this study has suggested a way to develop more user-friendly indoor map design, this study still has some limitations that need to be addressed in the future study. One of the limitations of this study is that the indoor space has been confined to only shopping centers. There are various types of indoor space, such as airport, university, convention center, and so on. However, it was difficult to find a huge indoor space that allows to have vertical movements and changing floor levels with any provided navigation system. Although this study is conducted with a purpose to provide more efficient wayfinding when it comes to an indoor navigation, there are some cases where inefficient wayfinding is preferred depending on the design and the purpose of the building. For example, the mall could have been designed more complicated for people to find directions as exploring around the mall can bring more profits to the company.

Another limitation in this study is that the research was conducted in a laboratory only focusing on the spatial knowledge acquisition rather than on on-site which could have extended the research focus to decision making process when wayfinding. A good navigation system defined in this paper was based on whether aids help users acquire spatial knowledge well and whether acquired spatial knowledge leads to good decision making in wayfinding. In order to do the wayfinding task in the field, vertical transportation should be located at the beginning, middle, and end of the route, which was impossible to control. Also, it was difficult to control extraneous variables such as crowds or obstacles.

Therefore, further study is needed to determine whether people's wayfinding tendencies vary according to different indoor spaces with different characteristics, and whether the design implication of this study can be applied in other indoor spaces other than the shopping mall. It is also necessary to study whether the results of this study are not limited to acquiring spatial knowledge but applied to actual decision making in wayfinding in the field. To see if there is a difference in decision making in wayfinding according to conditions, virtual reality can be used to control the extraneous variables of the indoor space and manipulate the conditions.

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국문초록

실내 내비게이션 지도에 대한 디자인 시사점: 층 이동을 중심으로

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협동과정 인지과학 전공

최근, GPS를 대체하는 여러 실내 위치 추적 시스템(Indoor Positioning System, IPS)의 개발과 거대한 실내 공간의 수가 증가하면서 실내 내비게이션 시스템에 대한 중요성은 커지고 있다. 실내는 실외와 달리 공간이 한정되어 있으며 다층 (multi-level)이라는 점에서 실외와 차이점을 가지며 특히 많은 사람들은 다층의 특성에서 발생하는 수직 이동, 즉 층 이동으로 인해서 실내 길찾기에서 많은 어려움을 겪는다. 그러나 실내 내비게이션 시스템에 대한 연구는 주로 IPS와 같이 기술적인 접근에 한정되어 있으며, 실내 내비게이션 시스템의 중요한 요소 중 하나인 지도 디자인에 대한 연구는 아직 초기 단계에 머물러 있다. 따라서 본 연구는 실내 환경에서 사용자들의 길찾기를 지원하기 위해 실내 내비게이션 시스템은 어떻게 디자인되어야 하는가에 대답하는 것을 목적으로 연구를 진행하였다.

먼저 이를 위해 예비 연구(preliminary study)에서 문맥적 탐구 (contextual inquiry)와 후속 인터뷰, 그리고 사례 연구를 진행했으며,

결과적으로 총 6개의 디자인 시사점을 도출했다: 1) 길찾기 과제의 특성을 고려해 지도 방향(map representation) 디자인하기 2) 경로에 대해 적절한 기준 및 수의 청크(chunk)를 사용하기 3) 긴 일직선 길 중간에 피드백 삽입하기 4) 거리 정보는 부수적인 수단임을 고려하기 5) 천장의 높이에 따른 길찾기 전략 차이를 반영하기 6)층 이동을 앞당겨서 경로를 제안하기. 도출한 예비 연구의 디자인 시사점 중 실내 길찾기에 영향을 미치는 중요한 특성인 층 이동과 관련하여 경로 내 최적의 층 이동 시점을 알아보기 위해 본 연구(main study)를 진행하였다. 실험에서는 사람들의 경로 내에서의 층 이동 시점(먼저 층 이동, 중간 층 이동, 마지막 층 이동)에 차이를 두어 정보를 제공했을 때, 사람들의 공간 지식(spatial knowledge) 획득의 수행에 차이가 있는지 확인하였다. 결과적으로 중간에 층을 이동하는 조건보다 먼저 층 이동을 하는 조건에서 두 층의 지도를 번갈아 보는 전환 횟수가 적었으며, 두 층의 경로 연결에 대한 체감 난이도 역시 낮았다. 따라서 본 연구는 실내 내비게이션 시스템 경로 디자인 시, 출발지와 최대한 가까운 시점에서 먼저 층 이동을 한 뒤 목적지 층에서 나머지 길을 찾아가도록 경로를 제공할 것을 제안한다.

주요어: 실내 내비게이션 지도, 실내 내비게이션 시스템, 층 이동, 공간 지식, 인지적 전략

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