TOWARDS PERSONALLY RELEVANT NAVIGATION: INTERACTION EFFECTS OF COGNITIVE STYLE AND MAP ORIENTATION ON SPATIAL KNOWLEDGE DEVELOPMENT

A Dissertation

by

HANNAH PARK

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Chair of Committee,	Manish Dixit
Co-Chair of Committee,	Stephen Caffey
Committee Members,	Jyotsna Vaid
	Wei Yan
	Patrick Suermann
Head of Department,	Phil Lewis

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ABSTRACT

Under the emergency situations such as floods and fires, or indoor navigation when the local landmarks and GPS is no longer available, the acquisition of comprehensive environmental representation became particularly important. While the previous indoor navigation studies have mainly focused on the navigation efficiency, training individuals to acquire spatial knowledge is often ignored. Spatial navigation is a multidimensional construct that commonly involves many spatial factors such as spatial learning perspective, spatial ability, spatial strategy and spatial knowledge. Several studies also demonstrated that individual differences may play an important role in spatial navigation. There are some studies have suggested that individual personality, especially cognitive style (Field Independent vs. Field dependent) may relate to individual spatial learning. The study hypothesized that a certain type of learning perspective may be more efficient than the others for individuals with different cognitive styles. Forty participants were recruited and performed spatial task in the virtual maze environment. Field Independent participants exhibit greater scores in spatial visualization and spatial orientation test. There was, however, no considerable difference in spatial relation ability between Field Independent (FI) and Field dependent (FD) participants. The notable finding is that the correlation between spatial visualization and cognitive style is more robust than the correlation between spatial visualization and gender. The study results also revealed that there was no significant interaction between cognitive style and everyday navigation strategy. Both FD and FI participants showed

more accurate canonical organization in their sketch map after they were guided by a north-up map. In terms of route knowledge, FI participants had more correct answers in the landmark sequencing tests after they were guided by a north-up map compared to their performance in forward-up map conditions. On the other hand, FD participants had higher accuracy in landmark sequencing tests in the forward-up map condition than their performance in the north-up map condition. In the route retracing test, however, there was no statistically significant effect of map orientation on different cognitive style groups. This study has suggested that cognitive style may have a potential effect on the relationship between map orientation and acquiring spatial knowledge.

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Contributors

This work was supervised by a dissertation committee consisting of Professor Manish Dixit of the Department of Construction Science, and Professors Stephen Caffey and Wei Yan of the Department of Architecture, and Professor Jyotsna Vaid of the Department of Psychological & Brain Sciences.

The data analyzed for Chapter 3 was provided by Nafiseh Faghihi.

All other work conducted for the dissertation was completed by the student independently.

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1. INTRODUCTION

1.1. Background

Spatial navigation means an individual's ability to locate and navigate through an environment by using spatial cues (Shahrzad & Nasser, 2015). This ability has been considered a critical skill of our daily life as we constantly migrate between known and/or unknown locations. According to Goodchild et al. (1998), "The ability to manipulate, interpret and store information about changing environment is a critical skill for humans' survival" (p.33).

With recent advances in the information technology and the availability of personal mobile navigation systems, determining directions to reach a destination has become much easier. However, the acquisition of comprehensive environmental representation is still important since we might encounter situations where technology may fail, and we may need to rely solely on our own spatial knowledge to plan a path and navigate to a destination (Hirtle & Raubal 2013; Richter 2013). Such situations may include, for example, 1) navigating in situations with limited landmarks and confusing visuo-spatial cues (e.g., construction site, alien terrain, under natural disaster situation), 2) navigating in indoor spaces where the GPS system does not guide accurately (Radoczky 2003, Hohenschuh 2004), and 3) break down or loss of devices during navigation. Indoor navigation (e.g., indoor Positioning, Localization and Navigation), especially, has gained increasing attention recently in building technology (Huang & Gartner, 2010; El-Sheimy & Li, 2021; Cadena et al. 2016). Building Information Modeling (BIM) and Internet-of-

Things (IoT) signal (e.g., Wifi, Bluetooth, etc) has often combined for indoor positioning (Vasisht et al. 2016; Zhuang et al. 2016).

While the previous indoor navigation studies have mainly focused on the navigation efficiency (e.g., how fast people get to the target location by following the route guide), training individuals to acquire spatial knowledge (e.g., a mental model of the space) is often ignored (Gartner & Uhlirz 2005). However, in the circumstances of crowd evacuation from large and complex building spaces (e.g., sports events or concert), knowing detailed internal connectivity of the space is important factor to shorten the evacuation time. In the study by Pelechano & Badler (2006), they simulated the evacuation where fire occurred at several sites within the building, the total evacuation time decreased as the number of trained agents increased. Their results also show that if the trained individual consists at least 10 % of total population, they observed a large amount of difference in evacuation time (Pelechano & Badler, 2006).

However, a number of recent studies have shown that individuals navigating with mobile technology have shown lower survey knowledge acquisition. Many researchers have demonstrated that the lapse of attention on the surroundings due to the use of mobile navigation device and its continuous spatial updating adversely impacts spatial learning (Gardony et al. 2013; Wang & Spelke, 2000). Another possible cause of spatial knowledge degradation could be a discrepancy between the information provided by a digital map and individual differences in inherent spatial schemata used for interpreting spatial relations. For example, recent investigations suggested that our cognitive survey maps are not always oriented with reference to north (Brunye et al. 2015; Werner and Schmidt, 1999; Montello, 1991). Rather, they can be oriented with respect to convenient reference systems for organizing spatial knowledge such as major streets. In addition, Blajenkova et al. (2005) found evidence of individual difference in use of spatial reference frame (spatial strategy) is related to the types of spatial representation that an individual creates. For example, the participants who rely on landmark features during navigation form different spatial representations than those on directional cues (e.g., turns and direction). Therefore, it is important to acquire a complete and accurate spatial representation of our environment as quickly as possible while navigating in familiar as well as unfamiliar settings. To do that, it is necessary to understand how we develop the mental representation of a spatial environment while navigating.

1.2. Significance

Effective learning of spatial information is becoming increasingly crucial in recent years with intensifying natural events such as flooding, wildfires, tropical storms, and earthquakes. With the emerging new technologies and frequent occurrence of such radical events, the future of work is being transformed and is projected to involve work conditions with altered or extreme spatial environments. The future workforce may need to work and operate under extreme conditions that may either impair their spatial cognitive abilities or demand much superior spatial skills. Furthermore, the exploration of desolate and hard to reach altered environments such as space, deep ocean, and polar regions is increasing that would necessitate preparing a workforce that can operate safely, efficiently, and more productively (Clément et al., 2015; Stapleton et al., 2016; Kanas, 2015; Marin & Beluffi, 2018; Smith, 2014; Tiziani, 2013). The ability to gather and process complete and accurate spatial knowledge and navigate through such spatial environments would become critical to help future workers to adapt to and operate under extreme altered conditions (Clément et al., 2015; Bertels, 2006). Accordingly, it is necessary to understand why individuals are different in their navigation ability and what are the internal variables involved in navigation activity.

1.3. Definition of Spatial Navigation

Spatial navigation defined by Montello (2005) consists of two components: locomotion and wayfinding. Locomotion refers to navigation behavior in response to sensory information such as obstacle avoidance and steering. Wayfinding refers to navigation behavior which requires planning and decision making. Another classification was proposed by Allen (1999) was based on the following three tasks: 1) exploratory navigation (e.g., exploring in the new city), 2) travel to familiar destination (e.g., commuting from home to workplace), and 3) travel to novel destinations (e.g., wayfinding guided by maps). A more detailed taxonomy of navigation was introduced by Wiener et al. (2009). Their taxonomy is started from Montello’s definition of spatial navigation: *locomotion* and *wayfinding*. They then classified *wayfinding* into two parts with respect to the existence of an external aid such as map, signage, or route instructions (see Figure 1.1). In terms of external aids, some studies have investigated the different types of aid other than visual aid for supporting wayfinding especially for people with dementia. Those other types of aids include auditory and tactile cues

(Grierson et al., 2011; Yi et al., 2015). However, auditory, and tactile wayfinding aids and unaided wayfinding behavior are not the scope of current study. For the purposes of this research, spatial navigation in this paper is defined as wayfinding behavior with external visual aid based on Wiener's taxonomy.

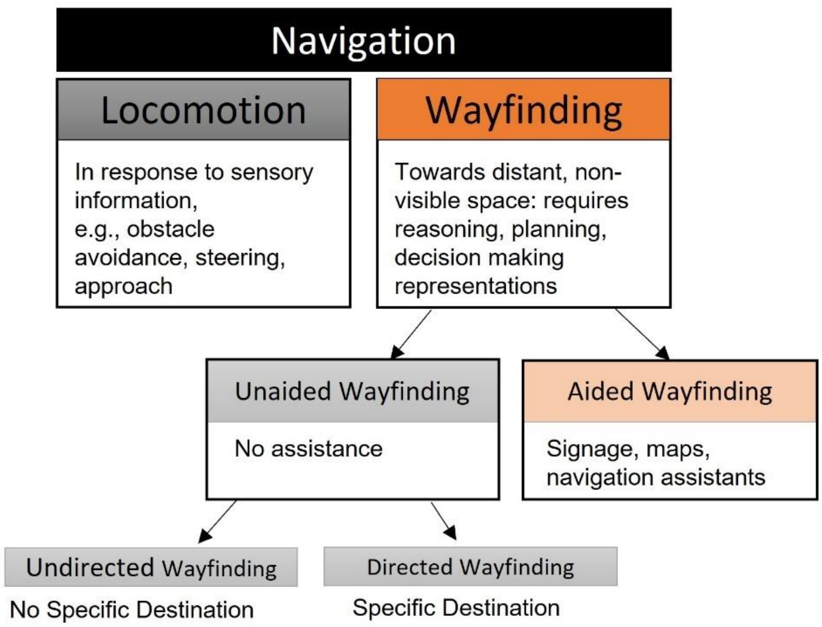

Figure 1.1 A Navigation Taxonomy Addressed by Wiener et al. (2009).

2. LITERATURE REVEIW

2.1. Spatial Navigation Variables

Spatial navigation is a multidimensional construct that commonly involves three main processes: 1) gathering spatial information, 2) manipulating the gathered information, and 3) creating mental representation which is often called spatial knowledge or spatial representation. Thus, the factors directly associated with spatial navigation may also relate to how we gather the spatial information (e.g., spatial learning perspective) and how we manipulate this information (e.g., spatial ability and spatial strategy) and lastly, how we organize the gathered information into a useful mental representation (e.g., spatial knowledge). Numerous studies attempted to describe the process of spatial navigation and identified variables that may affect navigational performance.

2.1.1. Spatial Learning Perspective and Map Orientation

Spatial navigation requires encoding different sensory information (e.g., spatial position of buildings and street names) and integrating that information into a useful representation (Weisberg et al., 2014). This may occur through direct exploration (ground-level) or sometimes studying external spatial representations such as a map (aerial) (Throndyke & Hayes-Roth, 1982; Boccia et al., 2016). Table 2.1 summarizes different features of a ground-level and an aerial spatial learning perspective. Figure 2.1 shows examples of different spatial learning perspective. A ground-level learning involves direct interaction with spaces from an egocentric (or horizontal) perspective. In this learning perspective, people continually gathering information with reference to themselves in a dynamic stream. In an aerial learning perspective (or map-learning), people collect static spatial information indirectly from an allocentric perspective (i.e., a bird's eye view). Therefore, ground-level and aerial learning can be differentiated in terms of their modes of learning experiences (e.g., direct vs. indirect), learning perspective (e.g., egocentric vs. allocentric), modes of information collection (e.g., dynamic vs. static), orientation (e.g., orientation free vs. fixed orientation). In these regards, different spatial learning perspective may derive different forms of spatial knowledge (Throndyke& Hayes-Roth, 1982; O'Neill, 1992).

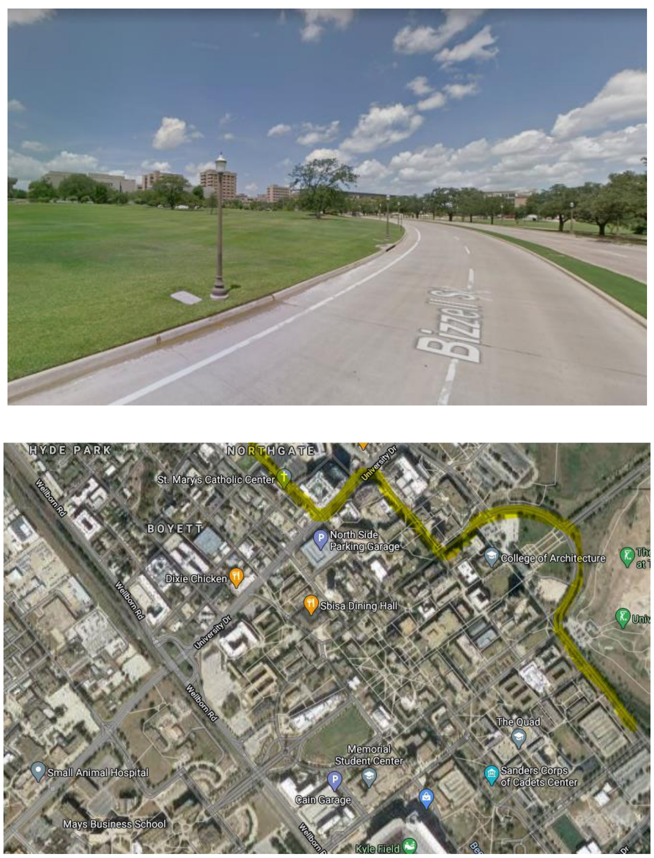

Figure 2.1 Ground-level learning (top) and aerial learning (bottom)

Thorndyke and Hayes-Roth (1982), for example, conducted an experiment comparing two groups: one group of participants worked inside a building for up to 2 years (round-level learning) and the other group studied a map of the building (aerial learning). Their results showed that the map learning contributes to survey knowledge of the environment such as Euclidean (straight-line) distance and object location judgments, whereas ground-level learning contributes to route distance and orientation information. Golledge and his colleagues (1995) also conducted a study comparing map versus ground-level learning. They concluded that map learning is more effective in understanding survey-level knowledge (e.g., estimate distances, angles, linkages) within an environment (Golledge et al., 1995).

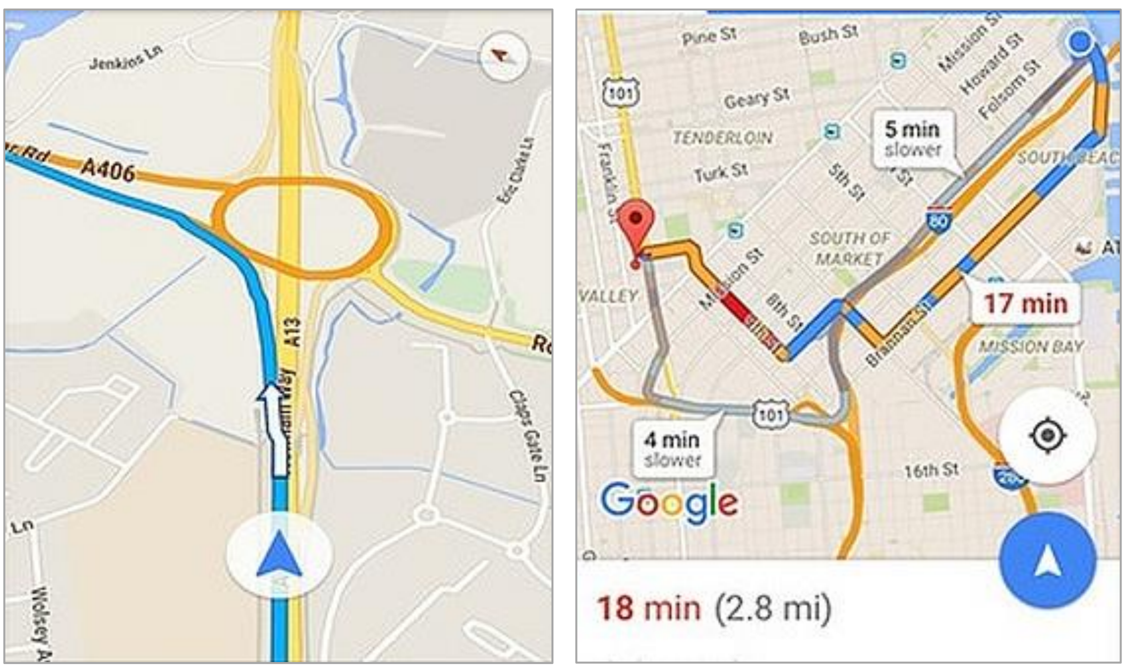

Figure 2.2 Example of forward-up map (left) and north-up map (right)

With reliance on mobile technology, we often learn the environment with both ground-level and aerial learning (Richter et al. 2010; Munzer et al. 2006; Parush et al. 2007). For example, we directly explore a new environment (ground-level) with the Google map (aerial). In this case, the orientation of the map in the display might play an important role in navigation. The orientation of the map can also have two types: forward-up display, and north-up display (see Figure 2.2, Aretz & Wickens, 1992). Cuevas et al. (2001) explored the effect of map orientation (e.g., north-up vs. track-up) on the performance of computer-based navigation tasks. They found that the forward-up group had more difficulties in the tasks (higher workload) and rated the map display less helpful.

Table 2.1 Differences in Spatial Learning Sources (modified from Throndyke & Hayes-Roth, 1982)

Feature	**Types of Spatial Learning**	
	Ground-level	**Aerial**
Learning Sources	Direct exploration	External representations
Spatial Knowledge	Route & Survey	Survey
Learning Experience	Direct	Indirect
Perspective	Egocentric (horizontal)	Allocentric (vertical)
Modes of Information	Dynamic	Static
Orientation	Orientation free	Fixed orientation

2.1.2. Spatial Ability

Spatial ability is one of the key cognitive abilities that helps humans represent, transform, generate and recall spatial information (Linn & Peterson, 1985). It has been asserted that spatial ability is not a unitary concept but consists of several cognitive sub-skills (Voyer et al., 1995). Three dominant spatial abilities frequently discussed in literature are: (1) spatial visualization (SV) abilities to mentally manipulate spatial objects and patterns (Kozhevnikov & Hegarty, 2001; Su et al., 2015); (2) spatial orientation (SO) abilities to perceive an object from different perspective (Ekstrom et al., 1976); and (3) spatial relations (SR) abilities to mentally relate the two- and three-dimensional views of the object (Hegarty & Waller, 2004; Gagnon, 1985; Ray et al, 1981; McGee, 1979; Vandenberg, 1975; Su et al., 2015; Contero et al., 2005) (see Figure 2.3). Golledge et al. (1995) described that SV is “the ability to mentally manipulate, rotate, twist or invert two- or three-dimensional pictorially presented visual stimuli.” (p. 136), SO is “the ability to imagine how a configuration would appear if viewed from a different orientation or perspective.” (p. 136), and SR is “the ability to estimate or reproduce distances, angles, linkages and connectivities” (p.136).

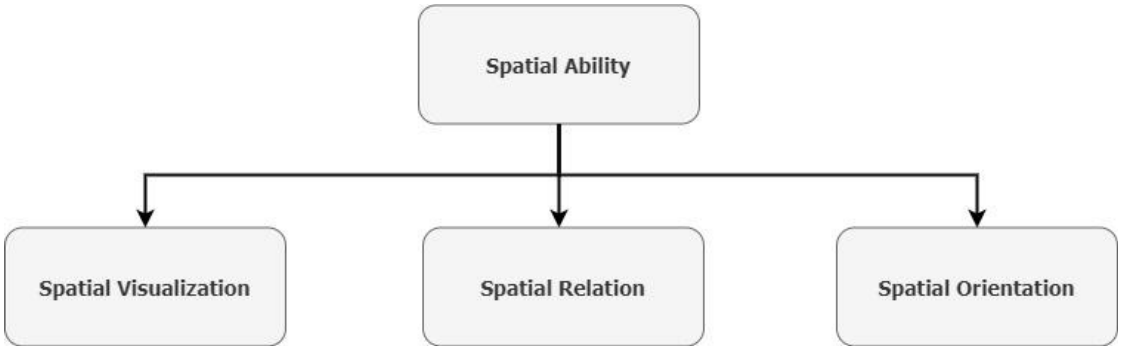

Figure 2.3 Spatial ability dimensions addressed by Kozhenikov & Hegarty (2001).

2.1.3. Spatial Strategy

The process of encoding the sensory inputs of spatial information into mental spatial representation is termed “spatial strategy” or “spatial processing.” While navigating through or working in a spatial environment, spatial information is continuously gathered and updated through vestibular, somatosensory, and visual systems. As shown in Figure 2.4, this information is processed using mainly two types of spatial strategies to develop a complete and accurate spatial representation: (1) route strategy and (2) survey strategy (O’Keefe & Nadel, 1979).

The route strategy, also known as “self-to-object” strategy, involves identifying and relating spatial objects and features of a spatial environment with respect to one’s own position (O’Keefe & Nadel, 1979). For instance, a person understanding an object to be either on the left- or right-hand side of his/her body denotes egocentric strategy (O’Keefe & Nadel, 1979). Therefore, in spatial learning, egocentric strategy relies on directional cues (“left turn” or “right turn”) and landmark cues. A survey strategy, on the other hand, involves relating spatial objects with reference to other spatial objects

(O'Keefe & Nadel, 1979). People perceiving, for example, the position of a chair to the left or right of a table or location of a store to the east or west of a train station apply the allocentric strategy. In spatial navigation, allocentric strategy often relies on Euclidean information (e.g. NSWE or distance).

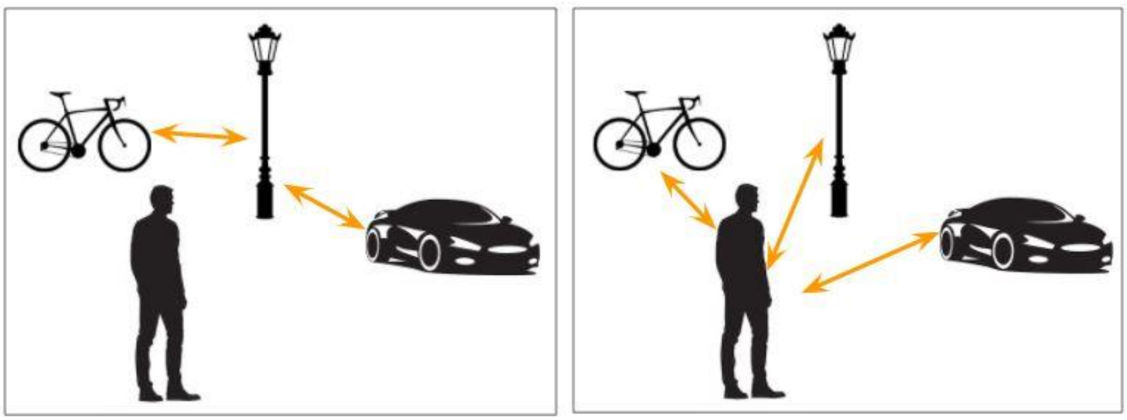

Figure 2.4 Survey strategy (left) and route strategy (right).

Some recent studies suggested that there is individual preference in using a certain type of spatial strategy (Pazzaglia et al., 2000; Pazzaglia & De Beni, 2001). Pazzaglia et al. (2000) used a self-report questionnaire for measuring individual spatial strategies. Their results showed that individuals preferentially use a specific spatial strategy (e.g., Landmark, Route and Survey strategy). They concluded that individual spatial strategy may correspond to the type of spatial knowledge (e.g., landmark, route or survey knowledge). Furthermore, gender was shown to correlate with a specific spatial strategy that individual may adopt to orient themselves in environment. Chai & Jacobs (2010), for example, reported males relying on a survey reference frame and directional cues, whereas females on landmarks and positional cues. Others suggested that these differences have neural correlates. Marchette et al. (2011) described that people with larger hippocampus tend to use more of allocentric strategy. Some studies also suggested that the size of hippocampus can be changed after spatial training (Woollett & Maquire, 2011). London taxi drivers who have extensive spatial experiences, for example, were found to have a larger hippocampus as compared to a normal population (Maguire et al., 2006).

2.1.4. Spatial Knowledge

Spatial knowledge which is the understanding of the spatial structure of an environment is the end product of a spatial learning process (Mondschein et al., 2010). Spatial knowledge can be of two types (see Figure 2.5): (1) route knowledge; and (2) survey knowledge (Throndyke & Hayes-Roth, 1982). Route knowledge (or "procedural knowledge") often denotes the knowledge about a path/route from one point to another in terms of an egocentric spatial relationship (Thorndyke & Hayes-Roth, 1982). It is often conceptualized as a sequence of landmarks or turn instructions (e.g., ahead, left, or right) (Montello et al., 1999).

In contrast, survey knowledge refers to global spatial relations of objects and places in an environment (Thorndyke & Hayes-Roth, 1982; Siegel & White, 1975; Golledge, 1999). Therefore, it is frequently conceptualized as a "map like" spatial representation (Gramann, 2013). Survey knowledge can be acquired without direct exploration through, for instance, reading a map which illustrates spatial information in an aerial perspective (Thorndyke & Heyes-Roth, 1982; Giraudo & Pailhous, 1994;

Golledge et al., 1995). O'Keefe & Nadel (1979) have suggested that survey knowledge allows greater flexibility in navigation than route knowledge. They found that individuals who do not rely upon survey knowledge are more likely to become disoriented when they deviate from a learned route. Therefore, survey knowledge is often considered as the most comprehensive form of spatial knowledge (Golledge et al., 1995).

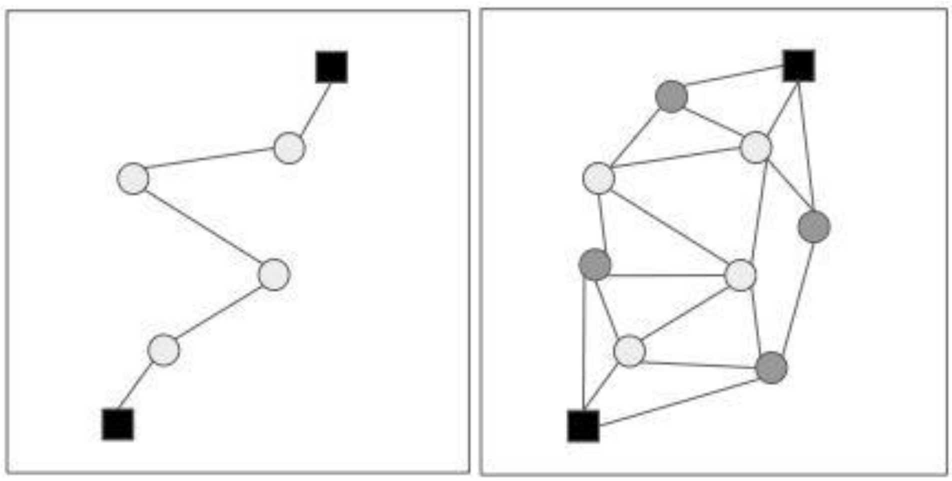

Figure 2.5 Route knowledge (left) and survey knowledge (right) according to Siegal and White (1973)

2.2. Individual Differences in Spatial Navigation

Several studies demonstrated that individual differences may play an important role in spatial navigation. For example, Ishikawa and Montello (2006) found that some of the participants obtained spatial knowledge about a learned environment within the first exposure, whereas some did not show any improvement at all over the 14-week spatial navigation study. They argued that individual variance of performance in the spatial knowledge tasks is correlated with individual traits such as spatial ability. Several studies have argued that individual differences in spatial ability may correlate with individual "enduring characteristics" (Hegarty et al, 2021, p.13) which are consistent across time and context.

2.2.1. Gender

Many past studies shown that gender is highly related to spatial ability which leads to differences in spatial navigation performance (e.g., Galea & Kimura, 1993; Dabbs et al., 1998; Montello et al., 1999; Hegarty et al., 2006; Castelli et al., 2008; Lawton, 1994; Bosco et al., 2004; Weisberg et al., 2014; Boone et al., 2018). Linn & Peterson (1985) conducted a meta-analysis and found males performing better than females on two types of spatial abilities: mental rotation and space perception. For the spatial working memory ability, however, mixed results presented. Some studies could not find significant difference between gender on spatial working memory tasks (Galea & Kimura, 1993; Dabbs et al. 1998; Voyer et al., 2017) whereas some studies found males significantly outperformed females (Montello et al., 1999; Saucier & Green, 2002).

In terms of spatial knowledge tasks, however, mixed results have been reported between route and survey knowledge tasks. Many studies reported that males outperformed females on survey knowledge tasks (Dabbs et al., 1998; Montello et al., 1999; Castelli et al., 2008; Schmitz, 1999; Soucier & Green, 2002), whereas relatively less studies found them performing significantly better than females on route knowledge tasks (Montello et al., 1999; Weisberg et al., 2014). One study by Lawton (1994) found females outperformed males on route knowledge tasks. These mixed results may relate to the different use of spatial strategy between gender.

Gender has been demonstrated as an important mediator of a preference for the use of a certain type of spatial strategy. Past studies suggested that those men and women use different types of strategy to navigate through an environment (e.g., Lawton, 1994, 1996, 2001; Montello et al., 1999). Lawton (1994) found that men were more likely to use survey strategy than women (e.g., distances and cardinal directions) (e.g., landmarks and right/left turns). His findings are consistent with other studies, which demonstrated males use more of environmental cues, whereas females more of salient landmark cues (Choi & Silverman 2003; Galea & Kimura 1993). Galea & Kimura (1993) and Dabbs et al. (1998) also reported females outperforming males in recalling landmarks tasks.

Although past findings indicate that there are large gender differences in spatial variables, there are active debates on the causes of the difference. Some argues the cause of gender differences could be biological difference. Some researchers addressed that the gender difference in spatial visualization (e.g., mental rotation) may be due to the different structure of the parietal lobe which is the brain region that controls the spatial ability between gender (Koscik et al., 2009; Salinas et al., 2012). According to Goldstein and colleagues (2001), males have 20% greater parietal lobe volume, and the surface area is larger than females. However, the recent meta-synthesis of three decades of human brain studies have raised a doubt on their findings (Eliot et al., 2021). They argue that when individual brain size is accounted, the gender difference of brain structure or laterality is trivial (Eliot et al., 2021).

Moreover, many studies addressed social and environmental causes of gender differences in spatial abilities. Hyde (2016) argues that since there is a lack of spatial curriculum in the schools, gender differences may be due to differences in spatial related activities such as the time spent in sports and video game playing. This assumption could be supported by the study findings that boys engage in more spatial play and higher quality play (Jirout & Newcombe, 2015; Levine et al., 2012; Cherney & Voyer 2010). Studies have also shown that spatial abilities can be improved by training (e.g., see the metal analysis by Uttal et al., 2013; Kornksem & Black, 2015; Ishikawa, 2021). In the study conducted by Feng (2007), female participants in an experimental group were trained for 10 hours on a video game. The results show that the females who received the video game training performed spatial tasks as well as the males that had not had the training. Schug et al. (2022) also found childhood experiences inferred from the childhood range size and Lego play was associated with higher score in the mental rotation test. They also compared two different regions, Faroe Islands, and the United States. Faroe females who reported more childhood spatial experience than the US females performed as good as the US males. This result indicates that spatial ability is largely associated with previous spatial experiences (Schug et al., 2022). Given the above discussion among spatial navigation scholars, gender difference in spatial variables is still a subject to debate in the literature.

Table 2.2 Example of studies investigated gender differences in spatial variables

Study (Year)	**Perspective**	**Spatial Abilities**			**Spatial Strategy**		**Spatial knowledge**	
		SV	SR	SO	Ego	Allo	Route	Survey
Galea & Kimura (1993)	Survey	M>F					M=F	M>F
Dabbs et al. (1998)	Survey	M>F					M=F	M>F
Malinowki & Gillespie (2001)	Both						M>F	M>F
Saucier & Green (2002)	Route	M>F				M>F	M=F	M>F
Montello et al. (1999)	Both	M>F	M=F		--	--	M=F	M=F
Hegarty et al. (2006)	Route	M>F		M=F				M>F
Castelli et al. (2008)	Route	M>F				M	M=F	M>F
Schmitz (1999)	Route						M=F	M>F
Weisberg et al. (2014)	Route	M=F		M>F				M=F
Lawton (1994)	Route	M>F			F>M	M>F		
Lawton & Kallai (2003)					F>M	M>F		

Note: SV = spatial visualiztion, SR = spatial relation, SO = spatial orientation, M = male, F = Female, -- = no significant correlation

2.2.2. Cognitive Style

There are some studies have suggested that individual personality, especially cognitive style may relate to individual spatial learning. (Mazza et al., 2019). Cognitive style refers to the preferred ways or strategy in which individuals acquire and process information which is expected to be consistent across time and contexts (Messick, 1984). Cognitive style has been traditionally considered as a unitary bipolar dimension (Blazhenkova & Kozhevnikov, 2008). Field independence and field dependence are the most well-known dimensions classifying individual cognitive styles (Schwartz & Phillippe, 1991). Field independent learners are able to distinguish figures as discrete from their backgrounds, whereas field dependent individuals learn figures as an integral part of the background in which the figures are presented (Witkin et al., 1977). Kirby et al. (1988) have suggested that field dependent learners are more holistic and rely more on imagery. Field independent learners, by contrast, rely more on analytical strategies (Kirby et al., 1988). The popular measures of cognitive style in spatial learning literatures include Group Embedded Figures Test (GEFT, Oltman et al., 1971), Gestalt Completion Test (Street, 1931) and Hidden Patterns test (French et al., 1963).

2.2.3. Cognitive Style and Map Orientation

Some studies also found that individual factors such as cognitive style is highly associated with spatial learning perspectives. The results of Pazzaglia & Taylor (2007) showed that people with field dependent predisposition performed better with ground-level learning perspective than aerial perspective. Conversely, people with field independent predisposition were less dependent on learning perspective. In other words, people who have high preference for survey representation are more flexible to change from one type of perspective to another. Li et al. (2016) examined the effect of cognitive style and the perspective of the map on orientation tasks and navigating tasks. In navigating tasks, they measured how often the participants refer to the map while they are navigating in virtual environment, and the total task completion time. Two different map perspectives were provided: one with north-up and is the other with track-up map. Results indicated that field dependent individuals perform significantly well in orienting tasks with the track-up map than with the north-up map. Field independent individuals, however, did not show any difference in the orienting tasks with both map perspectives. In navigating tasks, field dependent individuals perform significantly better when they used track-up map than north-up map. Field independent individuals, on the other hand, showed superior performance when using north-up map. Given the above evidence, a certain type of learning perspective may be more efficient than the others for individuals with different cognitive style.

2.2.4. Cognitive Style and Spatial Ability

It has been demonstrated that individual spatial abilities, especially spatial visualization (SV) and spatial orientation (SO) affect cognitive style or vice versa. A study by Boccia et al. (2016) investigated correlation between cognitive style and spatial abilities. The study used mental rotation task to measure spatial visualization ability and perspective taking task to assess spatial orientation ability. Their results showed that individuals' predisposition towards field independence predicted higher performance on mental rotation and perspective taking tasks. Likewise, Li et al. (2016) reported that field independent individuals showed a higher accuracy in mental rotation tasks than field dependent ones. Such a different performance on spatial ability tasks depending on the type of cognitive style may, to some extent, be a result of the different ways in which individuals organize/process spatial information. Field independent individuals are more likely to perceive a field in terms of its components in processing spatial information, whereas field dependent individuals perceive a field as a whole (Witkin, 1977). Therefore, spatial tasks that require extracting input information (object) from contextual surroundings may be more difficult for field dependent individuals (Li et al., 2016; Boccia et al., 2016).

2.2.5. Cognitive Style and Spatial Strategy

The correlation between cognitive style and learning perspective discussed above may also be explained by an individual's predisposition towards processing of environmental information. Several studies suggested that different cognitive styles react differently to different types of spatial information gathering. For example, Denis et al. (1999) conducted a study with different cognitive style participants: one group showed a preference for adopting survey representations and another group showed a preference for remembering landmarks. They provided only a verbal description of a route direction, which does not include any description of holistic spatial features of the environment. The group who showed preferred to use survey representation made more errors in navigation than the group preferred to use landmark cues. In another study, Pazzaglia & De Beni (2001) showed similar findings that the group with a higher preference for adopting survey representation made more mistakes in navigation when they were provided with verbal route directions instead of holistic spatial information. These results suggest that providing appropriate spatial information based on cognitive style is important to maximize the effect of spatial learning. However, only a limited number of studies were found which investigated the relationship between cognitive style and spatial strategy.

2.2.6. Cognitive Style and Spatial Knowledge

The effect of cognitive style on spatial knowledge has mixed results across studies. Boccia et al. (2017) showed that field independent individuals are associated with better performance on survey tasks. They concluded that the more an individual is field independent, the more developed the survey knowledge. On the other hand, Kroutter (2010) found that cognitive style was associated with navigation behavior but was not associated with learning outcomes (spatial knowledge). This result suggested that the dimension of cognitive style affected an individuals' spatial strategy (a way of processing environmental information) but not spatial knowledge. Therefore, more studies may be needed to examine the effect of cognitive style on spatial knowledge.

In conclusion, the previous studies have demonstrated individual cognitive style may relate to essential factors that affect human spatial navigation. Different levels of ability to extract input information from contextual surroundings depending on individual's cognitive style may cause different abilities in spatial ability tasks, use of spatial strategy and favored spatial learning perspective. However, mixed results were found in terms of the spatial learning outcomes (spatial knowledge).

2.3. Addressed Research Gap

Based on the literature review, existing knowledge and research gaps are identified.

(1) Based on the current literature review, relatively little research has been found to identify the relationship between cognitive style and spatial navigation.

(2) Although several studies investigated whether people with different cognitive styles prefer different map orientations (Cuevas et al., 2001; Li et al., 2016), it has not yet been identified if a certain map orientation affects spatial knowledge acquisition of an individual with different cognitive style.

(3) Some studies investigated the relationship between individual cognitive style and spatial abilities. However, it has not been thoroughly investigated on all three components of spatial ability (e.g., spatial visualization, spatial orientation, and spatial relation).

(4) Some literature provided evidence that individuals with different cognitive styles might take different spatial strategies (Pazzaglia & De Beni, 2001; Denis et al., 1999). Those studies, however, have a limitation since they did not use the standard cognitive style measure. Therefore, additional research with standard cognitive style measures is needed.

(5) More studies may be needed to examine the effect of cognitive style on spatial knowledge acquisition since the existing studies show mixed results (e.g., Boccia et al., 2017; Kroutter, 2010).

3. EXPLORING SPATIAL ABILITIES

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3.1. Introduction

With emerging new technologies, the future of work is being transformed and will involve the exploration of desolate and hard to reach altered environments such as space, deep ocean, and polar regions (Clément et al., 2015; Stapleton et al., 2016; Kanas, 2015; Marin & Beluffi, 2018; Smith, 2014; Tiziani, 2013). Such environments pose extreme visual or gravitational conditions that may aff ect our ability to work safely and productively. Two commonly reported difficulties adversely influencing work performance and worker safety include: (1) misaligned body and visual axis due to weightlessness (e.g. visual reorientation illusion), and (2) absence of familiar visuospatial cues (NASA, 2015; Zhu et al., 2011). Failure to create a clear spatial representation of space could result in poor performance and even risk of injury under such conditions (Zhu et al., 2011). Therefore, reliable training technologies for workers to adapt to extreme environments must be developed in order to generate significant benefits in such work domains (London et al., 2017; Clément et al., 2015; Bertels, 2006; NASA, 2015). Although extreme environments have various environmental conditions that might affect work performance (e.g. temperature), this study addresses the following kinds of extreme settings: spaces with conflicting body and visual orientation.

The main knowledge gaps addressed in this paper are summarized as follows. First, this study empirically demonstrates how extreme conditions, particularly, with conflicting visual and body verticals affect a specific dimension of spatial ability. While some studies have experimented with spatial abilities in conditions where a visual orientation is upright (e.g., Matsakis et al. 1993; Leone et al. 1995), in extreme environments, a visual reference frame may not always be upright and can constantly change with time (Harris et al., 2017; Kanas, 2015). Moreover, spatial ability consists of two major dimensions including object manipulation ability and spatial orientation ability (Hegarty & Waller, 2004; Gagnon, 1985; Ray et al, 1981; McGee, 1979). Most of the research on spatial ability under extreme environment, however, has been focused on object manipulation ability (e.g., mental rotation test), and less attention has been paid to spatial orientation ability (Matsakis et al., 1993; Leone et al, 1995). Second, this study will investigate the relationship between individual's tendency to adopt a certain spatial strategy (egocentric vs. allocentric) and their use of spatial reference frame (body vs. visual) under such conditions. A recent study suggested that there might be an individual characteristic that favors a specific reference frame over another when acquiring spatial representation (Gramann, 2013; Gluck & Fitting, 2003). The spatial strategy indicates the process of encoding spatial information to construct an accurate spatial representation (O'Keefe & Nadel, 1978). Depending on the spatial reference frame that one relies on, a spatial strategy can be of two types: egocentric or allocentric.

An egocentric strategy involves updating the position of objects in a spatial environment relative to one's body reference frame. An allocentric strategy, on the other hand, updates the position of objects with respect to the visual frame of reference including other objects in the environment (Kozhevnikov & Hegarty, 2001). Although some studies have proposed the existence of reliable individual differences in spatial strategy usage, they have not been empirically tested (Gramann, 2013; Gluck & Fitting, 2003). The purpose of this study is to understand how extreme conditions with statically and dynamically conflicting visual and body orientation influences spatial ability. The study also investigated the relationship between a tendency to adopt a certain spatial strategy (egocentric vs allocentric) and the use of a certain spatial reference frame (body vs. visual) under such conditions. We contend that identifying individual differences in spatial strategy preference could help guide training methods for working under extreme conditions.

3.2. Research Methodology

3.2.1. Participants

Thirty-two participants (20 males and 12 females) at Texas A&M University with normal or corrected-to-normal vision took part in the study. All participants were recruited through a notice sent in the university's email system. Participants were undergraduate students, graduate students, and doctoral researchers. Their ages ranged from 18 to 39 years old, with a mean age of 24.8 (SD=6.27). All the participants provided written consent prior to the study and research was carried out in agreement with the Institutional Review Board of Texas A&M University. Study participation was voluntary.

3.2.2. Study Environment

The study environments were created in the Unity game engine (http://unity3d.com/) which allows creating and running games in customized environments and writing codes for desired performance (Unity 3D, 2019). We created a cubical virtual room with a space shuttle-like interior (Figure 3.1 left). All four walls of the space were covered with the same texture and color. The ceiling contained a brighter shade in order to match the general “light-from-above” heuristic (Champion & Adams, 2007). The floor of the room was covered with darker metal textures. We intentionally used the distinct texture and color for the floor, walls, and ceiling to give a clear surface identity, which also helped replicate the real work environment such as Russian Mir Station which has modules with dark floors and light ceilings (NASA, 1995).

In order to test how misalignment of the visual axis and body axis affects the spatial ability, we created three environmental conditions. The first condition was a *Normal* condition in which the body axis of a subject was aligned with the visual axis. This condition served as the control for the other two conditions. The second condition was a Static condition in which the visual axis tilted at a randomly chosen fixed angles while the subject’s body axis was upright. The tilting angles ranged from -90 degrees to 90 degrees in 15-degree intervals. The angle for x, y, and z axes were chosen within the range by using a random number generator. The third condition was a Dynamic condition in which the visual axis (the VR room) was programmed to continuously rotate randomly around x, y, and z axes while the subject was seated upright (see Figure 3.1 right).

During the experiments, the participants sat erect in a swerve chair and viewed the interior of a virtual module through a high-resolution (640 X 480 pixels per eye) color stereo head-mounted display (HTC Vive) that had a 60-degree diagonal field of view and 100% stereo overlap. Participants were free to look around the virtual environment while seated on the chair during the experiments.

Figure 3.1 VR Study Environment: Aligned (left), Misaligned (middle) Condition. Reprinted from [Park et al., 2021].

3.2.3. Tasks

Participants completed the following individual tasks:

The Navigation Strategy Questionnaire (NSQ: Zhong, 2013; Zhong & Kozhevnikov, 2016) measures individual everyday spatial strategy. The NSQ was designed to assess the strategies that different individuals engage in when they encode environmental information. There were 44 items assessing the individual preferred spatial updating strategies including 12 survey strategy items, 17 egocentric survey strategy items and 15 route strategy items. Survey strategy refers to the use of Euclidean information of space such as cardinal/compass direction and exact distances (e.g., "I tend to judge my orientation in the environment in terms of cardinal directions (north, south, east, and west)”). Egocentric-survey strategy also refers to the use of Euclidean information of space. The difference between survey strategy and egocentric survey strategy is “field perspective” (Zhong, 2013). Egocentric spatial strategy relies on the first-person perspective, whereas survey strategy relies on a top-down perspective (e.g., “I can point to the exit after several turns in a building without relying on salient landmarks/objects as points of reference.”) Route strategy refers to a reliance on environmental information such as visible signs, landmarks or direction of turn (e.g., “When I navigate, I pay attention to the landmarks at the turning points and try to remember their sequence”).

The Mental Cutting Test (MCT: Vandenberg & Kuse, 1978) and Purdue Spatial Visualization Tests: Visualization of Rotation (PSVT: R) measure object manipulation abilities. The MCT requires participants to view different 3D stimuli being cut with slanting planes at different angels along with five 2D answer choices. In this test, participants were asked to imagine the cut sectional profile and select a matching 2D view. In PSVT: R, participants were asked to imagine rotated versions of three-dimensional objects in the same direction as visually indicated in the instructions. The participants then selected the right answer from the given five choices.

The Perspective Taking Ability (PTA: Kozhevnikov & Hegarty, 2001) is a measure of spatial orientation ability. In this test, a set of seven objects is presented and participants are asked to imagine themselves standing at one object facing another object and indicate the angle to a third object by drawing a line on the answer sheet (e.g. Imagine you are standing at the Yellow facing Red, point to the Blue.). The original test has seven objects such as a house, traffic lights, tree, etc. We used seven different colored spheres (with no top and bottom) in order to avoid implying to the participants the direction of the top and bottom of the space. The participants were prevented from physically rotating their answer sheets.

The Subjective Vertical test was conducted as an informal interview to identify whether participants rely on the visual axis or body axis for the spatial reference frame. In this test participants were asked to point to the floor of the space at the end of the Dynamic and Static condition. More specifically, the participants were told: "Please point to the floor of this room and explain why."

For all three psychometric spatial ability tests (MCT, PSVT: R and PTA), the traditional paper-based items were digitized and integrated into the developed environments in VR. Since the discomfort is often experienced within 10 minutes of the tests, we limited testing to only 5 items, which took no more than 10 minutes. This was done to minimize simulation sickness. In an earlier pilot study with 25 participants involving traditional paper-based spatial tests, we found that the error rate of participants was 30% for some task items and 60% for others, and we designated these items as easy and difficult, respectively. Accordingly, we included 2 easy and 3 difficult tasks in the 5 test items. Although there was no time limit for all three spatial ability tests, no subject took more than 10 minutes to finish each test.

3.2.4. Procedure

All participants were tested individually, and the total study duration was approximately one hour. At the beginning of the study, participants completed a demographic questionnaire followed by the NSQ on the computer. Next, the investigator briefly introduced the VR study tasks.

3.2.5. Study Design

All participants were randomly assigned to one of three test groups. Each group participated in all environmental conditions (Normal, Static and Dynamic) but performed only one spatial task (MCT, PSVT: R and PTA). We took this approach because of two reasons. First, we wanted to avoid the participants repeating the same spatial test to minimize a practice effect. Second, we wanted to minimize the simulation sickness that might be caused by long exposure in VR environments, especially under the Dynamic condition. Thus, with this study design each participant did only one spatial test at each environmental condition.

3.3. Findings and Discussion

3.3.1. Spatial Ability in Altered Environments

The dependent variable used in MCT and PSVT analyses was accuracy, coded as correct or incorrect. In PTA analysis, the dependent variable was calculated based on the number of degrees of deviation from the correct response. As smaller deviations showed better performance, we reversed this relationship by subtracting each response deviation from 360°. After this operation, larger numbers would show better performance. Each row in the data set belonged to a single response from a participant for each item of a spatial ability task.

The coded data were then submitted to Generalized Linear Mixed-effects Model (GLMM) for MCT and PSVT, and Linear Mixed-effects Model (LMM) for PTA to examine the effect of Normal versus Static or Dynamic condition on each spatial ability performance. The analyses were conducted in R (R version 3.5.2; R Development Core Team, 2018) using the lme4 package (version 1.1.20; Bates, Maechler, Bolker, & Walker, 2015). We included test items as a random effect to account for the variance coming from different levels of difficulty of the test items. In addition, participants were added as another random effect due to the different levels of spatial abilities among them. For instance, some participants may have had experiences in jobs that improved their spatial abilities. Moreover, some participants may come from educational backgrounds that required taking courses that were focused on sharpening some aspects of spatial abilities.

In all following reports of mixed-effects analyses for each spatial ability task, the base model consisted of the random intercepts of test items and participants as well as the fixed effect of condition (Normal, Static, or Dynamic), which is the main predictive variable of interest in this study. Other variables were tested in comparison models against the base model and improvement to the model fit was assessed using a chi-square analysis on the -2LogLikelihood (ΔLL) change in model fit.

3.3.2. MCT

As the base model did not converge, the random effects of items and participants were removed in separate efforts to see which change would help the model to converge.

Removing the random effect of participants resulted in model convergence. So, the analysis was continued by a beginning model consisted of the random intercept of stimuli items and the fixed effect of condition.

Taking a forward selection approach, each of the random slopes of test items and participants were added in a comparison model but none of them converged. The beginning model was then compared to comparison models by adding gender and subjective vertical of participants in separate steps. Neither gender nor subjective vertical could improve the model. In the final model, which was the same as the beginning model- only the difference between performance in Normal (38% correct) versus static (21.7% correct) conditions approached significance. See Table 3.1 and Figure 3.2 (Left) for a summary of the results.

Table 3.1. Summary of the GLMM for Random Effect of MCT Items and Fixed Effect of Environment Condition. Reprinted from [Park et al., 2021].

	Accuracy			
Predictors	*Odds Ratios*	*SE*	*z*-value	*p*
Intercept	0.26 (0.12 – 0.55)	0.38	-3.54	< .001*
Normal vs. Dynamic	0.51 (0.21 – 1.27)	0.46	-1.44	0.15
Normal vs. Static	2.29 (0.97 – 5.39)	0.44	-1.90	0.058+
Dynamic vs. Static	1.18 (0.46 – 2.98)	0.47	0.34	0.73
$N_{\text{Test items}}$	5			
Test items	SD = 0.44, SD^2 = 0.2			
Marginal R^2 / Conditional R^2	0.036 / 0.091			

Note: The numbers in parentheses represent confidence intervals for *Odds Ratios*

*+ approached significance, * p < .05*

3.3.3. Spatial Visualization (PSVT:R)

Taking a forward selection approach, each of the random slopes of stimuli items and participants were added to the base model in a comparison model but none of them converged. The base model was then compared to comparison models by adding gender and subjective vertical of participants in separate steps. Neither of gender or subjective vertical models converged. Thus, the base model remained as the final model. This model revealed significant differences in performance under Normal (56.4% correct) versus Static (30.9% correct) as well as Normal versus Dynamic (36% correct) conditions but no significant difference between Static and Dynamic conditions. See Table 3.2 and Figure 3.2 (Right) for a summary of the results.

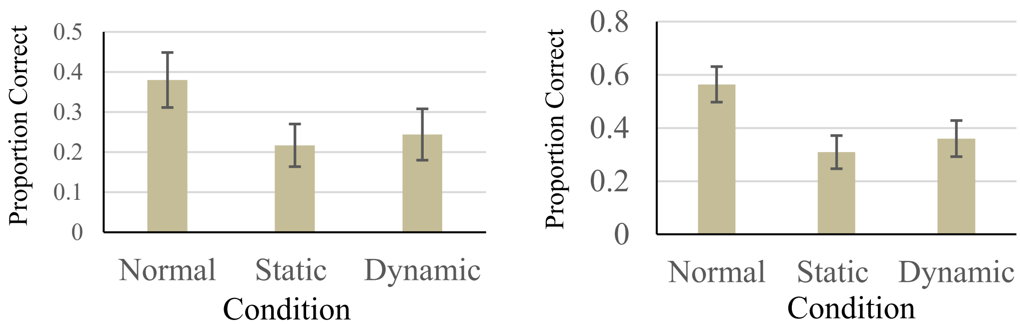


Figure 3.2 (Left) Proportion of correct answers in MCT per environmental condition. (Right) Proportion of correct answers in PSVT per environmental condition. Error bars represent SE. Reprinted from [Park et al., 2021].

Table 3.2 Summary of the GLMM for Random Effect of Participants and PSVT Stimuli Items and Fixed Effect of Rotation Condition. Reprinted from [Park et al., 2021].

Predictors	Accuracy Odds Ratios	*SE*	*z*-value	*p*
Intercept	0.40 (0.16 – 1.00)	0.47	-1.96	0.05*
Normal vs. Dynamic	0.39 (0.16 – 0.92)	0.44	-2.14	0.032*
Normal vs. Static	0.30 (0.13 – 0.72)	0.44	-2.72	0.007*
Dynamic vs. Static	1.29 (0.54 – 3.09)	0.45	0.57	0.57
N Test items	5			
Participants	SD = 0.19, SD^2 = 0.04			
Test items	SD = 0.76, SD^2 = 0.58			
Marginal R^2/ Conditional R^2	0.065 / 0.213			

Note: The numbers in parentheses represent confidence intervals for *Odds Ratios*

*+ approached significance, * p < .05*

3.3.4. Spatial Orientation (PTA)

Taking a forward selection approach, each of the random slopes of stimuli items and participants were added to the base model in a comparison model but none of them converged. The base model was then compared to a comparison model including gender. Adding gender improved the base model (ΔLL=2.53, $p < .02$) and motivated adding the interaction term between condition and gender. However, the interaction term did not improve the fit of the previous model and was removed. Then, subjective vertical of participants was added in a comparison model but did not improve the model fit. The final model consisted of the random intercepts of stimuli items and participants as well as the fixed effects of condition and gender. This model did not show any significant differences in performance under different conditions, but the significant effect of gender showed that male participants ($M_{accuracy}$ = 348.64°, SD = 11.65) outperformed female participants

($M_{accuracy}$ = 340.93°, *SD* = 26.82). See Table 3.3 and Figure 3.3 for a summary of the results.

In summary, the experimental results generally supported our hypothesis: misalignment of the visual axis and body axis creates difficulties in spatial abilities as indicated by a consistently lower score in Static and Dynamic conditions than in Normal condition. This phenomenon significantly appears in object manipulation ability (MCT and PSVT: R) versus spatial orientation ability (PTA).

Table 3.3 Summary of the LMM for Random Effects of Participants and PTA Stimuli Items and Fixed Effects of Rotation Condition and Gender. Reprinted from [Park et al., 2021].

	(360 – degrees of error)			
Predictors	*Estimates*	*SE*	*t*-value	*p*
Intercept	341.68 (334.91 – 348.46)	3.46	98.83	<0.001*
Normal vs. Dynamic	-2.27 (-9.32 – 4.79)	3.60	-0.63	0.53
Normal vs. Static	1.14 (-6.72 – 9.00)	4.01	0.28	0.78
Dynamic vs. Static	-3.41 (-10.71-3.90)	3.73	-0.91	0.37
Gender (M vs. F)	-7.46 (1.22– 13.71)	3.19	2.34	0.02*
N Test items	6			
Participants	*SD* = 5.681, SD^2 = 32.28			
Test items	*SD* = 3.65, SD^2 = 13.33			
Marginal R^2/ Conditional R^2	0.044 / 0.134			

Note: The numbers in parentheses represent confidence intervals.

*+ approached significance, * p < .05*

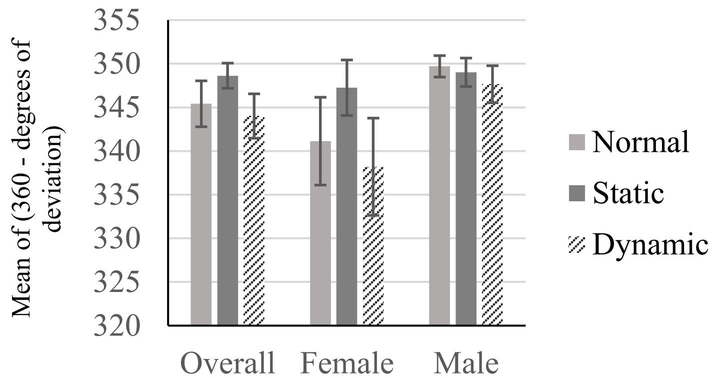


Figure 3.3 Accuracy of performance in PTA per environmental condition and per gender. Higher bars show better performance. Error bars represent SE. Reprinted from [Park et al., 2021].

3.3.5. Relationship between the Spatial Reference Frame and Navigation Strategy

To analyze individual navigation strategy, we summed participants' ratings on statements constituting the three types of strategies (i.e., survey strategy vs. egocentric-survey strategy vs. route strategy). The average ratings for each of the strategies were used for purposes of comparing the three types of strategies. Table 3.4 presents the descriptive statistics of the three strategy scales separated by subjective vertical groups. Overall, participants reported using route strategies more often than both survey and egocentric survey strategies.

Table 3.4 Individual Navigation Strategy per Subjective Vertical and Gender Group. Reprinted from [Park et al., 2021].

Navigation Strategy	*Body (n=10)*		*Visual (n=22)*		*Male (n=20)*		*Female (n=12)*		*Overall (n=32)*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Survey *	3.37	0.76	2.98	0.76	3.37	0.76	2.98	0.76	3.22	0.77
Ego Survey *	3.44	0.48	3.00	0.41	3.44	0.48	3.00	0.41	3.27	0.50
Route *	3.65	0.56	3.84	0.58	3.65	0.56	3.84	0.58	1.69	0.47

* Scale ranges from 1 (low) to 5 (high)

To examine the relationship between navigation strategies and subjective vertical, a 3 (ego-survey vs. survey vs. route) x 2 (visual vs. body) mixed-model ANOVA was performed on NSQ scores. The subjective vertical category was the between-subject factor and Navigation Strategy was the within-subject factor. The ANOVA showed a significant interaction between Navigation Strategy and Subjective Vertical, F (1.86, 55.79) = 6.37, $p < 0.004$, $\eta^2 = 0.18$ (Greenhouse-Geisser corrected). As shown in Figure 3.4 (the mean NSQ scores were converted to z scores in this figure), this interaction revealed different distributions of NSQ scores across the two subjective vertical groups for each navigation strategy. The consistent use of a certain type of spatial reference frame in both everyday navigation (identified by NSQ) and under extreme conditions (identified by the subjective vertical test) may indicate that an individual would prefer a certain type of spatial strategy. Gramann (2013) proposed that an individual has a certain spatial strategy preference attributed to experience with an environment, biological factors, language and/or geographical region the one lives in.

3.3.6. Gender Difference in NSQ

To examine the relationship between navigation strategies and gender, a 3 (Survey vs. Ego-Survey vs. Route) x 2 (male vs. female) mixed-model ANOVA was performed on NSQ scores. The interaction between the two variables approached significance (Greenhouse-Geisser corrected: $F(1.79, 53.5) = 3.12$, $p = 0.06$). However, at a descriptive level, males use both egocentric-survey strategy and survey strategy more than females. However, females used route strategy more than males (see Table 3.4 and Figure 3.4). The fact that males rely more on survey representation whereas females rely more on route representation is consistent with previous findings. Many studies found males significantly perform better on survey representation tasks in comparison to females, whereas females perform better on landmark recognition tasks (Galea & Kimura, 1993; Dabbs et al, 1998; Malinowki & Gillespie,2001; Hegarty et al., 2006; Castelli et al. 2008; Lawton, 1994). Thus, our results add to previous work in showing that that the use of a certain type of spatial strategy may differ by gender.

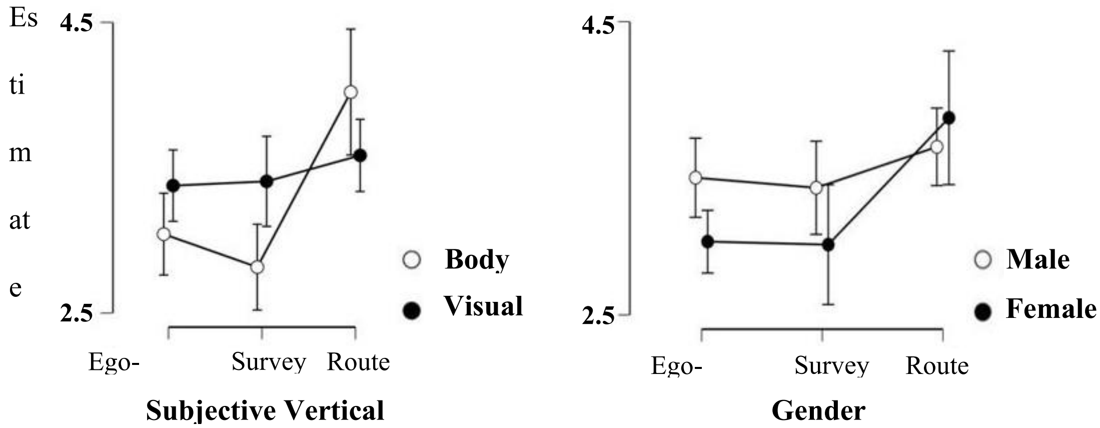


Figure 3.4 (Left) Relationship between NSQ and Subjective Vertical; (Right) Relationship between NSQ and Gender. Reprinted from [Park et al., 2021].

3.4. Conclusions

The present study aimed to investigate how the extreme condition where the visual vertical conflicts with the body vertical may affect spatial abilities. We also examined individual tendency to adopt a certain spatial strategy (egocentric vs allocentric). We observed that misaligned visual and body axes can adversely affect human spatial ability. Results of the statistical analysis show that object manipulation ability is affected more than spatial orientation ability. The significant effect of condition on the PSVT-R test in our study does not support the previous null effect of microgravity on mental rotation test reported by Matsakis et al., 1993 and Leone et al, 1995. One explanation could be the study environment. That is, in the present study, participants experienced microgravity through visual cues but in the mentioned previous studies, participants were physically present in the Russian MIR station but were seated in a body restraint and were prevented from seeing any visual cues by curbing their sights to only the computer screen during the experiment. Therefore, tasks requiring object manipulation ability such as a robotic operation for installation and repair of external systems under extreme environment might need extra support. Our results also confirm the previous assertions of Gramann (2013) that individuals favored one spatial strategy over the other. Most importantly, gender differences were observed in the use of spatial strategy. Males significantly rely on an egocentric-survey strategy which requires the use of Euclidean information of space. Although the results for women were not statistically supported the trend was for women to use a route strategy more for their everyday navigation which relies upon visible signs, landmarks or direction of the turn. This finding is in line with the previous finding that men prefer strategies rely on Euclidean features such as distances and directions versus women prefer strategies that rely on landmarks (Galea and Kimura 1993; Castelli et al. 2008; Dabbs et al. 1998). The present study has some limitations that should be acknowledged. The measure of spatial ability was a simplified version due to the limitation of study duration. Also, the measure of everyday navigation strategy use was an indirect measure based on self-report. Thus, our findings would need to be replicated with additional measures of spatial ability including performance measures. In conclusion, four key conclusions emerged from this study. First, the consistent use of a certain type of spatial reference frame in both everyday navigation (identified by NSQ) and misaligned visual cue condition (identified by the subjective vertical test) may indicate that people have individual preferences for a certain type of spatial strategy. Second, a significant interaction between navigation strategy and the choice of subjective vertical in misaligned condition was found. Participants who often use route (egocentric) strategy in everyday navigational activities were more likely to rely on the body axis in the extreme condition. On the contrary, participants who reported using survey (allocentric) strategy in navigation were more likely to rely on the visual axis. Lastly, these findings inspire the potential possibility of individual differences in cognitive style may play an important role in spatial learning. Therefore, understanding the individual cognitive style might offer useful ideas for creating the effective navigation guide that optimize spatial knowledge acquisition.

Author Contributions: Conceptualization, H.P. and M.D.; methodology, H.P. and M.D.; VR development, H.P.; formal analysis, N.F.; writing—original draft preparation, H.P.; writing—review and editing, M.D., J.V., A.M.; visualization, H.P.; supervision, M.D.;

4. RESEARCH METHODOLOGY

4.1. Research Objectives and Hypothesis

The research questions underlying the rationale for this study are:

(1) What are different individual variables that affect spatial navigation?

(2) How individual cognitive style is related to spatial navigation?

(3) How can we develop individual-appropriate navigational intervention not only for guiding direction to the destination but also for helping to acquire spatial knowledge of the environment?

In order to answer the above research questions, the main objectives of this research are three-fold:

(1) to demonstrate how individual cognitive style relates to spatial navigation, specifically spatial knowledge acquisition.

(2) to investigate whether the cognitive style moderates the relationship between map orientation (forward-up vs. north-up) and spatial knowledge acquisition.

(3) to verify previous findings on the relationship between cognitive style, spatial ability and spatial strategy.

Given the evidence that a certain type of learning perspective may be more efficient than the others for individuals with different cognitive styles (Pazzaglia & Taylor, 2007; Li et al., 2016). The research objectives were reached by testing four research hypotheses: (H1) FI participants will have more accurate spatial knowledge in North Up map condition than Forward up map condition..; (H2) FD participants will have more accurate spatial knowledge in Forward Up map condition than North Up map condition; (H3) FI participants will achieve higher score on all spatial ability dimensions than FD participants, given their better ability to extract salient information from the surrounding field and recognize other people's perspective (Li et al., 2016; Boccia et al., 2016); and (H4) FI participants will report higher score on survey strategy than FD participants, given that field dependent individuals are known to have a preference for landmarks while field-independent ones for using survey representations when they are navigating (Denis et al., 1999; Pazzaglia & De Beni, 2001). Figure 4.1 presents the research model of the study.

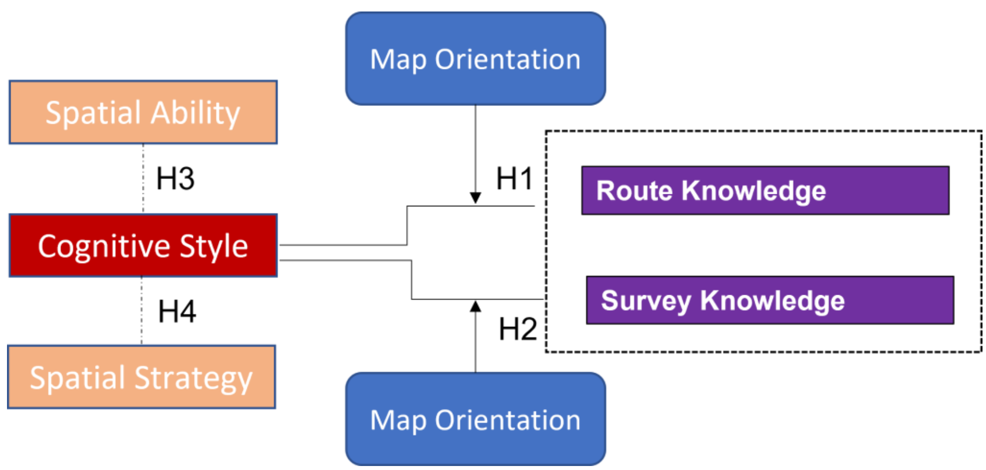


Figure 4.1 Research Model

4.2. Participants

There were forty participants (17 females), each of whom had a normal or corrected-to-normal vision. This sample size is comparable to that of earlier studies, which investigated spatial ability in virtual environments (see Table 4.1). Participants were recruited through an announcement sent through the university's email system. All participants were students and staff from Texas A&M University. The inclusion age criteria were young adults between 18 to 45 years old. The age criteria are selected because cognitive speaking, there are age differences in representing the environment layout and spatial navigation performance (Rosenzweig & Barnes, 2003; Moffat, 2009; Devlin & Wilson, 2010). All participants provided an electric consent form prior to the study through DocuSign and the study was approved by the university's Institutional Review Board. All participants were compensated with a $15 gift card for participation.

Table 4.1 The sample size of earlier studies investigated spatial ability in virtual environments.

Author	Year	Title	N.	Publisher
Aoki et al.	2007	Virtual-Reality-Based 3D Navigation Training for Emergency Egress from Spacecraft	47	Aviation, Space, and Environmental Medicine
Giudice & Li	2011	The Effects of Visual Granularity on Indoor Spatial Learning Assisted by Mobile 3D Information Displays	20	International Conference on Spatial Cognition
Sandstrom et al.	1998	Males and females use different distal cues in a virtual environment navigation task.	48	Cognitive brain research (Elsevier)
Tlauka et al.	2005	Gender differences in spatial knowledge acquired through simulated exploration of a virtual shopping centre	32	Journal of Environmental Psychology (Elsevier)
Foreman et al.	2004	Distance underestimation in virtual space is sensitive to gender but not activity–passivity or mode of interaction	40	Cyberpsychology & Behavior
Ross et al.	2006	Gender differences in spatial navigation in virtual space: Implications when using virtual environments in instruction and assessment	25	Virtual Reality (Springer)
Cutmore et al.	2000	Cognitive and gender factors influencing navigation in a virtual environment	32	International Journal of Human–Computer Studies

				(Elsevier)
Castelli et al.	2008	Spatial navigation in large-scale virtual environments: Gender differences in survey tasks	40	Computers in Human Behavior (Elsevier)
Tan et al.	2006	Large displays enhance optical flow cues and narrow the gender gap in 3-D virtual navigation	32	Human Factors (Sage)
Kraemer et al.	2017	Verbalizing, visualizing, and navigating: The effect of strategies on encoding a large-scale virtual environment.	40	Journal of Experimental Psychology: Learning, Memory, and Cognition (APA)

4.3. Contact-Free Study Design

Due to the impact of the COVID-19 Pandemic, the main study was conducted contact-free using the Zoom platform. Contact-free study means the study does not require any in-person visits and can instead be completed from home or another convenient location of each participant's choice. The electronic informed consent form was shared with the participants through DocuSign prior to the study. At the beginning of the study, they were given the time to ask any questions before signing the consent. The study environment was shared using the *share screen* function on Zoom. Each participant was given permission to *remote control* the keyboard and the mouse of the investigator's computer, so they were able to explore the study environment which was installed on the investigator's computer. This *remote-control* function allowed to avoid complications of installing the program on each participant's computer. All spatial tasks were digitalized and were available online. The investigator shared the direct URLs of each task on the chatbox and instructed participants to click on the link at the right time of the study.

Some may argue that virtual navigational experiences through computer screens could be less reliable compared to navigational experiences in a real or highly immersive environments. However, it has been empirically demonstrated by previous researchers that the spatial performance measures between the virtual and real environment are typically correlated (Richardson et al., 1999, Waller, 2005).

The limitation of contact-free study still exists, however, in terms of controlling the experimental environment. For example, the screen size, resolution, distance of the participants to their screen, or interruption could not be controlled. In order to minimize distraction, participants were asked to put their browser in full-screen mode. In the pre-study questionnaire, one question item asked the screen size of their current device to check the variance. Table 4.2 describes the participants' computer screen size. Two participants did not answer. The size ranges from 11.4 inches to 21.5 inches. The average screen size is 14.44 inches.

Table 4.2 Participants' computer screen size (inch)

N	Mean	SD	Min	Max
38	14.44	2.126	11.4	21.5

4.4. Study Environment

The VR environments were created in the Unity 3D game engine. Unity 3D offers the ability to customize environments and interactions through scripts to emulate specific performance and functionality. The environments for testing individual navigation performance were in the form of a maze, with perpendicular turns (see Figure 4.2). A virtual maze enables to create of the exact same stimulus conditions for all study conditions which gives more control over experimental settings. In the real-world environment, it is hard to find two different environments with the same stimulus conditions. For these reasons, a maze has been a popular environmental setting used in previous navigation studies (Lingwood et al., 2015; Li & Giudice, 2018).

In each maze environment, there were seven landmarks positioned along the path. The landmarks are natural or "artificial" elements that people usually see in everyday life. Table 4.3 shows a list of landmarks presented in each map. The height of maze walls was intentionally designed low so that participants could be able to construct internal connectivity between landmarks. The low maze wall also allows use of global landmark for those who prefer to use allocentric (survey) strategy. Figure 4.4 presents a layout of the two maze environments used in this study. The red line indicates the route participants had to follow. The small circles represent the position of seven local landmarks.

Table 4.3 A list of natural and artificial landmark positioned in each maze.

	Maze A	**Maze B**
1	Stool	Drawer
2	Chest	Lamp
3	Tree	House Plant

4	Desk	TV
5	Cone	Cone
6	Bike	Motorcycle
7	Globe	Tree

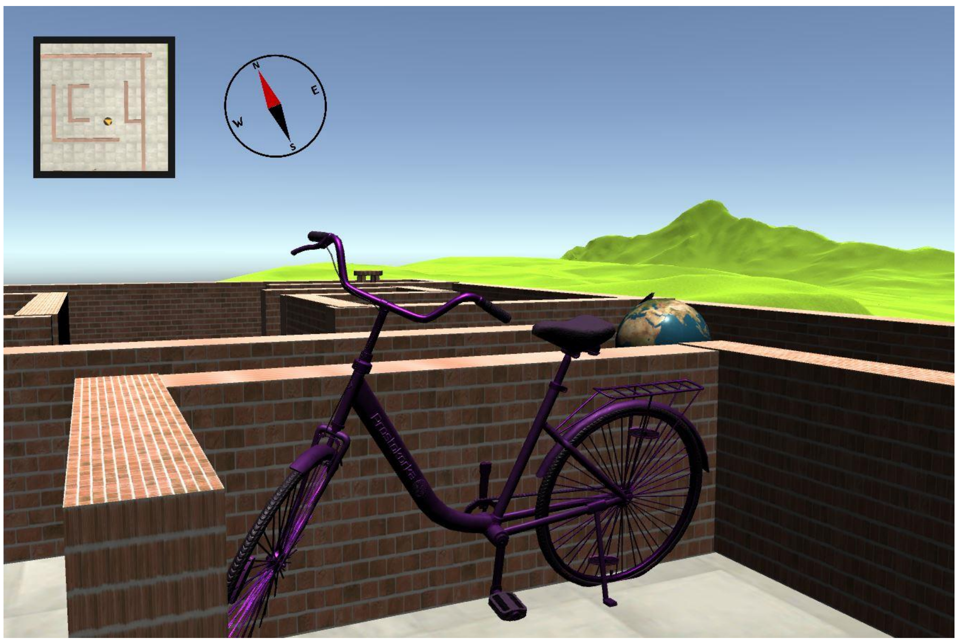


Figure 4.2 A screen shot of the virtual maze environment. On the left top corner, there are a guide-map and compass. The compass indicates the cardinal direction (north, east, south, and west) in real time with respect to the participant's facing direction.

Figure 4.3 A guide map; forward-up map (left) and north-up map (right).

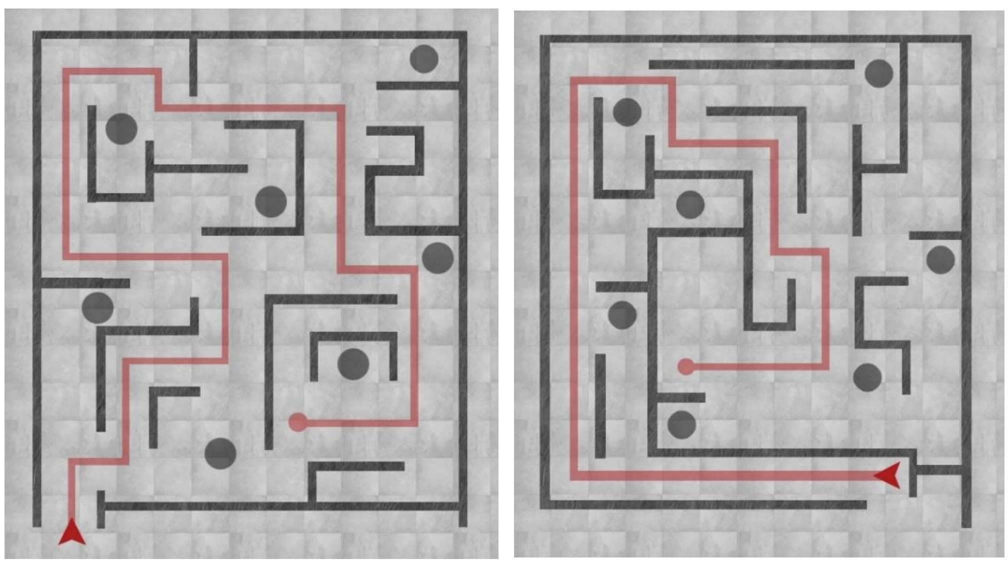


Figure 4.4 The virtual maze type A (left) and type B (right). The red line indicates the route participants had to follow. The small circle indicates the position of seven local landmarks.

The GPS-like map and a compass indicating the virtual north will be displayed in the left upper corner. The participant's position and facing direction will be displayed on the map with an arrow icon along with the guiding trail. This guide-map will be given only during the learning phase. The guide-map is always maintained one of two orientations: 1) North-up: the map maintained constant orientation aligned with the virtual north direction; 2) Forward-up: the map always upright with respect to the participant's facing direction. All participants have experienced both map conditions. Therefore, two different maze environments were constructed so that participants experience all map conditions (e.g., north-up and forward-up) without the learning effect. Two environments, however, are the same in terms of the number of landmarks, segments, and intersections. Each maze was constructed with a simple textured wall with a white tile floor. The basic structure of the maze is the same as those used in previous studies by Castelli et. al. (2008).

4.5 Test Materials

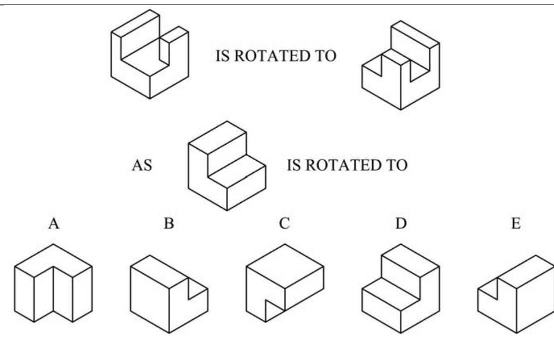
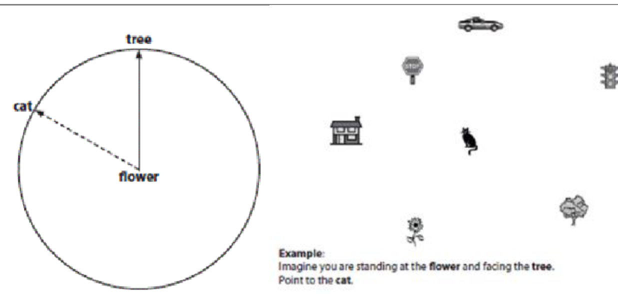
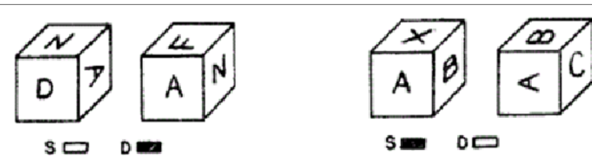
4.5.1 Demographics and Navigation Strategy

The study administered two questionnaires. First, a demographics questionnaire enquired participants' age, gender and major. The individual navigation strategy was accessed using *Navigation Strategy Questionnaire* (NSQ: Zhong, 2013; Zhong & Kozhevnikov, 2016). The test included the following three sub-dimensions, grouped as survey, procedural and egocentric-spatial updating (Zhong & Kozhevnikov, 2016). Please see Chapter 3 Task section for more details about NSQ. Although egocentric-spatial updating measures the spatial strategy that acquire spatial representation from different perspective than survey strategy, both dimensions assess similar underlying constructs. Zhong (2013) reported that egocentric spatial updating and survey strategy are highly correlated (*r=0.67, p<.01*). Therefore, the study used two sub-dimensions: 1) survey strategy and 2) procedural strategy from NSQ.

4.5.2 Spatial Ability Measures

All three dimensions of spatial ability (e.g., spatial visualization, spatial orientation, and spatial relation) were tested. There are much evidence tells that moving through space requires not just one aspect of spatial ability but a combination of its sub-dimensions as we need to properly perceive a spatial environment, find shortcuts and keep track of locations (Ekstrom & Isham, 2017). Some studies support their findings that spatial abilities (specifically, spatial visualization and spatial orientation) predict spatial navigation performance, and both may involve similar cognitive processes (Oman et al., 2000; Dünser et al., 2006; Kozhevnikov et al., 2006). Spatial relation ability, however, has received relatively less attention compared to the other two dimensions. Kozhevnikov et al., (2006) have suggested that future research is needed on identifying other aspects of spatial abilities (e.g., spatial relations) which may contribute to navigational tasks. They also expected that it would be beneficial not only for advancing navigation theory but also for personal training. Therefore, the study comprehensively tests all three spatial ability dimensions of each participant by using standard assessments. Among a wide variety of standard tests, the following three spatial ability assessments have predominantly been used in spatial ability research: Purdue Spatial Visualization Test: Rotation (PSVT:R), Perspective Taking Ability Test (PTA), and Card Rotation Test (see Table 4.4).

Table 4.4 Spatial ability dimensions and their assessments.

Assessment	Dimensions	Sample Items
PSVT:R	Spatial Visualization	
PTA	Spatial Orientation	
Cube Comparison	Spatial Relations	

4.5.2.1 Purdue Spatial Visualization Tests: Visualization of Rotation (PSVT:R)

PSVT:R measures object manipulation ability in terms of mental rotation. In this test, participants were asked to imagine rotated versions of 3D objects in the same direction as visually indicated in the instructions. Participants then selected the right answer from the given five answer choices which were originally developed by Guay (1977). The choice of PSVT:R has been made based on the popular use of it in previous spatial studies (for a recent overview see meta-analysis by Maeda & Yoon, 2011). Moreover, the previous studies reported strong reliability and validity evidence to support the use of the PSVT:R (Alkhateeb, 2004; Battista et al., 1982; Guay & McDaniel, 1978; Sorby & Baartmans, 1996, 2000; Sorby, 2000). Since minimizing study duration is important in human subject research, PSVT:R which has smaller items (12 items) is much more beneficial than other instruments such as the Mental Rotation Test (Vandenberg & Kuse, 1978) which consists of 20 items.

4.5.2.2 Perspective Taking Ability (PTA)

Perspective Taking Ability (PTA) assesses spatial orientation ability. In this test, a set of seven objects was presented from the top-down view. Participants were asked to imagine themselves standing at the position of one object while facing another object. Then, indicating the angle to a third object by drawing a line on an answer sheet (e.g., *Imagine you are standing at the Cat facing House. Now, point to the Flower.*). The answer sheet provided a picture of a circle where the imagined standing point (*Cat* in this example) was drawn in the center of the circle and the imagined facing object (*House* in this example) was indicated with a drawn line pointing vertically up from the center. The original format of the test was a paper and pencil test, but the format has been digitized in this contact-free study (see Figure 4.5). In the Unity program, the picture of the circle and the seven objects were presented along with the next button. The angle to the third object (i.e., a red line) can be rotated by pressing the left and right arrow keys on the keyboard. Clicking the next button submits the answer and directs to the next item.

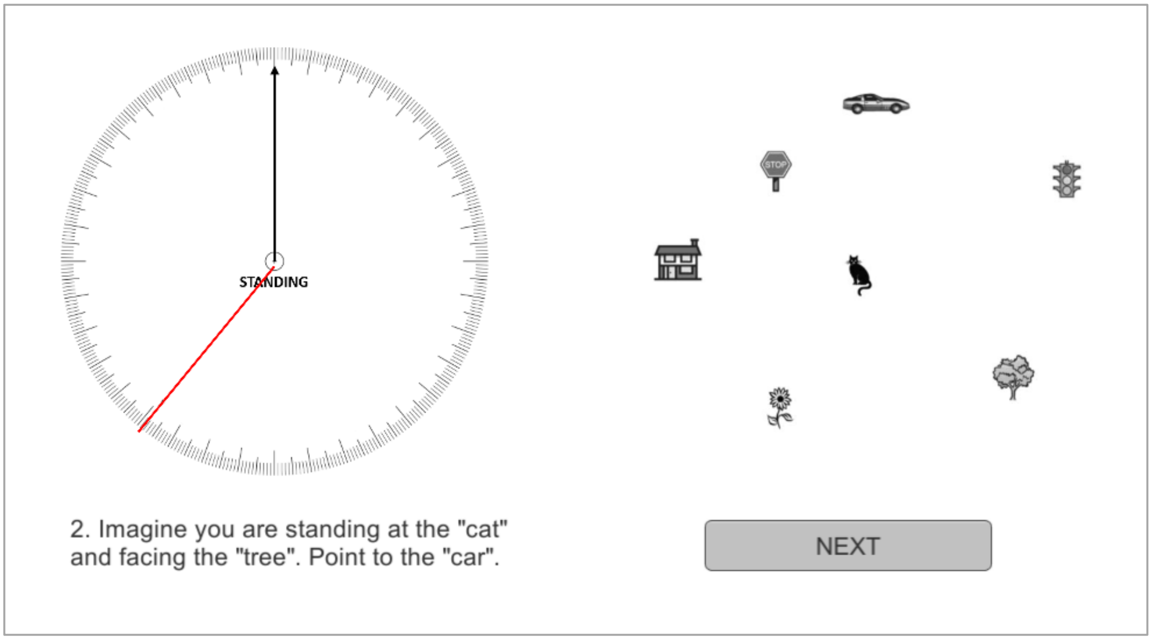


Figure 4.5 An example of digitized PTA

4.5.2.3 Cube Comparison Test

One of the scales used for the spatial relations component is the Cube Comparison test which was developed by Ekstrom et al. (1976). Each test item consists of a pair of cubes. There are different designs, numbers, or letters on each face of a given cube. The test asks participants to compare two given cubes and decide whether they are the same or different cubes. They were informed that there are hidden faces of a given cube, but no letters, numbers, or symbols appear on more than one face of a cube. The participants were asked to answer total of 21 items in a period of 3 minutes.

4.5.3 Cognitive Style Measure (Group Embedded Figure Test)

Group Embedded Figure Test (GEFT) is the most widely used assessment to measure individual cognitive style (Witkin et al., 1971). The test provides simple visual figures embedded inside the complicated visual figures. The participants are asked to locate the hidden simple figure in the complex figure within a given time (20 minutes). The test consists of three sections. The first section is the practice section to make participants familiar with the test. The score of the first section is not included in the total score. The score ranges from 0 to 18. The score between 0 to 11 identified as FD individuals and the score between 12 to 18 identified as FI individuals.

4.5.4 Route Knowledge Measures

4.5.4.1 Landmark Sequencing Test

Landmark sequencing test assesses participants' route knowledge. There are 8 pairs of photos depicting scenes from the experiment environment (see Figure 4.6). They were told to judge which scene occurred first than the other if walking from the start point to the end point. A participant's score was the sum of correct responses (ranging from 0 to 8).

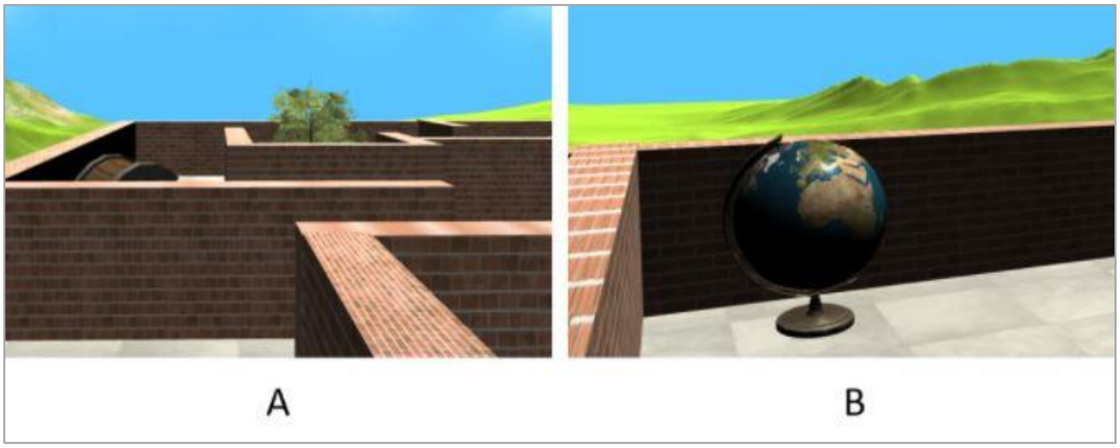


Figure 4.6. An example of landmark sequencing test.

4.5.4.2 Route Retracing Test

Another route knowledge test was the *route retracing test* (explained in more detail in Procedure), adopted from Wiener et al. (2020). When participants reached to the endpoint of the maze, they were asked to walk all the way back to the starting point following the exact same route they had taken. The total egress time of the route retracing was used as the route knowledge indicator.

4.5.5 Survey Knowledge Measures

4.5.5.1 Pointing Direction Task

The pointing direction task adopted from Kozhenikov et al. (2006) was used to access participants' survey knowledge. This test is similar to Perspective Taking Ability (PTA) test which is a measure of spatial orientation ability. In the PTA test, they were given a top-down view of a set of seven objects in each item. In the pointing direction test, on the other hand, no reference of landmarks' position was provided. They are only given a list of landmarks in random order with a name tag for the purpose of avoiding the confusion of matching their name (see Figure 4.7). The participants need to solely rely on their mental representation of the maze in order to answer the question. They were asked to imagine standing in a given position at the maze, facing one landmark and pointing to another (e.g., Imagine you are standing at the “Tree” facing the “Desk”, point to the “Stool”). There is total of 12 items. The absolute pointing angular error was measured. There was no time limitation on this task. As same as the PTA test in this study, the test items were programmed and presented by using Unity. The angle to the third landmark (i.e., a red line) can be rotated by pressing the left and right arrow keys on the keyboard. Clicking the next button submits the answer and directs to the next item.

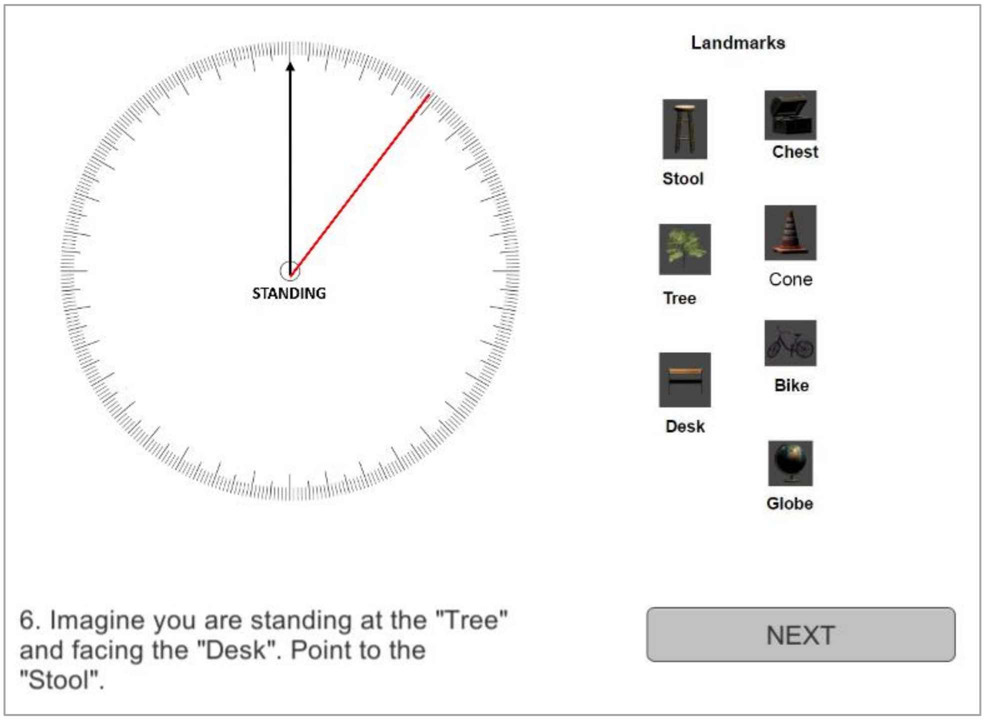


Figure 4.7 An example of pointing direction task item

4.5.5.2 Sketch Map Test

The sketch map test has been widely adopted as a measures of survey knowledge of the learned environments in many spatial researches (Galea & Kimura, 1993; Tu Huynh & Doherty, 2007; Billinghurst & Weghorst, 1995). In this test, participants were asked to draw a map of space with landmarks and other spatial features on a sheet of paper. They were encouraged to draw as much detail as possible in a period of 10 minutes. At the end of the study, they were asked to scan the hand-drawn maps and email them to the investigator. The example of sketch map test is shown in Figure 4.8

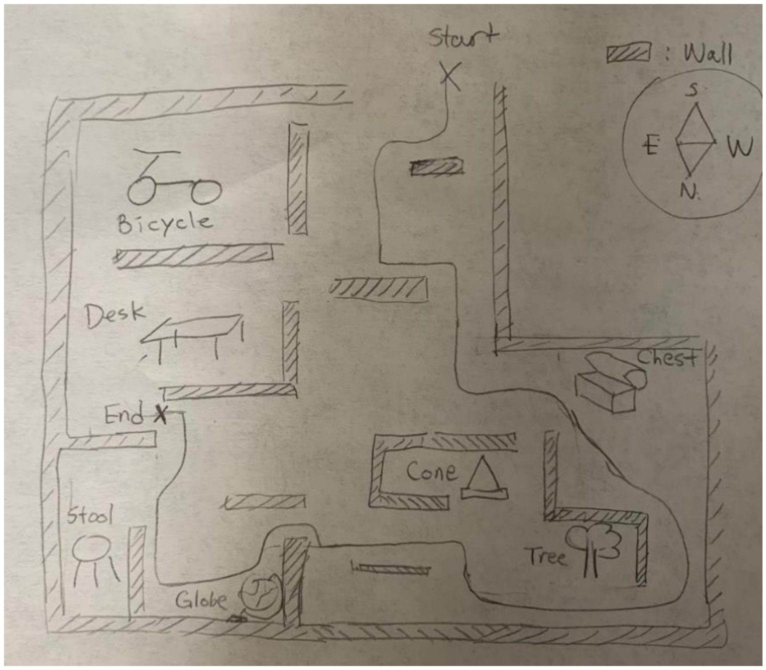


Figure 4.8 An example of sketch map test

4.6 Procedure

Participants begin with a demographic questionnaire, Navigation Strategy Questionnaire (NSQ), and three spatial ability tests (e.g., PSVT:R, PTA, and Cube Comparison) followed by Group Embedded Figure Test (GEFT). Then, the participants were given verbal instructions about the navigation test in the virtual maze. Since the study was designed to be contact-free, the investigator shared the screen in Zoom and assigned the keyboard and mouse control over to the participant. In the virtual environment, they were able to passively walk along a route by pressing the following keys: W (going forward), S (going backward), A (left turn) and D (right turn).

Before starting the experiment in virtual maze environments, participants familiarized themselves with the keyboard button functions for 5 min by exploring in a practice maze. The practice maze has identical graphical elements such as patterns and textures for walls and floors to those used in the experimental phase but with a much simpler route design. No data was collected in this practice phase.

After the participant familiarized the control of the virtual environment in the practice maze, they were introduced first maze environments either maze A or maze B (see Figure 4.4). In each maze environment, there were two phases. The first phase is learning the environment with a guide-map: (1) north-up map or (2) forward-up map. The order of environments (*Maze A & Maze B*) and the orientation of guide-map (*North Up & Forward Up*) were counterbalanced across all participants to eliminate any ordering effect (see Table 4.5). There was a single trial for each map condition since the map environment is relatively simple.

Table 4.5 The counter balanced order of maze and guide-map orientation.

	Maze		**Guide-map**	
Group 1	A	B	North Up	Forward Up
Group 2	B	A	Forward Up	North Up
Group 3	A	B	Forward Up	North Up
Group 4	**B**	**A**	North Up	Forward Up

In the beginning, participants were asked to explore the environment along the prescribed route guided by a map to adopt an entire configuration of the maze. All participants were encouraged to remember the whole layout of the environment. There was no time limitation in the learning phase. To ensure that participants always took the correct route, the investigator corrected them if necessary. Upon arriving at the endpoint, they were asked to trace back to the initial start point following the exact route they have taken (*Route retracing test*). In this *route retracing test*, the guide-map is not provided. Participants should rely on their mental representation of the environment. On reaching the start point, total egress time was measured. No feedback on turning errors was provided during the route retracing test.

Next, participants have performed survey and route knowledge tests on the order of pointing direction test, sketch map test, landmark sequencing test. Subjects then took a short break. After the short break, participants have introduced the second maze environment. The same procedure was repeated for the second maze. In the second maze, however, participants were assigned a different orientation guide map to the one they had in the first maze. The effectiveness of the intervention (map orientation) will be inferred from the participants' performance on both route and survey knowledge tasks. The total study duration was approximately two hours.

Table 4.6 Study procedure

Order	**Format**	**Data Collected**
1	Pre-study questionnaire	Demographics
2	Navigation Strategy Questionnaire (NSQ)	Everyday spatial strategy

3	Cube comparison test	Spatial relation ability
4	Purdue Spatial Visualization Test: Rotation (PSVT:R)	Spatial visualization ability
5	Perspective Taking Ability (PTA)	Spatial orientation ability
6	Group Embedded Figure Test (GEFT)	Cognitive style
7	Practice maze	No data collected
8	Spatial learning phase	No data collected
9	Route retracing task	Route Knowledge
10	Point direction test	Survey Knowledge
11	Sketch map test	Survey knowledge
12	Landmark sequencing test	Route Knowledge

5 RESULTS

After data were gathered from participants, statistical analysis was done by using Jasp (version 0.14.1). In this section, detailed information about the statistical results of this study is given. Descriptive analysis was conducted in order to obtain an overall information about the statistical results. Repeated measure ANOVA with covariates, independent sample t-test and correlation were used as well. Firstly, results of descriptive analysis of participants demographics in terms of gender, major, cognitive style, navigation strategy and spatial abilities were reported. After that the interaction effect of map orientation and cognitive style on spatial knowledge tasks was assessed.

5.1 Participants Demographics

Table 5.1 describes the population of participants in terms of gender and age. The participant population was well divided between males (57.5%) and females (42.5%) with both genders having the similar mean age. As the ages of the participants are very homogenous, no age effects were considered in the analysis.

Table 5.1 Participant demographics

	N	%	Mean	SD
Female	17	42.5	23.47	4.06
Male	23	57.5	24.14	2.34
Total	40	100	23.8	3.84

Table 5.2 describe the breakdown of participants' major by gender. There were two female and two male participants who did not provide their major information. 77.8% of 36 participants were STEM major. The higher portion of STEM major participants in this study was due to the study population sampled from Texas A & M University. According to a 2021 report by the American Society for Engineering Education, the College of Engineering at Texas A&M ranked 5th in the nation in undergraduate enrollment. In male participants, STEM major consists relatively high portion (90.5%).

Table 5.2 Participant major by gender

	Female (%)	Male (%)	Total (%)
STEM	9 (60)	19 (90.5)	28 (77.8)
NON-STEM	6 (40)	2 (9.5)	8 (22.2)

5.2 Participants Cognitive Style

This section provides data about the cognitive style measured by Group Embedded Figure Test (GEFT). The score range of GEFT was 0 to 18. Figure 5.1 and Figure 5.2 represent the histogram and Q-Q plot of the GEFT score achieved by each participant. The distribution of GEFT scores was not normal (*skewness = - 0.811, SE = 0.374*), as the graph skewed to the right. Participants with scores ranging from 0 to 11 were classified as field-dependent (FD), and participants with scores ranging from 12 to 18 were classified as field-independent (FI). Specifically, 37.5% of total participants were classified as field-dependent (FD) and 62.5% of participants were classified as field-independent (FI). Table 5.3 shows the differences in cognitive style between the gender and major.

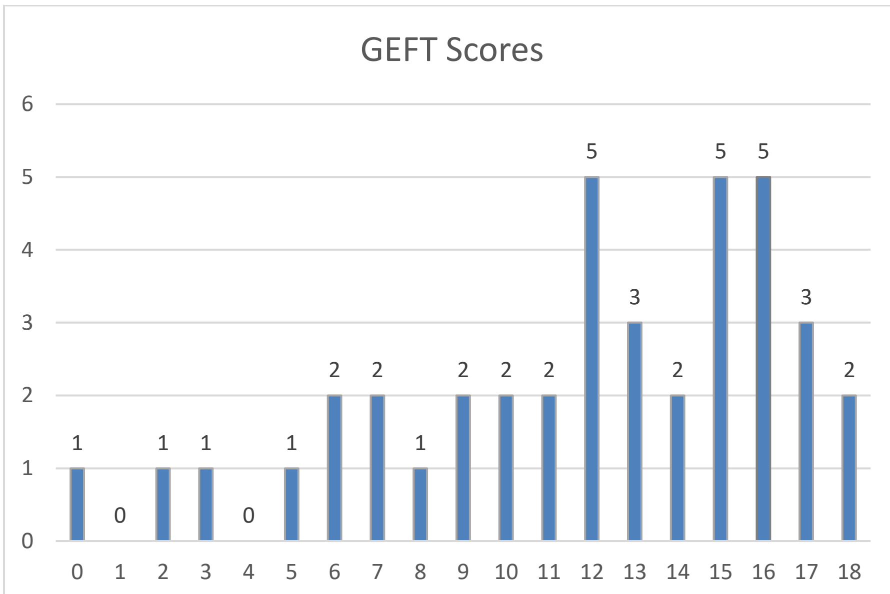


Figure 5.1 A histogram of GEFT scores

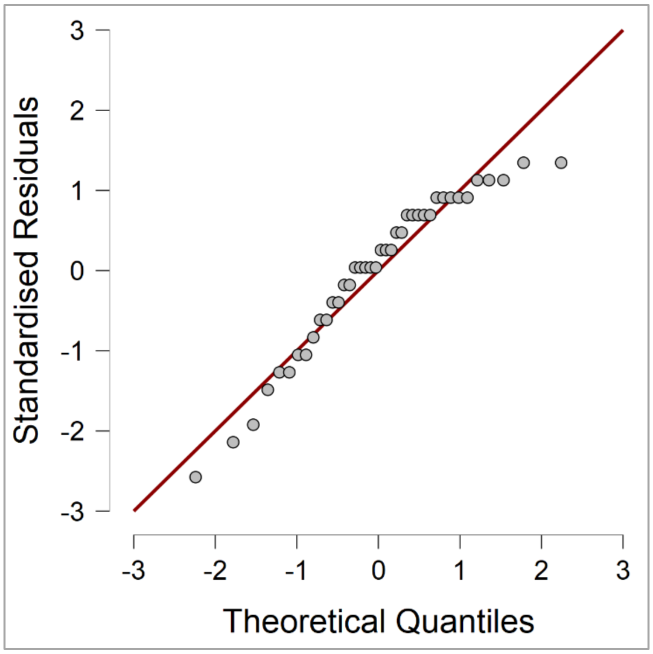


Figure 5.2 A Q-Q plot of GEFT scores

Table 5.3 Participants cognitive style by gender and major

	Gender (%)		**Major (%)**		**Total (%)**
	M (n=23)	F (n=17)	STEM (n =25)	NON-STEM (n=11)	(n=40)
FD	6 (26.09)	9 (52.94)	6 (24)	9 (81.82)	15 (37.5)
FI	17 (73.91)	8 (47.06)	19 (76)	2 (18.18)	25 (62.5)

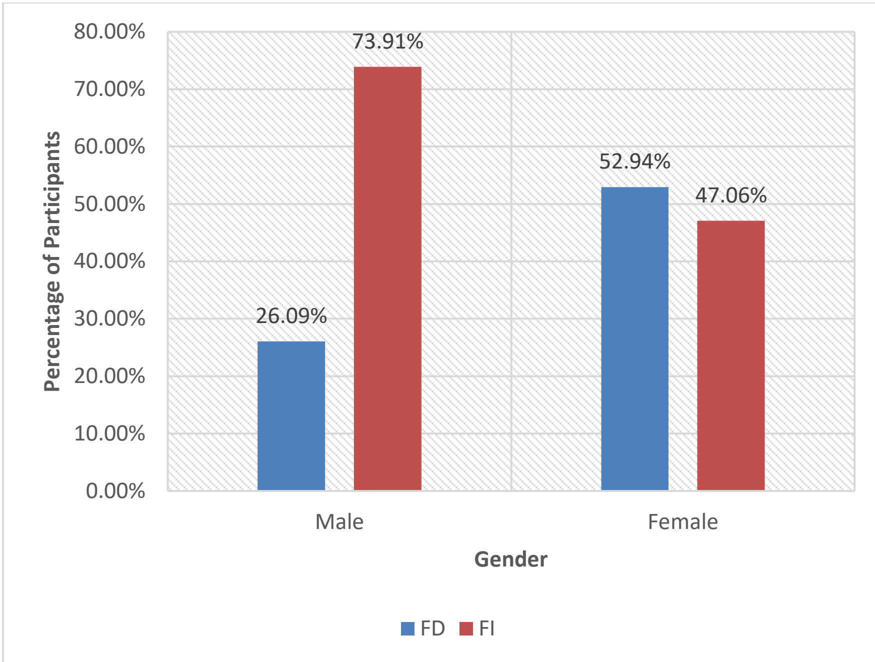


Figure 5.3 Gender differences in cognitive style

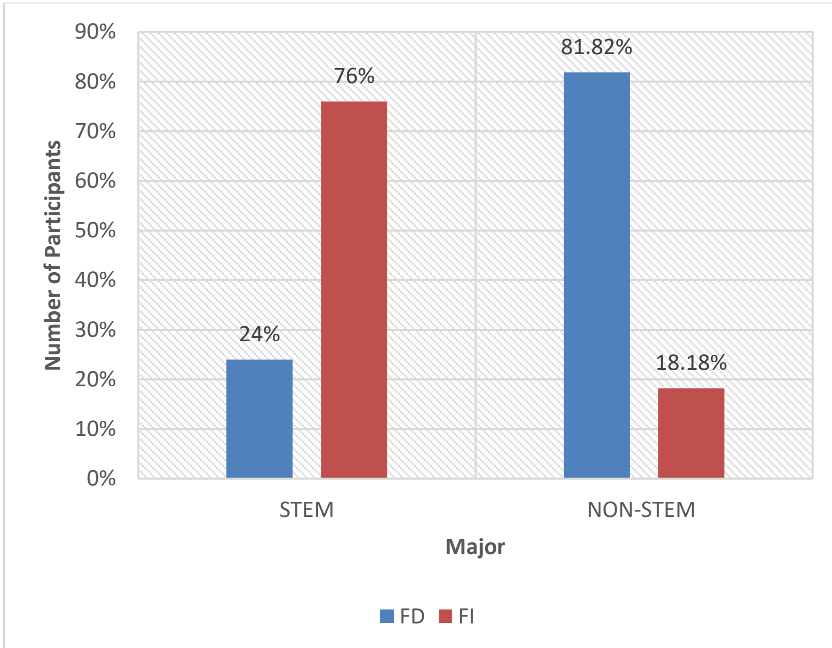


Figure 5.4 STEM vs. Non-STEM in cognitive style

5.3 Self-Reported Navigation Strategy (NSQ)

Navigation strategies measured through Navigation Strategy Questionnaires. Participants generally reported higher scores in procedural strategy (*M=17.64, SD = 2.75*) than survey-based (*M=15.11, SD= 2.95*).

5.3.1 Relationship between Gender and NSQ

Table 5.4 shows the results of NSQ, in terms of mean and Standard Deviation (SD) by gender. Male participants reported higher scores in survey-based strategy (*M=16.29, SD = 2.53*) compared to female participants. On the other hand, female participants reported higher scores in procedural strategy (*M=18.8, SD=3.23*) that that of male participants (*M=16.81, SD=1.97*).

Table 5.4 Means and Standard Deviations of Spatial Strategies by Gender

	Male		Female		Total	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Survey	16.29	2.53	13.47	2.75	15.11	2.95
Procedural	16.81	1.97	18.8	3.23	17.64	2.75

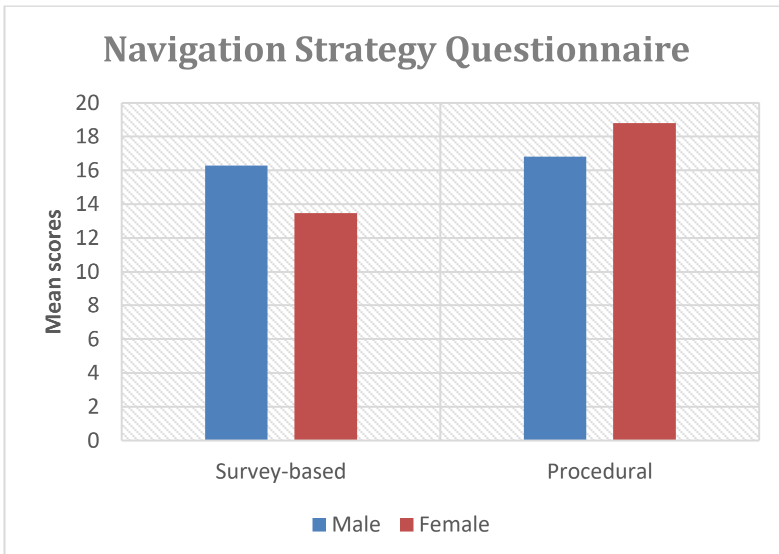


Figure 5.5 Gender difference in navigation strategy (NSQ)

To examine whether the gender differences on two subsets of navigation strategy are statistically significant or not, independent sample T-test was performed. Table 5.5 shows the results of these analyses. The results shows that there was significant gender difference for all navigation strategies subsets: survey strategy $t(38) = 2.773$, $p= 0.009$; and procedural strategy $t(38)= -2.206$, $p=0.034$.

Table 5.5 Independent samples t-test of NSQ with respect to gender

	Test	Statistic	df	p	η^2

Survey	Student	2.773	38.000	0.009	0.887
Procedural	Student	-2.206	38.000	0.034	-0.705

5.3.2 Relationship between Cognitive Style and NSQ

To examine whether the differences between cognitive style groups on two subsets of navigation strategy are statistically significant or not, independent sample T-test was performed. There was no significant difference in navigation strategy between FD and FI groups, $p>0.05$. Therefore, cognitive style may not relate to self-reported everyday navigation strategy.

Table 5.6 Means and Standard Deviations of Spatial Strategies by Cognitive Style

	FD		FI	
	Mean	SD	Mean	SD
Survey	15.07	2.92	15.14	3.04
Procedural	17.73	3.43	17.57	2.23

Table 5.7 Independent Samples T-Test results of cognitive style and NSQ

	Test	Statistic	df	p	η^2
Survey	Student	-0.143	38.000	0.887	-0.047
Procedural	Student	0.238	38.000	0.813	0.078

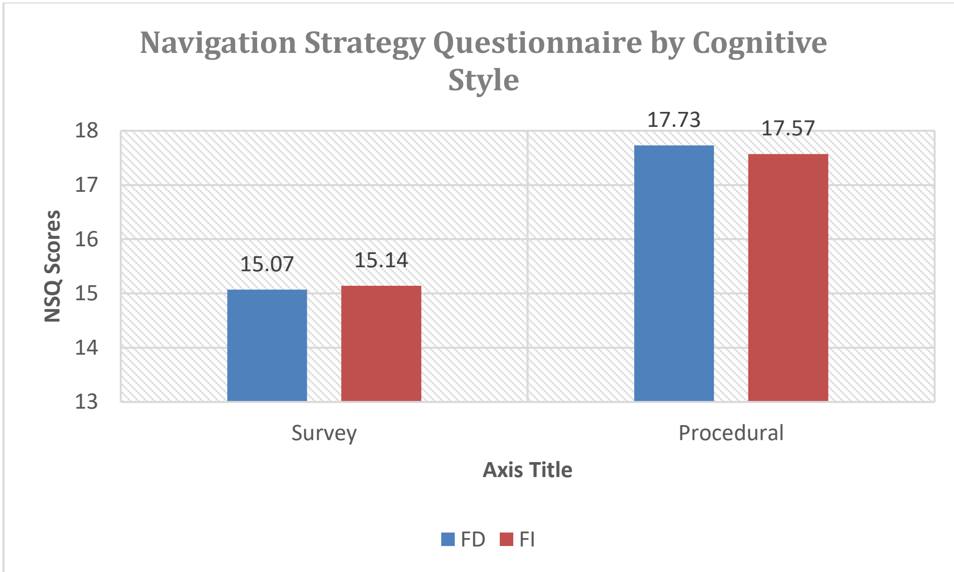


Figure 5.6 Cognitive style difference in navigation strategy (NSQ)

5.4 Spatial Abilities

The PSVT:R and Cube Comparison test data were coded as correct or incorrect. The PTA scores were calculated based on the degrees of deviation from the correct response. The smaller deviations showed better performance. Table 5.8 shows the results of participants' performance of each spatial ability test, in terms of mean and Standard Deviation (SD).

The table also shows the difference on spatial abilities between gender (male vs. female) and cognitive style (FD vs. FI). In spatial visualization, mean score of male participants(*M=54.21*) and field- independent (*M=59*) are higher than that of females (*M=41.43*) and field-dependent (*M=33.07*) participants. The same trend observed in spatial orientation, male (*M=33.26*) and FI (*M=36.94*) participants showed less angular error than females (*M=60.42*) and FD (*M=56.8*). There is no considerable amount of mean difference in spatial relation between gender. The mean score of FI (*M=53.25*) is slightly higher than FD (*M=45*) in spatial relation test.

Table 5.8 Means and standard deviation of spatial ability test scores by gender and cognitive style.

	Male		Female		FD		FI		Total	
	M	SD	M	SD	M	SD	M	SD	M	SD
Spatial Visualization	54.21	21.43	41.43	21.43	33.07	11.1	59.00	21.5	44.79	22.05
Spatial Orientation	33.23	18.19	60.42	29.67	56.8	27.89	36.94	23.96	44.77	27.01
Spatial Relation	50.00	15.9	50.00	17.87	45.00	16.07	53.25	16.33	50.00	16.49

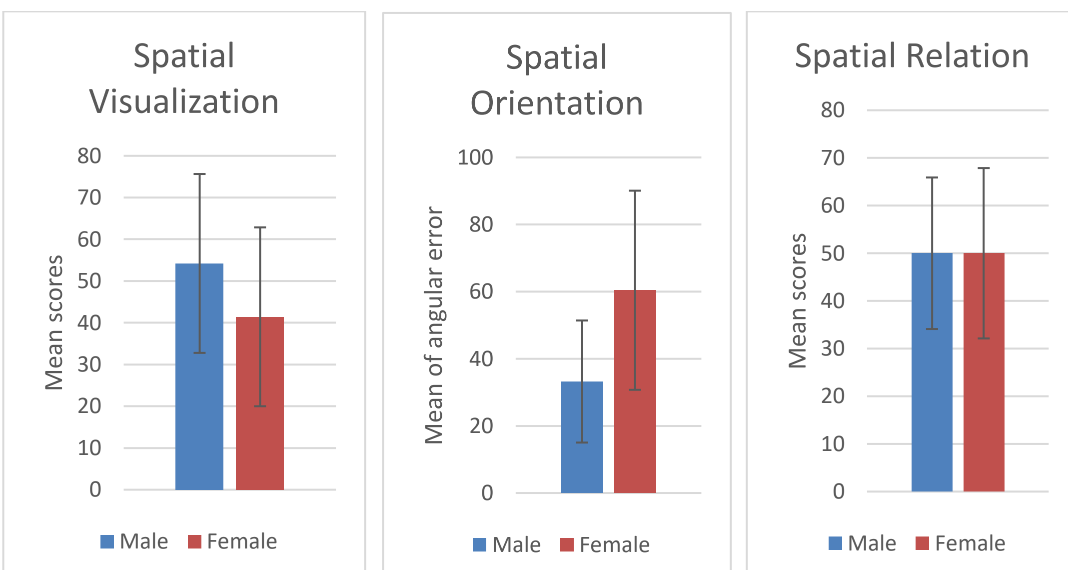


Figure 5.7 Gender differences in spatial abilities. In spatial orientation, higher score indicates lower performance.

To further examine whether the gender differences on three dimensions of spatial ability are statistically significant, independent sample T test was performed. A Shapiro-Wilk test of normality and Levene's test of homogeneity of variance were performed. A deviation from normality found in spatial visualization data *(Shapiro Wilk test on male: p=0.02, female: p=0.007)*, and unequal variance found in spatial orientation data *(Levene's test: p=0.001)*. Therefore, Mann-Whitney U test and Welch's test were performed for spatial visualization and spatial orientation accordingly. Student's t-test used for spatial relation data which is parametric and assumed equal variance. Table 5.9 shows the results of these analyses. There was a significant gender difference favoring male on spatial orientation ability; $t\ (21.848) = -2.702,\ p = 0.014$. However, no significant effect found on spatial visualization; $U = 193,\ p = 0.059$, and spatial relation, $t\ (38) = 0.354,\ p = 0.725$.

Table 5.9 Independent Samples T-Test result of spatial ability tests with respect to genders

	Test	Statistic	df	p	η^2
Spatial Visualization	Mann-Whitney U	193.000		0.059	0.379
Spatial Orientation	Welch	-2.702	21.848	0.014	-1.009
Spatial Relation	Student	0.354	38.000	0.725	0.123

5.4.1 Relationship between Spatial Ability and Navigation Strategy (NSQ)

The relationships between spatial ability and navigation strategy were examined using partial correlations, controlling for cognitive style. In this analysis, the continuous scale of GEFT data was used instead of categorized data. There was no significant partial correlation between spatial ability and two navigation strategies.

Table 5.10 Pearson Correlations among Spatial Abilities and Spatial Strategies

			Pearson		Spearman	
			r	*p*	*rho*	*p*
Spatial Visualization	-	Survey	0.242	0.174	0.233	0.192
Spatial Visualization	-	Procedural	-0.043	0.812	-0.146	0.417
Spatial Orientation	-	Survey	-0.304	0.091	-0.121	0.508
Spatial Orientation	-	Procedural	0.155	0.397	0.071	0.700
Spatial Relation	-	Survey	1.426e-4	0.999	-0.020	0.912
Spatial Relation	-	Procedural	-0.199	0.266	-0.302	0.088

Conditioned on variables: Cognitive Style

5.4.2 Relationship between Spatial Ability and Cognitive Style

In order to examine the effect of cognitive style on three different dimensions of spatial abilities, independent sample T test was performed. A Shapiro-Wilk test of normality and Levene’s test of homogeneity of variance were also performed. The Levene's test result of all spatial ability data was statistically non-significant ($p>0.05$) indicating that equal variance is assumed. However, the Shapiro-Wilk test results showed a deviation from normality ($p < 0.05$) in spatial visualization and spatial orientation data. Therefore, non-parametric Mann-Whitney U test was performed for spatial visualization and spatial orientation. Table 5.10 shows the results of these analyses. There was significant difference between cognitive style (FD vs FI) for spatial visualization ability; $U = 38.5$, $p < 0.001$, and spatial orientation; $U = 172$, $p = 0.044$. However, there was no significant difference in mean scores between FD and FI found on spatial relation; $t(38) = -1.531$, $p = 0.134$.

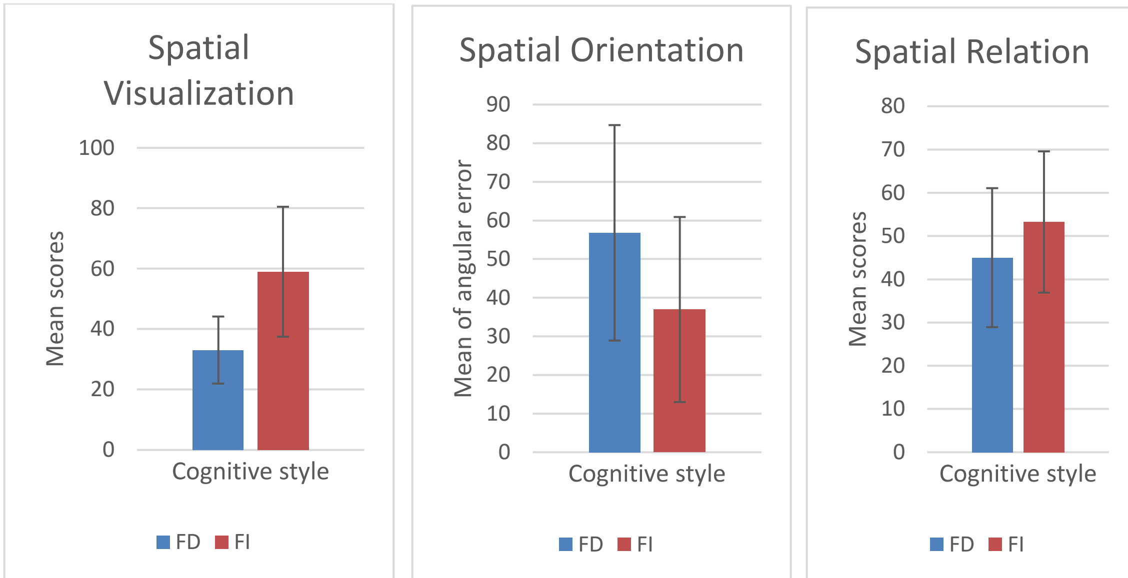


Figure 5.7 Differences in spatial abilities between cognitive style groups

Table 5.10 Independent Samples T-Test results of spatial ability tests with respect to cognitive style

	Test	Statistic	df	p	η^2
Spatial Visualization	Mann-Whitney U	38.500		< .001	-0.718
Spatial Orientation	Mann-Whitney U	172.000		0.044	0.433
Spatial Relation	Student	-1.531	38.000	0.134	-0.5

5.5 The Effect of Map Orientation on Spatial Knowledge Development

5.5.1 Pointing Direction Test

In Table 5.11, descriptive statistics on pointing direct test were given where a smaller number indicates better performance. The descriptive data and Figure 5.8 indicate that the angular error guided by north-up maps (*M=79.77, SD= 22.26)* was slightly higher than that of using forward-up maps (*M=73.93, SD=20.52*). The descriptive results suggest that participants performed a slightly better on pointing direction task when they were guided by forward-up map.

Table 5.11. The angular error in pointing direction test with respect to the map orientation condition

Condition	N	Mean	SD	Min	Max
North Up	40	79.769	22.262	32.417	14
Forward Up	40	73.391	20.522	119.800	100.167

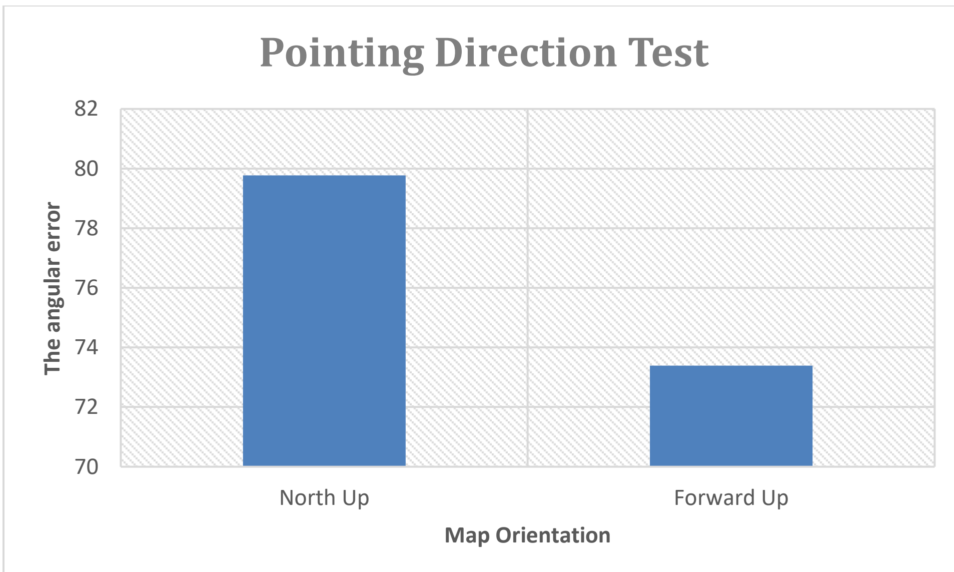


Figure 5.8 A graph of the angular error in the pointing direction test in different map orientation conditions.

In addition to the descriptive results, independent sample *t*-test was conducted to see whether the mean difference between map orientation was statistically significant. A Shapiro-Wilk test of normality and Levene's test of homogeneity of variance were also performed. The Levene's test result was statistically non-significant *(p=0.38)* indicating that equal variance is assumed. However, there was a deviation from normality found in forward-up map data ($p<0.05$). Therefore, the result of Mann-Whitney U which is a non-parametric test was also reported (see Table 5.12). The test result, however, was not statistically significant *(Mann-Whitney U: p=0.172).*

Table 5.12 Independent sample t-test of mean differences of pointing direction angular error between north up map condition and forward up map condition.

Test	Statistic	df	p	η^2
Student	-1.220	65	0.227	-0.298
Welch	-1.218	64	0.228	-0.298
Mann-Whitney U	451.500		0.172	-0.195

5.5.2 Pointing Direction Test by Cognitive Style

Table 5.13 shows mean and standard deviation of the angular error on pointing direction test in each map orientation condition, divided by cognitive style groups. The results indicated that field-dependent (FD) participants had a higher angular error when using the north-up maps (*M=85.568 , SD=16.373*) than when using the forward-up maps (*M=75.78 , SD=14.022*), whereas field-independent(FI) participants had no considerable amount of difference in angular error between north-up map (*M=70.576 , SD*=26.281) and forward-up map (*M=71.245, SD=25.688*) conditions (see Figure 5.9). These results indicate that FD individuals might be affected by map orientation favoring forward-up map when they are acquiring survey knowledge. On the other hand, FI individuals are not dependent on map orientation for acquiring survey knowledge.

Table 5.13 The angular accuracy in pointing direction test by cognitive style

Condition	Cognitive Style	N	Mean	SD	Min	Max
North Up	FD	15	85.568	16.373	61.25	119.8
	FI	25	70.576	26.281	32.417	105.083
Forward Up	FD	15	75.780	14.022	47.75	95.75
	FI	25	71.245	25.688	14	100.167

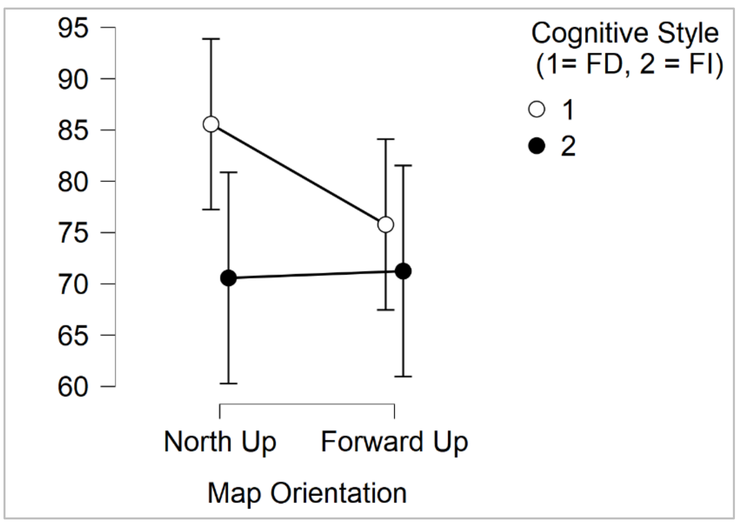


Figure 5.9 Descriptive plot of the angular accuracy in the pointing direction test by cognitive style.

In order to investigate whether the difference between cognitive groups with respect to the map orientation was statistically significant, further analysis conducted. A repeated measures ANOVA was performed on pointing direction test with map orientation (North up vs. Forward Up) as a within-subjects variable and cognitive style

(FD vs. FI) as a between-subjects variable. As is shown in Table 5.14, the main effect of map orientation on the accuracy of pointing direction test was not significant $F (1, 38) =1.24, p=0.273$. There was no significant interaction between map orientation and cognitive style, $F (1,38) =1.56, p=0.219$, was found.

Table 5.14 The results of ANOVA analysis of the effect of map orientation on pointing direction test

Cases	Sum of Squares	df	Mean Square	F	p	η²
Map Orientation	522.918	1	522.918	1.24	0.273	0.013
Map Orientation ∗ Cognitive Style	657.975	1	657.975	1.56	0.219	0.016
Residuals	16027.611	38	421.779			

Note. Type III Sum of Squares

5.5.3 Sketch Map Test

The participants' sketch map accuracy data were collected and analyzed in Gardony Map Drawing Analyzer (GMDA) (Gardony et al., 2016). There are three participants produced the low-quality map drawings which are unable to analyze. Thus, three participants data were excluded in this analysis which results total 37 sketch map data in each map orientation condition. The sketch maps were analyzed according to two factors in GMDA, namely: canonical organization and angle accuracy. Canonical organization score indicates the accuracy of the canonical relationships (N/S/E/W) for each landmark in the sketch map comparing to the target environment (e.g., maze). The score ranges from 0 to 1. Larger score indicating more accurate representation of the environment. Angle accuracy indicates the accuracy of the angles among the landmarks on the sketch map. The score ranges from 0 to 1 with larger scores indicating more accurate inter-landmark angle representation (Gardony et al. 2016). Table 5.15 shows the mean of canonical organization and angle accuracy in each map orientation condition. For the canonical organization, the mean of total participants in north-up map condition was *0.59 (SD=0.23)* whereas that of in forward-up condition was *0.514 (SD=0.251)*. For the angle accuracy scores, mean of total participants in north-up map condition was *0.618 (SD=0.199)* whereas that of in forward-up condition was *0.548 (SD=0.171)*. In general, participants have better environmental representation when they were guided by north-up map condition (see Figure 5.10).

Table 5.15 Mean of canonical organization and angle accuracy of sketch maps in different map orientation conditions. Larger score indicates more accurate representation of environment.

	Map Orientation	**N**	**Mean**	**SD**	**Min**	**Max**
Canonical organization	North-up	37	0.590	0.230	0.00	0.988
	Forward-up	37	0.514	0.251	0.00	0.988
Angle accuracy	North-up	37	0.618	0.199	0.339	0.988
	Forward-up	37	0.548	0.171	0.086	0.918

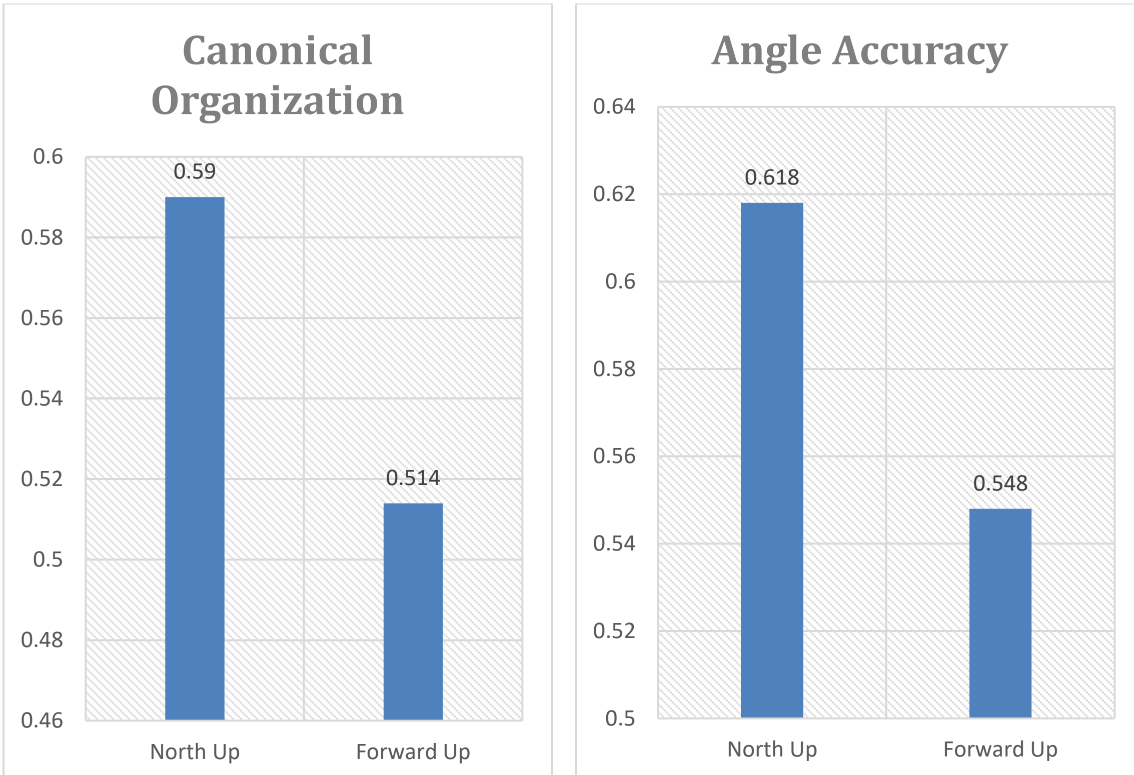


Figure 5.10 Means of canonical organization (left) and angle accuracy (right) of sketch maps

5.5.4 Sketch Map Test by Cognitive Style

When cognitive style differences were considered for the sketch map test, the following results were obtained from the descriptive analysis. The results of descriptive data for canonical organization and angle accuracy according to cognitive style were given in Table 5.16. For the canonical organization, the mean of participants classified as FD was lower (*M=0.568, SD=0.205*) than the mean score of participants classified as FI (*M=0.631, SD=0.2*) under north-up map condition. The same trend observed in forward-up map condition where FD individuals showed lower performance (*M=0.5, SD=0.249*) than FI individuals (*M=0.543, SD=0.223*).

For the angle accuracy scores in north-up map condition, participants classified as FD showed lower performance (*M=0.596, SD=0.175*) than participants classified as FI (*M=0.640, SD=0.206*). On the contrary, in forward up map condition, FD achieved higher score (*M=0.575, SD=0.126*) than FI (*M=0.508, SD=0.201*). One notable finding was that the mean difference between map orientation among FI group shows a larger discrepancy compared to the mean difference among FD group.

Table 5.16 Descriptive statistics for canonical organization according to cognitive style.

Map	GEFT	N	Mean	SD	Min	Max
North up	FD	11	0.568	0.205	0.218	0.772
	FI	26	0.631	0.200	0	0.988
Forward up	FD	11	0.500	0.249	0	0.816
	FI	26	0.543	0.223	0.218	0.988

Table 5.17 Descriptive statistics for angle accuracy according to cognitive style.

Map	GEFT	N	Mean	SD	Min	Max
North up	FD	11	0.596	0.175	0.339	0.890
	FI	26	0.640	0.206	0.366	0.988
Forward up	FD	11	0.575	0.126	0.346	0.837

	FI	26	0.508	0.201	0.086	0.918

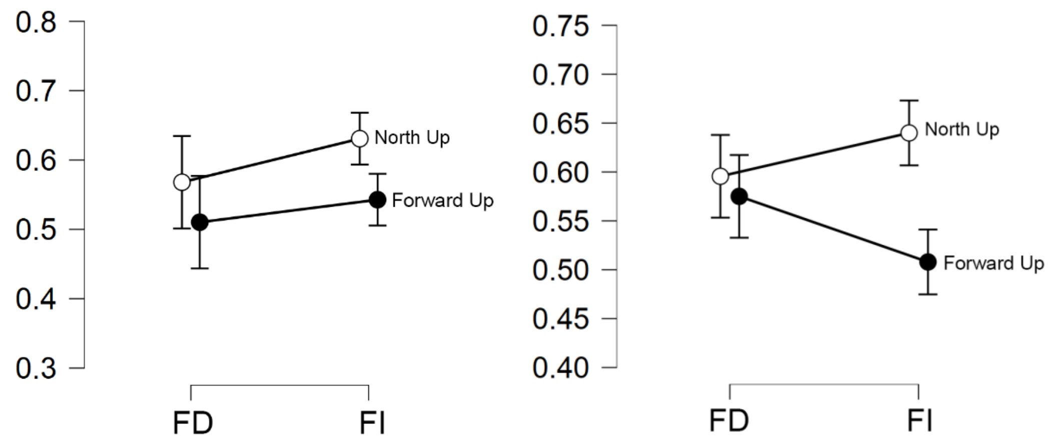


Figure 5.11 Mean of canonical organization (left) and angle accuracy (right) of sketch maps in different map orientation conditions by cognitive style.

Further analysis performed to investigate the effect of map orientation on survey knowledge in regards of cognitive style. A separate repeated measures ANOVA was conducted on each factor of sketch map data with map orientation (North up vs. Forward Up) as a within-subjects variable and cognitive style (FD vs. FI) as a between-subjects variable. Table 5.18 and Table 5.19 show the analysis results on canonical organization and angle accuracy respectively. There results revealed that there was no significant main effect of map orientation on canonical organization ($p>0.05$).

For the angle accuracy score, there was no statistically significant effect but a certain trend toward significance was found, $F(1,34)=4.056$, $p=0.052$. There was no significant interaction between the map orientation and cognitive style on both sketch map factors such that participants' cognitive style does not moderate the survey knowledge results under different map orientation conditions.

Table 5.18 The Repeated Measure of ANOVA analysis results of the Effect of Map Orientation on Canonical Accuracy.

Cases	Sum of Squares	df	Mean Square	F	p
Map Orientation	0.104	1	0.104	2.810	0.103
Map Orientation ∗ Cognitive Style	0.002	1	0.002	0.046	0.831
Residuals	1.259	34	0.037		

Table 5.19 The Repeated Measure of ANOVA analysis results of the Effect of Map Orientation on Angle Accuracy.

Cases	Sum of Squares	df	Mean Square	F	p
Map Orientation	0.099	1	0.099	4.056	0.052
Map Orientation ∗ Cognitive Style	0.053	1	0.053	2.166	0.150
Residuals	0.8.34	34	0.025		

5.5.5 Landmark Sequencing

Table 5.20 shows the mean of landmark sequencing accuracy in each map orientation condition. In north-up map condition, participants showed less accuracy compared to the score in forward-up map condition. The mean in north-up map is *4.939 (SD=1.435)* whereas the mean in forward-up map is *5.303 (SD=1.51)*. The results imply that participants may have better route knowledge after they were aided by forward-up map (see Figure 5.12).

Table 5.20 Descriptive statistics for landmark sequencing test in the map orientation conditions.

	Map Orientation	N	Mean	SD	Min	Max
Landmark Sequencing	North-up	40	4.939	1.435	2	2
	Forward-up	40	5.303	1.510	7	7

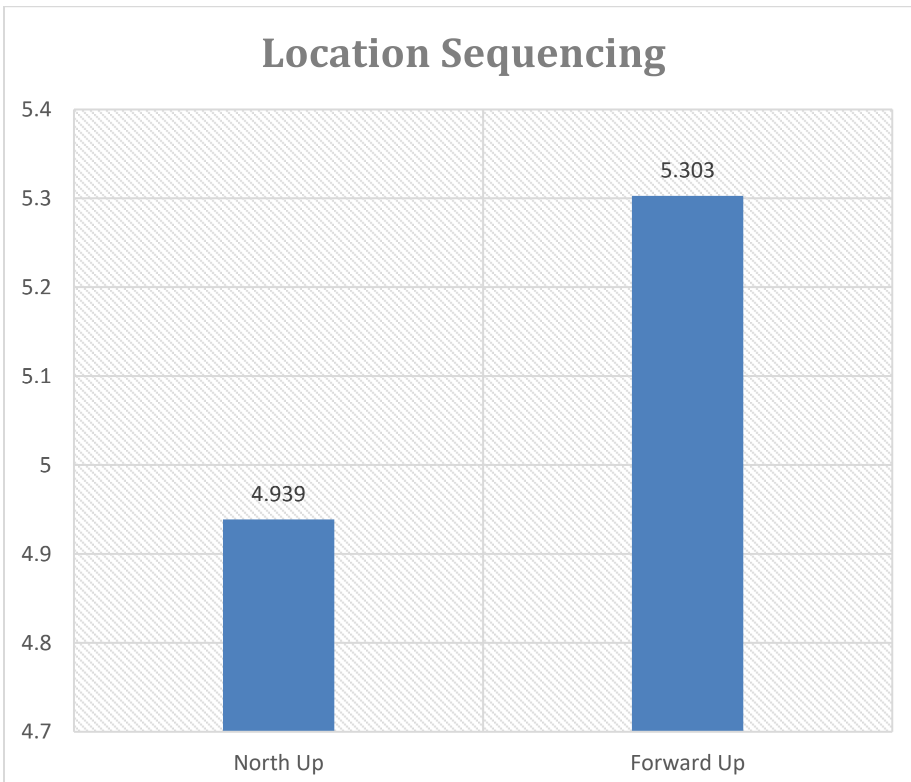


Figure 5.12 Means of landmark sequencing scores between two map orientation conditions.

5.5.6 Landmark Sequencing by Cognitive Style

When cognitive style differences were considered for landmark sequencing test, the following results were obtained. The results of mean differences on landmark sequencing accuracy according to cognitive style were given in Table 5.21. In north-up map condition, the mean of participants classified as FD was lower (*M=3.846, SD=1.068*) than the mean of participants classified as FI (*M=5.65, SD=1.182*). The same trend observed in forward-up map condition where FD individuals showed lower performance (*M*=4.939, *SD=1.44*) than FI individuals (*M*=5.303, *SD*=1.510). However, as shown in Figure 5.13, the mean difference in each map orientation conditions among FD group shows a larger discrepancy compared to the mean difference among FI group.

Table 5.21 Descriptive statistics for landmark sequencing test in the map orientation conditions by cognitive style.

Map Orientation	Cognitive Style	N	Mean	SD	Min	Max
North-up	FD	40	3.846	1.068	2	5
	FI	40	5.65	1.182	3	7
Forward-up	FD	40	4.939	1.435	3	7
	FI	40	5.303	1.510	2	7

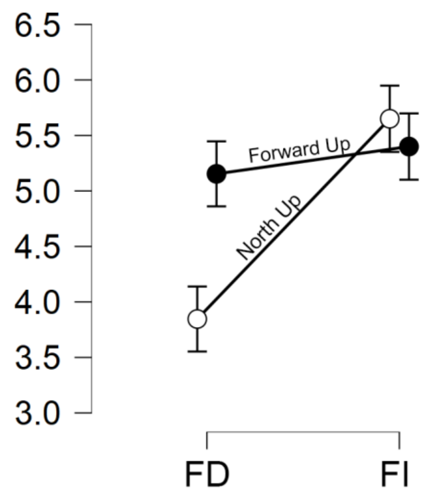


Figure 5.13 Mean of landmark sequencing score in different map orientation conditions by cognitive style.

Further analysis performed to investigate the statistical effect of map orientation on landmark sequencing score in regards of cognitive style. A repeated measures ANOVA was conducted with map orientation (North up vs. Forward Up) as a within-subjects variable and cognitive style (FD vs. FI) as a between-subjects variable. There was no significant main effect of map orientation for landmark sequencing test scores, $F(1, 35)=2.891, p = 0.099$, but there was a significant Map orientation * Cognitive style interaction, $F(1,35)= 6.27, p=0.018$. Post hoc comparisons revealed that for landmark sequencing, a significant difference between cognitive style groups (FD vs. FI) in north-up map condition ($p=0.002$). Also, a significant difference between map orientation (north-up vs. forward-up) among FD group was found ($p=0.044$) (See Table 5.23).

Table 5.22 Repeated measure ANOVA results for the main effect of map orientation on landmark sequencing score with cognitive style as a fixed factor.

Cases	Sum of Squares	df	Mean Square	F	p	η^2
Map Orientation	4.407	1	4.407	2.891	0.099	0.031
Map Orientation ✻ Cognitive Style	9.559	1	9.559	6.270	0.018	0.067
Residuals	47.260	35	1.525			

Table 5.23 Post Hoc Comparisons - Cognitive Style ✻ Map Orientation

		Mean Difference	SE	t	p_{holm}
FD, North.Up	FI, North.Up	-1.804	0.480	-3.755	0.002
	FD, Forward.Up	-1.308	0.484	-2.700	0.044
	FI, Forward.Up	-1.554	0.480	-3.234	0.010
FI, North.Up	FD, Forward.Up	0.496	0.480	1.033	0.917
	FI, Forward.Up	0.250	0.390	0.640	1.000
FD, Forward.Up	FI, Forward.Up	-0.246	0.480	-0.512	1.000

5.5.7 Route Retracing

The egress task completion time from the end point to the start point was recorded in unit of seconds. Table 5.24 shows mean and standard deviation of egress time under different map orientation conditions. The egress time under north-up condition was higher (*M=145.394, SD=94.031*) than the egress time of route retracing under forward-up map condition (*M=136.091, SD=80.038*). Participants in general might feel more difficult to retrace the route in north-up map condition.

Table 5.24 The egress time of route retracing test in different map orientation conditions.

	Map Orientation	N	Mean	SD	Min	Max
Egress time	*North-up*	40	145.394	94.031	29	375
	Forward-up	40	136.091	80.038	37	343

5.5.8 Route Retracing by Cognitive Style

When cognitive style differences were considered for route retracing test, the following results were obtained. The results of mean differences on the egress time according to cognitive style were given in Table 5.25. In north-up map condition, FD and FI participants took almost same amount of time on the route retracing task. The mean egress time for FD individuals were 145.769 seconds and for FI individuals were 145.15 seconds. In forward-up map condition, FI individuals took less amount of time (*M=124.35, SD = 66.867*) whereas FD individuals took a considerably more amount of time (*M=154.154, SD = 97.058*) (see Figure 5.14).

Table 5.25 Means and standard deviation for the egress time (in seconds) in route retracing task as a function of cognitive style.

	Map Orientation	Cognitive Style	N	Mean	SD	Min	Max
Egress time	*North-up*	FD	40	145.769	108.382	43	375
		FI	40	145.150	86.443	29	333
	Forward-up	FD	40	154.154	97.058	42	343
		FI	40	124.350	66.867	37	260

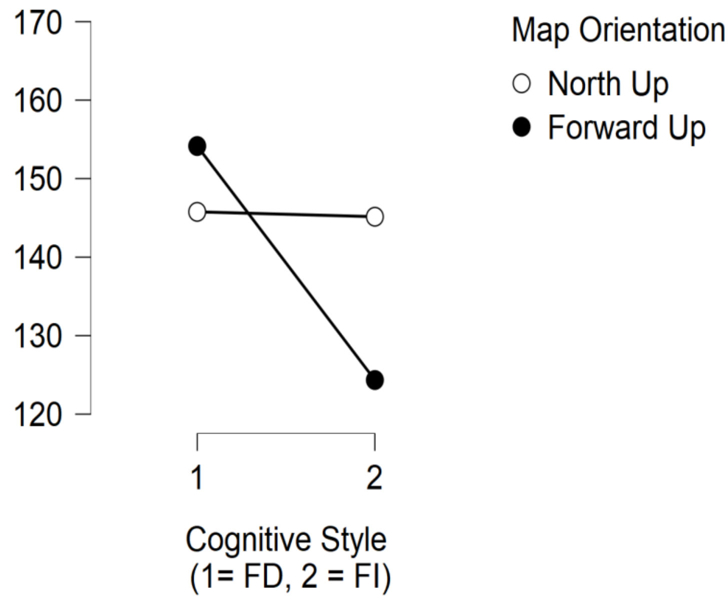


Figure 5.14 Mean of landmark sequencing score in different map orientation conditions by cognitive style.

Further analysis performed to investigate the statistical effect of map orientation on route retracing task in regards of cognitive style (see Table 5.26). A repeated measures ANOVA was conducted with map orientation (North up vs. Forward Up) as a within-subjects variable and cognitive style (FD vs. FI) as a between-subjects variable. There was no significant main effect of map orientation for the route retracing task, $F (1,38) =0.998, p = 0.324$. There was no significant interaction between Map orientation * Cognitive style, $F (1,38) =0.891, p=0.351$.

Table 5.26 Repeated measure ANOVA results for the main effect of map orientation on total egress time in route retracing task with cognitive style as a fixed factor

Cases	Sum of Squares	df	Mean Square	F	p
Map Orientation	2742.163	1	2742.163	0.998	0.324
Map Orientation ∗ Cognitive Style	2448.163	1	2448.163	0.891	0.351
Residuals	104361.787	38	2746.363		

6 DISCUSSION

The study explored the relationship between cognitive style and other spatial learning-related variables including three dimensions of spatial abilities, spatial strategies, and gender. The main purpose of this study was to examine the effectiveness of guide-map orientation on two different cognitive style groups (field-dependent vs. field-independent) in terms of acquiring route and survey knowledge.

6.1 Gender Difference

The gender difference in three dimensions of spatial abilities such as spatial orientation, spatial visualization, and spatial relation was first explored. The results replicated the previous findings by Weisberg et al. (2014) that males outperformed females in spatial orientation ability. The current study also found a significant difference favoring male in spatial orientation ability as indicated by the higher scores in PTA test.

The current study results also showed a similar trend to the previous findings that males outperformed females on spatial visualization ability (e.g., Galea & Kimura,1993; Dabbs et al., 1998; Saucier & Green, 2002; Montello et al. 1999; Hegarty et al.,2006; Castelli et al., 2008; Lawton, 1994). However, there was no statistically significant difference in the mean scores between female and male participants.

In spatial relation ability assessed by Cube Comparison test, there were no mean differences observed between male and female participants. Although relatively less attention has been made to spatial relation ability in the past research, there are some studies that tested gender differences in spatial relation ability (van der Ham & Borst, 2011; Park & Yoon, 2012). These studies agree with the current study that there is no significant gender difference in spatial relation ability. Overall, the study found spatial orientation ability of participants measured through PTA test appears to produce the most robust gender differences across all spatial ability dimensions. However, given the fact that navigation requires not just one aspect of spatial ability but a combination of its sub-dimensions, the current study result of no significant gender difference in the two spatial ability dimensions (spatial visualization and spatial relation) seems insufficient to account for the gender as the predictor of navigation ability.

The study also explored the relationship between gender and navigation strategy. The male participants reported higher score on survey strategy than females. Female participants, on the other hand, reported higher scores on procedural strategy compared to male participants. These results confirmed the previous finding that males favor survey-type spatial information such as canonical cues and metric relations whereas females favor route-type spatial information such as salient landmarks (e.g., Lawto n, 1994; Lawton & Kallai, 2003; Saucier & Green, 2002; Chai & Jacobs, 2010; Marchette et al., 2011). Although the study results replicate the previous findings, what causes this difference is still unclear.

6.2 Cognitive Style Difference

As the study hypothesized, participants who are FI in their cognitive style exhibit greater scores in spatial visualization and spatial orientation test. This is partially in line with previous studies that have found that field-independent learners outperformed spatial visualization ability (i.e., mental rotation of an object) than field-dependent learners (Li et al., 2016; Boccia et al., 2016; Hoyek et al., 2009). However, their studies have not examined the other dimensions of spatial abilities such as spatial orientation and spatial relation. The current study also tested and found that FI individuals outperformed FD individuals spatial orientation ability as indicated by greater scores in PTA test. There was, however, no considerable difference in spatial relation ability between FI and FD participants. The reason for a different performance on spatial ability tasks depending on the type of cognitive style is unclear, but one may speculate that it could be a result of the different ways in which individuals organize/process spatial information. As mentioned above, FD individuals, in contrast to FI individuals, have difficulty extracting salient information from the surrounding field. Thus, they performed worse on those spatial ability tests such as PSVT:R and PTA that require disregarding the deceptive cues from the field (Witkin, 1977; Boccia et al., 2016). Another notable finding is that the correlation between spatial visualization and cognitive style ($p<0.001$) is more robust than the correlation between spatial visualization and gender ($p=0.059$). This may support the argument that individual differences in spatial abilities are not related to biological gender. Although more future studies are needed on the role of cognitive style in human navigation, the current study also shows the possibility of cognitive style as an indicator of navigation ability.

Moreover, the study hypothesized that FI learners would be more likely to employ survey-based strategies than FD learners, whereas FD learners would be more likely to employ route-based strategies than FI learners. This assumption is based on the tendencies of each cognitive style in processing spatial information. FI individuals were known to rely on survey representation (e.g., NSWE) whereas FD individuals were known to rely on directional-based cues. However, the study results revealed that there was no significant interaction between cognitive style and everyday navigation strategy.

6.3 The effect of Map Orientation

The current study explored the effect of map orientation (north-up vs. forward-up) on acquiring spatial knowledge as a function of cognitive style. Use of north-up map improved performance on sketch map test regardless of participants' cognitive style, meaning that individuals guided by north-up map acquired more accurate spatial representation. After the cognitive style was taken into consideration, the impact of map orientation favoring the north-up map was noticeable in the overall completeness of the sketch map. In contrast to the study hypothesis, both FD and FI participants showed more accurate canonical organization in their sketch map after they were guided by a north-up map. That means navigation aided by north-up map helped them to acquire more accurate canonical spatial information even for FD individuals who have been known that favor directional-based cues. Given the learning traits of FD, the study assumed that FD individuals would adopt better survey knowledge with a forward-up map which provides spatial information they could easily process. One possible explanation of these opposite results is that providing information that could easily process results in disregarding other spatial information. For example, since FD has a basic propensity to accept sequential information more easily, this propensity may have been further strengthened by the information given by the forward-up map. Participants commented in the forward-up map condition that “I can't remember TV since I just follow the path”. Moreover, it has been noticed that they were easily confused left or right turn in the north-up map since the map orientation is not aligned with their body orientation (e.g., the viewing direction). However, they may have been able to naturally acquire the configuration of the entire space through those efforts to align the direction they view with the direction of the map. This could also explain the poor performance of FI’s angle accuracy in Forward-up map condition.

In terms of route knowledge, as the study assumed, FI participants had more correct answers in the landmark sequencing tests after they were guided by a north-up map compared to their performance in forward-up map conditions. On the other hand, FD participants had higher accuracy in landmark sequencing tests in the forward-up map condition than their performance in the north-up map condition. However, in the route retracing test, there was no statistically significant effect of map orientation on different cognitive style groups. In contrast to the study hypothesis, the descriptive results show that FD took a considerable amount of time in the forward-up condition which was even longer than their performance in the north-up map condition. These unexpected results could be explained that the route retracing test requires both route and survey knowledge. Route knowledge is generally encoded in an egocentric reference frame (e.g., turn left at X). Route retracing, however, from a different viewpoint to that route direction. It additionally requires an allocentric reference frame (e.g., the coordination between landmarks) (Wiener et al., 2012). Therefore, in line with the results from the survey knowledge test, a forward-up map impairs their ability to acquire allocentric spatial information. That results in poor performance in the route retracing tests which requires survey knowledge as well. Therefore, in future research, the route knowledge task should be reconsidered and administered in different tasks.

The study has certain limitations that are important to mention. One limitation is the number of trials and participants was relatively small. Future research should increase both. The population characteristics in terms of educational diversity and background are also limited to the university population mostly STEM field. Another limitation was derived from the contact-free study settings. The study could not control the external environmental factors such as screen size, resolution, and distance of the participants. The internet connection issue has been raised for some participants that resulted in some buffering when they were performing the spatial task. In future studies, screening participants in terms of their screen size and the resolution may improve the level of control of the study environment.

7 CONCLUSIONS

It has become common to use GPS when traveling somewhere. Taking Google Maps as an example, the default setting is a forward-up map, so people get used to that default map orientation from the beginning. However, the current study found that map orientation may cause a significant impact on some people, but not for some other people depending on their cognitive style and the given map orientation. As mentioned above, in recent years, the severity and number of extreme weather events such as floods, wildfires, and other emergency situations have been increased (Sadeghi et al., 2019). Under those emergency situations when the local landmarks and GPS is no longer available, survey knowledge is particularly important. Thus, people may need to naturally acquire the survey knowledge in their everyday navigation.

This study has suggested that cognitive style (e.g., field dependent and field independent) may have a potential effect on the relationship between map orientation and acquiring spatial knowledge. The obtained results also confirmed the previous findings on the relationship between spatial learning and other personal variables such as gender, spatial abilities, and spatial strategy. The research added to our understanding of how and to what extent map orientation and individual differences may play an important role in the ability of spatial knowledge acquisition. This study has suggested that a certain map orientation might be more beneficial for survey knowledge acquisition. The potential applications of the current and related future studies include, for instance, the development of a GPS application or tool to improve navigational performance and spatial knowledge acquisition (both route and survey knowledge) of end-users by adopting their cognitive style.

This research also introduced a new approach to contact-free human subject research. The COVID-19 has impacted human subject research activities. Many institutions determined to stop any research activities involving in-person interaction with participants at the beginning of the pandemic. Therefore, the current study took the first step in exploring alternative remote research activities to maximize the safety of all involved. Given that VR devices have had widespread adoption, future research could be done in metaverse settings that provide a more immersive environment for participants.

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