Human Wayfinding and Navigation in a Large-Scale Environment:
Cognitive Map Development and Wayfinding Strategies

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By

Rui Li

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ABSTRACT

In a large scale environment humans rely on their mental representations —cognitive maps— to solve navigational problems. To approach the understanding of how humans acquire, process, and utilize information from the environment, three groups of participants in this study performed several experiments associated with finding their way in a previously unknown environment. Experimental tasks included route retracing, pointing to previously visited locations, and a questionnaire regarding wayfinding strategies and cognitive map development. Each of three groups of participants was in one of three unique conditions: 1. learning and retracing with navigational landmarks indicating right and left turns at decision points; 2. during route retracing only generic landmarks were present at decision points (landmarks indicating left and right were present during learning but replaced during retracing); and 3. no landmarks were present during route retracing (landmarks indicating left and right were present during learning but removed before retracing started). Results supported the hypothesis that during the initial stages of visiting an unknown environment we build metric knowledge together with non-metric knowledge associated with the broad categories of landmark and route knowledge. In addition, the environment plays an important role in wayfinding performance and that characteristics of the environment contribute differently to the development of our cognitive map. Last but not least, the strategies humans use to solve wayfinding problems in a novel environment are not based on an individual type of environmental knowledge; in fact, we switch between different types of environmental knowledge when necessary. Shifting between strategies appears to be from more familiar environmental knowledge to less familiar knowledge. In particular, participants from group 3 (no landmarks during the retracing period) were more likely to walk off-route during retracing but exhibited more accurate metric knowledge of the environment. Based on the results of this experiment, they combined route- and survey-based strategies in wayfinding and switched from the most familiar knowledge to a less familiar strategy.

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INTRODUCTION

No matter whether you are walking to school every day as a student or finding a place of interest in a new city as a tourist, navigation is necessary. We can speculate that in prehistoric times the need to return home after a hunt was important (Dabbs et al., 1998). Even in modern times when humans must go to important places and arrive on time the ability to navigate is an important skill (Foo et. al, 2005). Navigation is defined as the ability to make one's way through any space. During this process, humans build internal representations of perceived environmental features and spatial relations among them in order to reach their destinations (Golledge, 1999). These representations of the knowledge and associated relationships are collectively referred to as our cognitive map. In recent years, demands of better navigational products such as GPS, Vehicle Navigational Systems, and Location-based Service require a more accurate understanding of potential user's wayfinding behaviours. This research aims to provide a theoretical basis for the improvement of navigational products in order to better facilitate use. It has have been increasingly important research topic in several disciplines such as behavioural geography, psychology. Findings in these disciplines contribute to the understanding of environmental acquisition and design of navigational aids and mapmaking. The most important environmental knowledge utilized by humans in navigation has been categorized into landmark-, route-, and survey-knowledge (Aginsky et al., 2000; Lovelace et al., 1999; Mcnaughton et al., 1991). However, there are still heated debates regarding the development of different types of environmental knowledge and navigational strategies, especially at different spatial scales. This study consists of an experiment in a real-world, yet controlled, environment to investigate how humans develop these different types of knowledge in wayfinding in an environment larger than human body.

Our cognitive map plays an essential role in solving navigational problems (Lloyd, 2000). Wayfinding is a special situation of navigation which consists of a purposeful, directed, and motivated process of determining and following a path between an origin and destination (Golledge, 1999). In addition, the route between the origin and destination, in many cases, cannot be perceived directly by the wayfinder at any single moment (Allen, 1999); hence, knowledge gradually perceived from the environment is needed to solve these wayfinding problems. The characteristics of environmental knowledge stored as an internal representation are similar to those on a cartographic representation (Cubukcu, 2003). Researchers suggested that the appropriate term for such a representation is a *cognitive map* (Cornell & Heth, 2003; Golledge, 1995, 1999; Hart & Moore, 1973; Montello, 2002). In past decades, many studies have assessed the strategies humans use in wayfinding. Some researchers have suggested that within environments humans rely on landmarks instead of the configurational knowledge of the environment (Foo et al., 2005). However, some others have argued that scale was an essential component in the acquisition of spatial knowledge, which resulted in qualitatively different wayfinding performances and strategy uses (Bell, 2002). Montello (1998) suggested that humans acquire not only landmark-based knowledge but also knowledge having metric characteristics (survey-based) from their earliest exposure to an unfamiliar large-scale environment. Therefore, the main purpose of this research is to conduct an experiment to assess people's wayfinding behavior in an unknown environment, especially an environment whose scale is relatively larger than human body. This raises a series of questions regarding aspects of this behaviour:

1. How do humans acquire and develop environmental knowledge?
2. How does environmental knowledge contribute to the construction of our cognitive map?
3. How do humans make use of the perceived environmental knowledge?

II

LITERATURE REVIEW

Human spatial cognition and wayfinding behavior has motivated research in disciplines such as environmental psychology, geography, architecture, and even artificial intelligence. Effective navigation consists of acquiring environmental knowledge during travel, building representations of the environment in our mind, and utilizing this representation to plan routes, and finding one’s way (Loomis et al., 1993). Gärling et al. (1984) observed that the process of navigation was an interrelated process between a wayfinder and the environment. All characteristics of the environment and the procedures a wayfinder uses to solve a navigational problem contribute to their wayfinding performance.

2.1 Scale of Environment

Scale is an essential component in the process of navigation because different size spaces result in qualitatively distinct knowledge acquisition (Bell, 2002; Montello, 1993). The widely accepted classification includes small-, medium-, and large-scale based on the absolute sizes of space. Gärling and Golledge (1987) suggested that small-scale space is comprehended from a single vantage point, from which the whole environment could be perceived. A single room or a small triangular route has served as an example of small-scale space in empirical studies (Foo et al., 2005; Loomis et al., 1993). Knowledge can be acquired directly in both small-scale and medium-scale space, though the latter is slightly larger than the former. For large-scale spaces such as a neighborhoods, towns, or cities which are much more complex and of a larger size, spatial relationship can not be perceived directly. In this space locomotion is required for a traveler to acquire and update information to make navigational plans (Gärling et al., 1984). Many researchers have studied wayfinding behavior independent of the scale of a space. To approach the understanding of human wayfinding behavior, studies examined non-human species like rats, then moved to the study of humans (Darken et al., 1998; Gärling et al., 1984; Kuipers, 1988; Montello, 1998; Siegel & White, 1975; Wehner, 1999).

Montello (1993) proposed another systematic classification based on the relative size of the space to the human body, which consists of *figural*, *vista*, *environmental*, and *geographical* space. The *figural* and *vista* spaces share similar characteristics with the previous small-scale space in that they could be perceived from a single vantage point. In a *figural* space the human body is larger than the space in question. The *vista* space is relatively larger than the human body but still can be comprehended from a single point. In Montello's description, an *environmental* space is larger than the body and cannot be comprehended directly without locomotion. Finally, *geographical* space is much larger than human body and must be learned through symbolic representations like maps (Montello, 1993). For example, the world map is used to understand the location and geographic relations of different countries in the study of cognitive ability at the *geographical* scale (Montello et al., 1999).

There are other models such as one consisting of the space of the body, the space around the body, the space of navigation, and the space of graphics as presented by Tversky (2003). However, it is similar to Montello's (1993) classification in that it made reference to the human body. In this study, the *environmental* scale introduced by Montello (1993) is the experimental space being used. The term *environmental* is also used in this study to indicate all activities in the large-scale environment.

2.2 Environmental Knowledge

At any scale, humans physically interact with spatial information through perception and locomotion to perform path selection and wayfinding activities (Golledge, 1995; Hart & Moore, 1973). Spatial information acquired in the environment, in the form of *environmental knowledge*, has traditionally been classified into three levels: landmark, route, and survey knowledge. Shemyakin (1962) first compared two types of topographical representations—route and survey knowledge. In his study, route knowledge was a representation derived by mentally retracing the route, while survey knowledge was the configurational knowledge of spatial locations. Conducting several experiments based on the theoretical work of Piaget & Inhelder (1967), Hart and Moore (1973) revised environmental knowledge into three successive levels. Their primary contribution was the use of the term: landmark knowledge. From the perspective of developmental psychology, the three levels of environmental knowledge were commonly recognized as being related in a successive order from landmark knowledge, through route knowledge, to survey knowledge. For example, through developmental experiments examining children's environmental abilities it was found that the three levels of environmental knowledge are comprehended gradually along with children's development (Allen et al, 1979). However, for adults who have already developed the cognitive abilities necessary for perceiving the three types of environmental information, the model based primarily on developmental theory was questioned. The dominant framework that derived from the developmental perspective suggested that the acquisition of environmental knowledge followed this developmental sequence from the lowest level, landmark knowledge, to the highest level, survey knowledge (Siegel & White, 1975). It has been argued recently that, for adults, higher level environmental knowledge would develop simultaneously with landmark knowledge when initial acquisition occurs (Montello, 1998).

2.2.1 Landmark Knowledge

Landmarks are discrete objects or scenes against a background stored in memory and recognized when traveling. Landmark knowledge is the knowledge of the lowest level acquired from the environment, which supports the easy identification of discrete geographical locations (Siegel & White, 1975). Although landmark knowledge is the simplest and most basic form of environmental knowledge, it is adequate for many simple wayfinding tasks (Siegel & White, 1975).

One of the roles that landmark knowledge commonly plays is the knowledge of particular locations. This was recognized by Downs and Stea

(1973) and termed *attributive information*. For example, a bus stop sign specifies the fact that buses stop there, and if a person needs to take a bus, he or she should wait for the bus at the location indicated by the landmark (bus stop sign).

Not only are landmarks used to confirm the location of an origin or destination, but it can also be used to maintain a route. By the utilization of ocean reefs as landmarks, a Puluwat canoe rower can maintain his sailing plan to reach one of hundreds of scattered islands over a multi-day voyage (Gladwin, 1970). Siegel and White (1975) concluded that landmarks are used as devices to maintain course. That is to say, using heading information and landmark knowledge, the subjects determine when to change direction in order to reach their destination.

In addition, landmark knowledge serves as an “anchoring schema” as discussed by Couclelis *et al.* (1987). The authors suggested that wayfinders made use of environmental cues and related each of them to its surrounding environment to establish anchor points that help them recognize the space they traveled before. With the facilitation of these reference points, wayfinders may develop cognitive maps more reasonably.

2.2.2 Route Knowledge

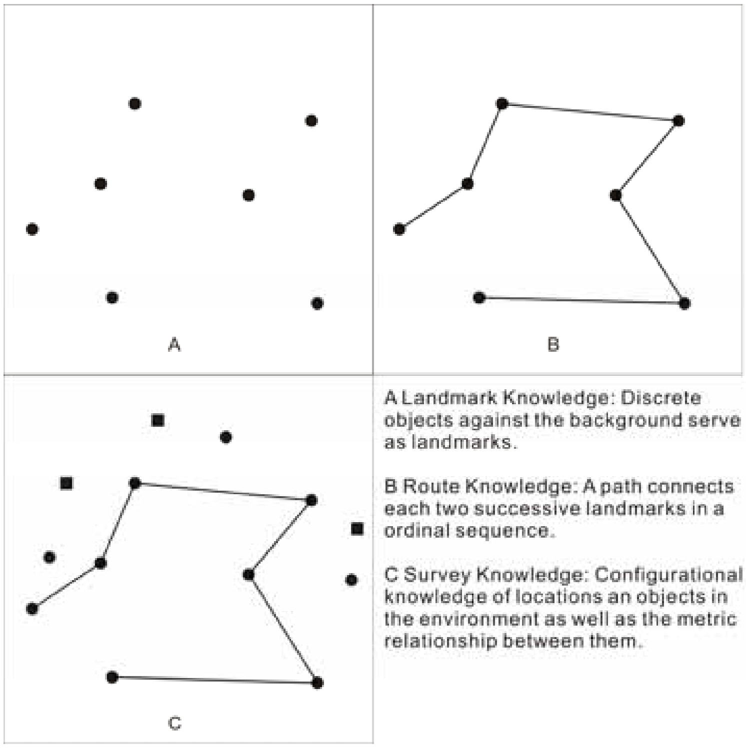
Route knowledge is typically described as sequences of landmarks connected by experienced paths of movement. As the second level of environmental knowledge, route knowledge is not just individual objects in the environment but the interconnectivity generated by individuals between these objects. Siegel and White (1975) implied that route knowledge is a *sensorimotor path* connecting those anchor points. It was said that, “If one knows at the beginning of a ‘journey’ that one is going to see a particular landmark (or an ordered sequence of landmarks), one *has* a route” (p. 24) and “A conservative (or radical) route learning system would then be, in effect, ‘empty’ between landmarks.” That is to say, only landmark but no other environmental knowledge between landmarks is perceived. The information between landmarks is irrelevant and incidental to maintaining a course. They concluded that route knowledge involves changes of heading which are indicated by landmarks and the gap between landmarks contains “incidental and irrelevant extent except to one that intermediary landmarks serve as course-maintaining devices (p. 26).”

The ordinal sequence of landmarks also reflects the development of route knowledge. Cornell et al. (1992) constructed an experiment in which participants were asked to retrace a route after being led. Participants performed well when tested on the path in the same direction and with the same sequence of landmarks as when they were led. However, when tracing the route in the opposite direction, participants’ performance was varied significantly.

2.2.3 Survey Knowledge

As the highest level of environmental knowledge, survey knowledge is a map-like representation of metric spatial relationships (e.g. distance and angle) between different sets of environmental information including landmarks and routes (Belingard & Peruch, 2000; Montello, 1998). It contains *configurational knowledge* of locations and features in the environment. Different from route knowledge, which relates to the course of a path, survey knowledge is more than a particular route plan but a source of environmental information (Montello, 1998). However, only the information related to a certain route will be utilized in route planning. Meanwhile, along with familiarity with a certain area, a person may integrate all the routes he or she has previously followed into their survey knowledge as a comprehensive representation of the area.

The term *configuration* was used to synthesize the previously perceived landmark knowledge and route knowledge to a higher level of representation. A traveler is able to use this presentation in wayfinding (Siegel & White, 1975). The same authors indicated three types of survey knowledge: *a perceived outline of terrain*, *a graphic skeleton*, and *a figurative metaphor*. The perceived outline of terrain is information related to the contour of a certain place, like the outline of the map of Canada. Bus routes within a city can exemplify the graphic skeleton. Radiating from the city terminal all the bus routes together portray a spatial representation of the city. The figurative metaphor is the imagery-based understanding of a certain layout. For example, the “straw hat” of Iran is the metaphor people use to understand the shape of the country. Figure 1 is the illustration of the three types of environmental knowledge.



A Landmark Knowledge: Discrete objects against the background serve as landmarks.

B Route Knowledge: A path connects each two successive landmarks in a ordinal sequence.

C Survey Knowledge: Configurational knowledge of locations an objects in the environment as well as the metric relationship between them.

Figure 1 Environmental Knowledge

Some other researchers have indicated that landmarks belong to a special type of route knowledge, hence they classified environmental knowledge into two categories: route knowledge and survey knowledge (Abu-Obeid, 1998; Sholl et al., 2000). This is based on the belief that landmark and route knowledge do not consist of metric properties (distances or angles) between objects in the environment. However, considering that landmark knowledge is based on individual objects in the environment, while route knowledge is the sensorimotor representation of the relations or links among the landmarks, the bulk of research does not support this hypothesis. Furthermore, landmarks and routes contribute differently to the process of wayfinding. In the present study, the classification of landmark knowledge, route knowledge, and survey knowledge is used. More importantly, investigating the wayfinding strategies that participants employed and the relative importance of landmarks and survey configurations are the author's primary interests.

2.3 Cognitive Map

All characteristics of a large-scale environment can not be acquired through observations made at a single moment in time or from a single location in space. On one hand, the information in the environment is far beyond an individual's capacity. On the other hand, our cognitive map develops over time and is sensitive to a navigator's age and experience. Individuals may build their cognitive map initially when entering a previously unknown environment, but more knowledge of the environment is necessary to improve its accuracy and completeness (Downs & Stea, 1973). When acquiring knowledge in an unfamiliar environment, a wayfinder processes the relative locations and attributes of phenomena in an environment into their cognitive map. The cognitive map was also previously called a *mental representation* (Billinghurst & Weghorst, 1995), *mental map* (Tversky, 2003), or con*figurational map* (Kuipers, 1982). In being called a map, the construction of environmental knowledge has been assumed to be similar to a cartographic representation (Gallistel, 1990). Suggestions from other researchers indicate that the cognitive map is quite different from a cartographic map. Our internal representation of the environment (cognitive map) has been determined to be "egocentric" and "momentary" rather than having the "geocentric" and "enduring" nature of cartographic maps (Wang & Spelke, 2002). Foo et al. (2005) investigated whether cognitive maps, like real maps, possess geometric properties. They indicated that humans do not appear to build metric knowledge in the form of geometry (like Euclidean) but do build some forms of coarse survey knowledge. They also inferred survey knowledge to be geometric. However, it still has yet to be determined if this coarse survey knowledge possesses any geometric properties. The present and future studies will be telling in this respect.

Two types of cognitive maps have been classified in the literature: those based on route knowledge and those based on survey knowledge (Siegel & White, 1975). A cognitive map built on either route or survey knowledge integrates landmarks into their structure. That is to say, landmark knowledge itself may not contribute to building a layout, but one's cognitive map may include landmark information as reference points. For example, no matter which kind of cognitive map will be developed, a wayfinder may identify the location of the origin and destination in order to estimate the most convenient route.

A route-based cognitive map is dominated by sequential information of environmental cues. In this situation, the cognitive map composes the sequence of heading points indicated by landmarks. To reach the destination correctly, the individual is reliant on tracing all the points in the correct order. In reality, some metric information may be applied to the cognitive map for the wayfinder to estimate the distance between successive points or the accumulated distance between successive points. However, this estimation is limited to the scope of the traveled route.

A survey-level cognitive map is dominated by configurational information, which is characterized as *configurational elements (Shemyakin, 1962)*. When planning a route in the environment, one considers not only the environmental knowledge related to the route, but also other environmental information besides the potential path and other surrounding information that might be out of sight but previously known, including metric information. Differences between cognitive maps are based on the dominant knowledge of each type: an individual traveling in an environment may initially rely on a route-based cognitive map and after tracing many different routes in the same environment, this person could merge all traveled routes into one configurational (survey) layout (Shemyakin, 1962). As the most important internal representation, the cognitive map plays a crucial role in wayfinding. In this study, the development of cognitive map is also one important concern.

2.4 Mode of Exploration

A wayfinder achieves his or her navigational goals through movement in the environment. After planning a route, the wayfinder may use different modes of locomotion, such as walking, biking, driving, or riding a bus. Although the modes of locomotion are diverse, the fact that the individual makes explicit decisions as to what path to follow is constant. In many experiments, researchers lead participants with little regard to the importance of active exploration. Feldman and Acredolo (1979) raised the question of how wayfinding behavior might be influenced by the mode of exploration. In their study, children were divided into two groups. One was led by experimenters (passive exploration) and the other group moved through the environment by themselves (active exploration). After traveling, all of them were asked to go to the same place in the environment. These results revealed that active exploration significantly improved performance. Findings from other studies supported this perspective as well (Bell & Saucier, 2004; Foreman, Stanton, Wilson, & Duffy, 2003; Lehnung et al., 2003). In some recent studies passive exploration is still used (Cornell & Heth, 2003; Cornell et al., 1992). Because a person is more likely to acquire only route-based knowledge immediately along a route in passive exploration, in this condition, acquired environmental knowledge is limited to the scope of the traveled path (Feldman & Acredolo, 1979). Through active exploration, the participants have the opportunity to explore the environment and develop a cognitive map possessing information beyond the planned route. The mode of exploration plays a very important role in influencing participant's acquisition of environmental knowledge, hence active exploration will be the mode of exploration used in all my experiments.

2.5 Wayfinding Strategies

During exploration, wayfinders update their environmental knowledge, which supports wayfinding. The strategies used to solve wayfinding problems can be categorized based on dominant environmental knowledge.

2.5.1 Position-based Navigation

Position-based navigation relies on external signals along a route indicating the observer's position and orientation without any memory requirements, (Loomis et al., 1993). In other studies it was also called *locomotor guidance* (Foo et al., 2005), *location-based navigation* (Baker, 1981), or *piloting* (Etienne, 1992). When using position-based navigation, wayfinders associate anchor points, which indicate particular locations based on their familiarity with the environment in which they are navigating. The environmental cues form a course-maintaining device with rules for next direction of transformation (Etienne, 1992). Baker (1981) in his study on zoology indicated that position-based navigation is not only limited to the distant visual landmarks but also the non-visual cues such as smell, sound, etc. serving as the indicator of a specific location.

Landmark-based navigation in which the anchor points are visual landmarks only is a special situation and also the most prevalent form of position-base navigation. It is the ability to orient oneself with respect to a known object or vista of a scene. Loomis et al. (1993) suggested this type of navigation requires external signals indicating the traveler's instantaneous speed and direction of travel. However, the non-visual cues also supplement landmark-based navigation when it takes place. Considering Loomis' definition of position-based navigation, that no memory requirements exist during locomotion, indicating that the environment is relatively small and simple, a wayfinder would not necessarily need to remember the sequence of landmarks. In other words, when a wayfinder is in a relatively large environment, this person has to memorize a certain order of landmarks or to store other environmental knowledge in order to solve wayfinding problems. In this condition, different types of wayfinding strategies are used.

2.5.2 Route-based Navigation

Route-based navigation involves remembering specific sequences of positions including landmarks, junctions, vistas, course-maintaining factors, turns, and so on (Foo et al., 2005). Retracing an outward journey is one form of route-based navigation in which a traveler has to be aware of the sequence of cues, turns, and other information and utilize them in the reverse order (Baker, 1981).

Besides a strategy relying on external cues such as landmarks (visual or non-visual), the internal cue called the “internal gyroscope system” is another type of strategy used in route-based navigation (Baker, 1981). When a wayfinder is traveling, he or she can refer to environmental cues to verify the route by using the external cues. In addition, the wayfinder is able to refer to the “internal gyroscope system” which updates the traveled route by integrating the turns and movements with the time spent on an outward journey to estimate the current position and direction.

2.5.3 Survey based Navigation

Survey-based navigation (sometimes called inertial navigation) involves survey knowledge gained from the cognitive map of the environment (Foo et al., 2005). The wayfinder associates relative distances, rotated angles, and the start point with locomotion. Loomis (1993) introduced a similar concept called *acceleration-based navigation*, in which a wayfinder integrated the linear and rotary position with respect to the initial position and orientation in the scope of cognitive map.

When using this type of navigation, a wayfinder could make use of other information stored in their cognitive map and update or change the route plan as necessary. Because of the awareness of other environmental knowledge, the wayfinder could travel based on not only the inertial estimation, but also other non-metric information, such as landmark knowledge. Although a wayfinder acquires the metric relationship among objects related to a route, the person could use landmark knowledge to confirm his/her location. A wayfinder could update his or her position by both the internal computation of the linear and rotary changes and reference to landmarks in the scope of their cognitive map (Sholl et al., 2000).

2.5.4 Path integration and dead reckoning

The ability of a traveler to update the distance and direction to a starting point that requires storing either a minimal homing vector or a more complete record of the path traveled is called path integration. In many studies, path integration was thought to be the same as dead reckoning (Aginsky et al., 2000; Etienne, 1992; Mcnaughton et al., 1991). Gallistel (1990) argued that differences existed between these two concepts. Sholl et al. (2000) tested this theory and found that the differences between dead reckoning and path integration were related to the utilization of environmental cues. Based on the use of environmental cues, dead reckoning has been divided into two categories: inertial dead reckoning and geocentric dead reckoning. In particular, path integration was a special situation of dead reckoning—inertial dead reckoning (Gallistel, 1990).

Inertial dead reckoning is a method of orientation that does not rely on familiar visual cues (Sholl et al., 2000). Dead reckoning is calculated internally based on a wayfinder's current position relative to his or her starting position. Loomis et al. (1993) indicated that in inertial dead reckoning the linear and angular estimations of the traveler are doubly integrated to corresponding locomotion with respect to the initial position and orientation.

Geocentric dead reckoning, which is similar to position-based navigation because of the utilization of familiar environmental cues, computes the body's position relative to the starting point. Using geocentric dead reckoning, an internal “map” is needed to update one’s position through the generation of the kinesthetic signals from body movement and reference to landmarks in the physical environment. Thus, when geocentric dead reckoning takes place, both the points from an origin to destination must fall into the scope of the cognitive map (Sholl et al., 2000).

Foo et al. (2005) also maintained that path integration was related to inertial navigation, suggesting path integration is not identical to dead reckoning. This is also supported by studies of Bell (2004) and Cornell (2003) that dead reckoning is a process including both inertial construction (cognitive map) and utilization of environmental cues (Golledge, 1995).

2.6 Problem and Gaps

The primary concern in studying human wayfinding behavior is the development of different levels of environmental knowledge. Results from different studies are varied because of the differences in experimental setting and measurement. For example, some researchers stated survey knowledge could develop earlier than landmark or route knowledge (Hirtle & Hudson, 1991). However, Abu-Obeid (1998) argued that route knowledge preceded survey knowledge. Some researchers found humans develop and access the two distinct types of spatial knowledge simultaneously (Cubukcu, 2003). In Foo's (2005) research, subjects were placed in a small-scale environment performing a triangle completion task through passive exploration. After the comparisons among shortcut performances of participants in different situations, such as with or without landmarks, and with landmarks of different-magnitude, it was found that humans did not appear to build metric survey knowledge but built some form of coarse survey knowledge. Moreover, humans would switch between two distinct navigational strategies when necessary: landmark-based and map-based navigation.

One reason for these different conclusions concerning the development of environmental knowledge is the scale of the space. For example, the conclusions from experiments in small-scale space cannot be simply applied to other spatial scales. In different-scale spaces, the cognition and behavior is driven by varied navigational strategies (Bell, 2002). Research on human navigation in large-scale spaces has been focused on the theoretical level (Montello, 1998) and in virtual environments (Aginsky et al., 2000; Belingard & Peruch, 2000; Darken, 1993; Darken et al., 1998; Gillner & Mallot, 1998) in order to better understand human wayfinding behaviors. There are still considerations that human performance may vary between an experimental environment and a real environment. It is necessary to understand the uncertainties of mental structures (what kind of knowledge acquired and how it is organized) and the process of navigation (the utilization of different types of knowledge) in real-world environments. These are important theoretical concepts for cartographic and navigational-aid design, as well as a better comprehension of human wayfinding behaviour.

Because the dominant framework of environmental knowledge acquisition is being questioned, wayfinding strategies based on the dominant framework should also be considered. As a result, a clear understanding of the strategies within the wayfinding process in a large-scale environment is necessary. Lawton (1996) developed a series of wayfinding scales to assess people's wayfinding strategies in indoor and outdoor environment. An important finding is that while route- and survey-based strategies exist, they both appear to be used in wayfinding with switching occurring when necessary. It seems that we switch between strategies based on context to solve wayfinding problems. She suggested that switching between strategies seems to go from a route strategy to an orientation strategy, in accordance to the dominant framework that route knowledge precedes survey knowledge (Hart & Moore, 1973; Siegel & White, 1975).

In conclusion, in the dominant framework humans only build non-metric knowledge and refer to that knowledge in a novel environment during early stages of learning. In its qualitative process of development, the next level of knowledge (route or survey) will not be developed until the knowledge on previous level (landmark) is sufficient. Compared with the alternative framework, which suggests all levels of environmental knowledge are acquired simultaneously from the first exposure to an unknown environment, the development of environmental knowledge is a quantitative process based on the wayfinder’s experience. Hence, one of the most important concerns in this study is to examine whether the most complex knowledge —metric knowledge— is developed during the early stages of exploration in a new environment. If so, the next intriguing consideration will be their specific wayfinding strategies and when and how such strategies are employed. Does an individual use one strategy exclusively or a combination of strategies during wayfinding in a large-scale environment. Based on the dominant framework, we could expect the switch between strategies to be from a non-metric strategy (route-based) to a metric strategy (survey-based). This leaves space for my current study to investigate if the alternative framework also supports a shift between strategies.

III

METHODS

In order to understand the aforementioned questions, experiments in this study are designed to assess specific aspects of human wayfinding behaviors in a large-scale environment: the construction of our cognitive map, the contribution of environmental knowledge to navigation, and the utilization of the cognitive map. In particular, the research objectives are:

1. The development of metric knowledge at the earliest stages of environmental exploration. Do participants acquire metric knowledge during their initial exposure to an unknown large-scale environment?
2. The contribution of landmarks to wayfinding performance and the development of a local cognitive map. How do landmarks facilitate participant’s solutions of wayfinding problems, and how do they contribute to the development of our cognitive maps?
3. The preference or utilization of non-metric and metric wayfinding strategies. Does a wayfinder only rely on one type of wayfinding strategy in a large-scale environment? If not, how does one combine multiple strategies? Or how does one shift between different strategies in a consistent fashion?

3.1 Environment

The goal is to reveal the role that landmarks play in human navigation and wayfinding. The Engineering Building at the University of Saskatchewan was chosen as the study site and one experimental route was established on its first floor. Several characteristics of this environment lend it to the objectives of this research. First, it matches the requirement of a large-scale environment. At any point on the designed path, participants cannot perceive the complete route from the origin to the destination directly but will have to acquire the information through physical movement. Second, as reported anecdotally by university students, this building is thought to be one of the most complex buildings on campus. It is similar to people’s ordinary wayfinding occurrences in an unfamiliar environment, in some ways more so (lack of reference information in many setting, for instance). Third, it has been argued that putting participants in an experimental setting, as opposed to naturalistic observation, will result in different performances from their daily behaviour. In particular, the role of landmarks can be experimentally manipulated. By using this environment the distortion of people’s wayfinding behaviour can be minimized. Fourth, the Engineering Building is located at the north side of campus which places it far from the Arts and Science area of campus (from where participants were recruited). In addition, by using an indoor environment, it prevents use of the sun or other campus buildings as external cues. As a result, it is useful as an environment which approximates the real-world in many ways while accepting that any experimental environment will be contrived to a certain extent. As indoor wayfinding has been one unavoidable part of modern people’s lives, the Engineering Building serves as a real-world yet controllable setting to investigate human navigation and wayfinding.

3.2 Participants

Sixty three participants took part, including 33 females and 30 males. However, two females and one male participant reported previous experience in the Engineering Building and considered themselves very familiar with the environment; their data was eliminated from the analysis. Therefore, 31 females and 29 males’ records were incorporated into the analyses with a range of age from 18 to 46. None of them had previous experience in this environment within the year immediately preceding the experiment, and the total number of visits for any participants was not more than one.

The 60 participants were randomly divided into three groups stratified by sex based on the order in which they signed up. The first group (landmarks and directional information provided on return trip) consisted of 11 females and 9 males, while the second (only landmark but no turn direction available on return trip) and third group (no landmark or turn information provided) were composed of 10 females and 10 males each. They were all assigned to each group randomly based on the order they signed up.

The Psychology Participant Pool and the Geography Participant Pool at University of Saskatchewan provided all but 11 participants. The 49 Participants, who were taking introductory level courses either in the Psychology or Geography Department, were granted bonus credits as reimbursement of their participation. The other 11 participants were volunteers contacted by the author. They were also students in this university who showed interest in taking part in this experiment but were not enrolled in the aforementioned courses. None of them received course credits or any kind of compensation for their participation.

Ethics approval for using human subjects in this experiment was issued by the Behavioral Research Ethics Board of University of Saskatchewan in March, 2006. All experiments were conducted between September, 2006 and January, 2007.

3.3 Materials

3.3.1 Landmarks

Papers in three different colours—yellow, green, and blue—served as controllable landmarks in this experiment and were placed at each intersection along the established route. These three colours had no conflicts with other colours in this building, which made them easily distinguishable from the environment. Furthermore, using paper allowed the experimenter to control the environmental setting quickly during each experiment. For certain experimental requirements, a landmark could be removed or changed to another colour easily by replacing sheets in different colours. Specifically, yellow sheets indicated that a left turn should be made, while a green sheet of paper indicated that participants should turn right. The blue sheet indicated no direction. The non-directional blue landmarks play two roles in this experiment. In the learning phase, at first, only one blue landmark is used indicating the end point of a route; in the retracing phase, the blue landmarks are only used to imply the traveled intersections without heading directions.

All the landmarks were posted either on the wall or on the floor at the intersections in order to imitate as realistic a wayfinding situation as possible. In people's ordinary experiences, environmental features used as landmarks are generally not in a consistent location when traveling (such as the same side of a path). The author attempted to place all the landmarks in a casual manner such so that the place of each coloured paper was different but did not influence participant's ability to see them.

Landmarks were used to create three different scenarios. All participants learned the experimental route using the same arrangement of landmarks. Once each participant walked on the route and learned the route information through active exploration, they were asked to complete tasks based on one of three different arrangements of landmarks: i) All the landmarks were kept the same as those when participants were exploring the route (Group 1). ii) All the on-route yellow or green landmarks were replaced by blue ones to make all the directional information disappear (Group 2). iii) All landmarks used for route learning were removed from the environment, so participants had to perform their tasks without landmarks (Group 3). For participants in group 1, they could do the first task immediately after learning the route. However, because of the replacement of landmarks, participants in group 2 and group 3 were asked to wait at the destination for about 4 minutes. The experimenter used this time to quickly change all the landmarks.

3.3.2 The Route

As the Engineering Building matches the requirement of a large-scale environment, it enables the design of a route at the environmental scale. The origin, where an airplane model is present, served as an overt landmark for participants to recognize their return destination. In addition to the airplane model, there were some other exhibits along the hallway on the first floor such as mechanical equipment or figures. It was important to reduce the possibility of participants using them as landmarks (as an object which is distinctive to its immediate environment could serve as a prominent anchoring point) (Allen et al., 1979). Correspondingly, the route bypassed most of these exhibits yet followed a not too complex path. Meanwhile, the path allowed posted coloured sheets to be distinctive to participants.

The route was arrayed on the floor that started at one exit on the north side and ended at another exit in the southern end of the building. Landmarks were posted at each intersection along the route which constituted of 6 right turns and 5 left turns to ensure participant's active wayfinding. In addition, handedness has been considered as a factor which may influence wayfinding behavior (Soh & Smith-Jackson, 2004). Although the relationship between turning direction and handedness is unconfirmed, the equal number of turns in each direction minimizes the bias of wayfinding performance which may result from handedness. When walking on the route, participants headed approximately northeast and then made several turns in a mixed order changing their direction to east 4 times, south 5 times, west once, and north once to reach the destination which was to the southeast of the starting point

(Figure 1). The total length of the route is 227.4m, which took participants an average of 3.5 minutes to walk at their ordinary speed. The length for this experiment is similar to other designs of indoor wayfinding experiment (Lawton et al., 1996; Lawton, 1996). Each participant was led to the origin through a tunnel on the second floor. Participants could acquire no route information until they reached the beginning area.

As a campus building used for educational and laboratory purposes the Engineering Building is generally occupied by students who are walking to classes, socializing, or resting during school hours. To avoid this influence on participants, all experiments were carried out in the evenings or on weekends when fewer people were in the environment.

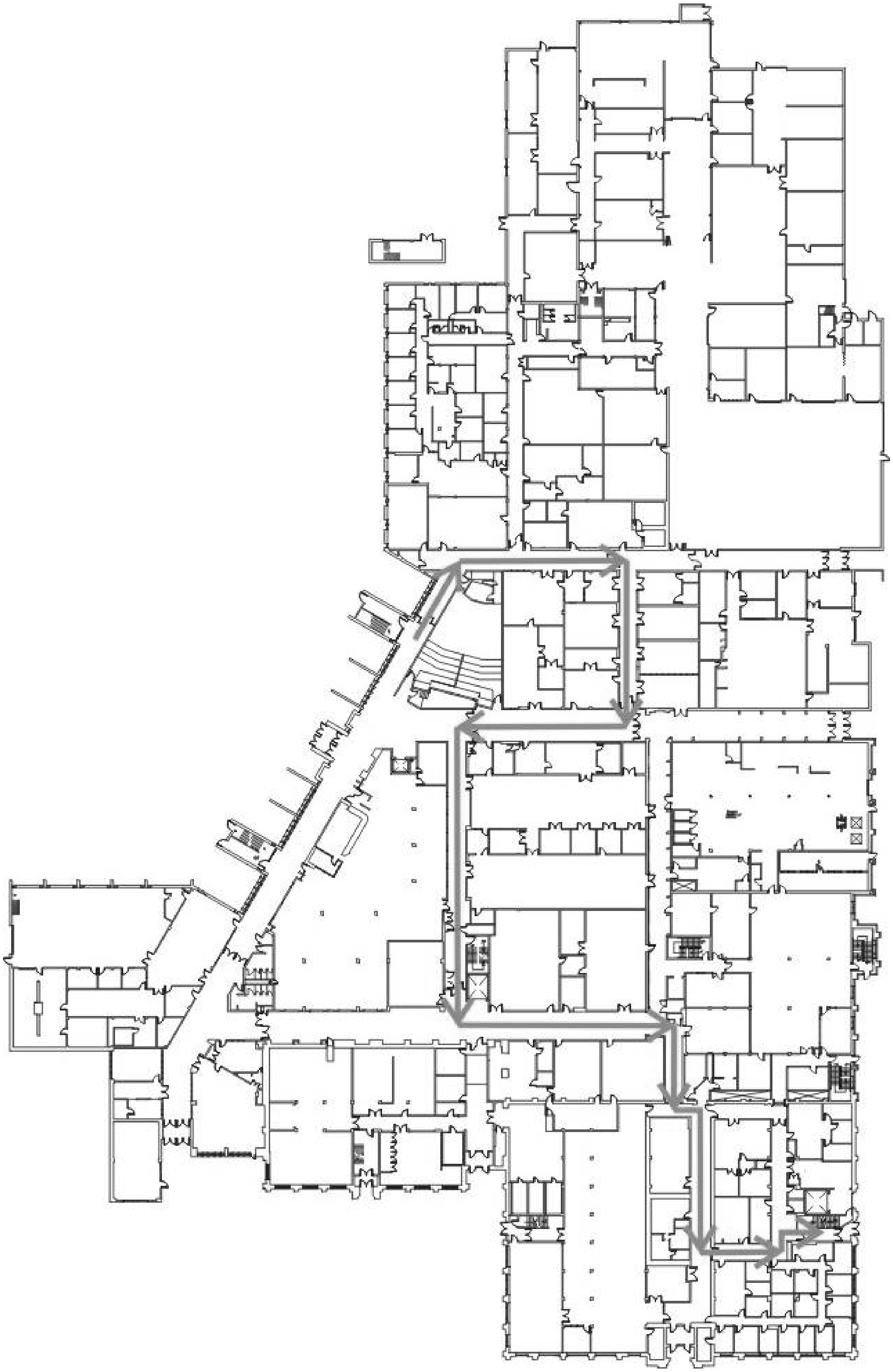


Figure 2. Experimental route in the engineering building

3.3.3 Devices

Several tasks were designed to investigate participants' wayfinding performance and formation of their cognitive maps. There were four main elements in this experiment: route learning, pointing to a distant point (pointing 1: from destination to origin and pointing 2: from origin to destination), route retracing, and completing a questionnaire. In addition to the coloured sheets, which were used as landmarks for route acquisition, some devices were used to record participants' performance such as time, pointing direction, and other related data.

A stopwatch was used to record participants' time to task. When each participant started walking on the route, the author followed him or her at an appropriate distance and recorded his or her travel time. This distance allowed the participant to complete the task without influence. While he or she was performing a task, the author also kept a record of the time the participant took to complete a task.

For pointing tasks, participants were required to point to a distant location at each end of the traveled route by using a type of compass. The compass was made of cardboard with two parts: a dial of 360° and a pointer attached at the center for participants to indicate any angle from 0° to 360° (Figure 2). Each participant was asked to stand at the same point facing the same direction with 0° showing on the compass. The participant moved the pointer on the dial to indicate the direction in which they believed the target to be and the angle was recorded. The author then compared it to the actual angle later.

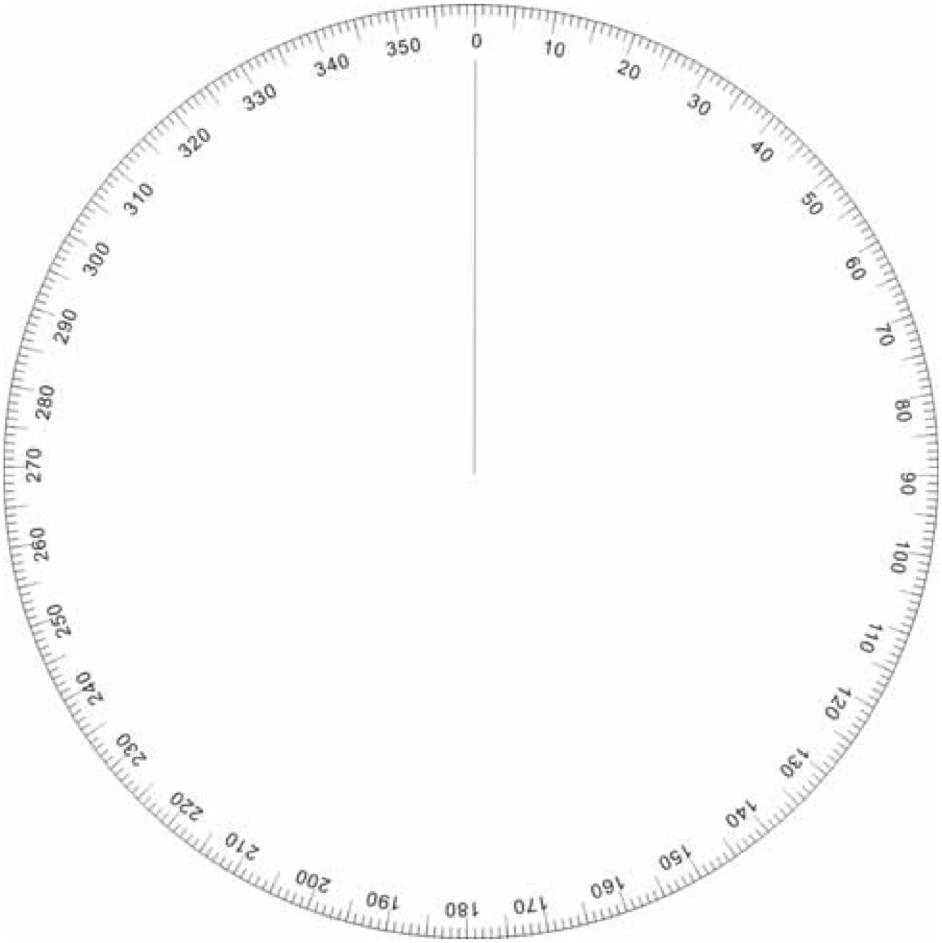


Figure 3. Compass with pointer for directional estimation

Two recording forms were also used during the experiment: a data collection and route retracing form. The data collection form recorded the group number, gender of a participant, and the time he or she used to travel and finish each task. Correspondingly, the route retracing form kept down the pointing angles, off-route behaviours and questions. There was a floor plan on the latter form. The author used this form to indicate the path followed by each participant during his or her return from the destination to origin. From this form turns, off-route errors, and total walked distance could be calculated as additional measures of each participant's wayfinding performance.

3.3.4 Questionnaire

The questionnaire, which served as an additional investigative tool, was composed of five sections. The first section of the questionnaire contained two paper-based spatial ability tests: the mental rotations task and object location memory task. The first part of Vandenberg's Mental Rotations Test (1978) was used. Once a participant was familiar with the questions, he or she was asked to indicate two identical objects out of four represented in different angles to a given object in each question. Each participant was required to complete 10 questions in total. The second task was administered according to the standard procedures of the Object Location Memory Test (OLMT) from Silverman (1992). Each participant was asked to browse a page of objects, which would be taken away in one minute: they were then showed a second sheet on which the same items were drawn but in a different arrangement. He or she had to circle the objects located in the same place and draw a cross over the objects that had been moved.

The second part of the questionnaire asked for general information about the participant. Besides their personal information such as age, gender, and current year of study, this part addressed participants' wayfinding experiences as well. For example, how many times they had been to the Engineering Building as the indicator of whether the data qualified for analysis, or have they ever been lost; also they rated their sense of direction on a scale from 1 to 100.

The third section included 12 statements and one question all regarding their wayfinding strategies. The 12 statements were adapted from Lawton's wayfinding strategy scales (1994; 1996; 2002), 9 of which deal with participants' survey-based navigational strategies while 2 address their route-based strategies, and the last one relates to the use of external cues in the environment. Participants used a five-category scale to indicate their degree of agreement from least (1) to most (5) to each statement. The question left space for participants to give a brief description of how they found their way back from the destination to the origin.

In the part 4 of questionnaire, participants were given a floor plan of the environment through which they had traveled and asked to draw the route that had been traveled from the marked start point on the floor plan. Billinghurst and Weghorst (1995) indicated that the route in a drawn sketch map was a valid method of investigating participants' cognitive map development in an unfamiliar environment. Sketch mapping on a blank form makes it difficult to standardize responses. At the very least the differences in distance could not be measured properly. The current method improved this situation by providing a common frame of reference to all participants. Furthermore, participants' turn errors in the sketch map were also recorded for additional analysis. The last part of questionnaire asked participants to rate the most difficult task for them in this experiment.

2.4 Procedures

All participants were tested individually on the first floor of Engineering Building. Each participant finished the experiment in the same sequence: route learning, pointing to the origin, route retracing, pointing to the destination, and questionnaire. Each participant signed up on the posted scheduled timeslots that had information about time and place to meet. The meeting location was a place on campus with which participants were familiar but was kept a proper distance from Engineering Building to avoid them visiting this building before the experiment. When a participant was met, they were given the consent form and a brief description of the experiment. Once they read the consent form carefully and had no uncertainty about the experiment, they were free to sign the consent and participate in the experiment. Each participant was led to the start point of the experiment through the tunnels on campus. This avoided the problem of inclement weather and reduced the chance that participants could determine their orientation and location by referring to the sun or campus architecture.

3.4.1 Route Learning

The principle of the route-learning phase is to allow participants to utilize active exploration to an unknown destination. The goal was to avoid participants being led by the experimenter along the path as in other research. When led by the experimenter, the participants are passive navigators reacting to the decisions of their leader, which will make the participants pay more attention to the experimenter and less to the surrounding environment

(Bell & Saucier, 2004). In contrast, active navigators make their own decisions and are more aware of where navigation decisions are made. Furthermore, active navigators acquire more spatial information and produce better environmental knowledge during navigation (Feldman & Acredolo, 1979).

When participants reached the start point of the route, the researcher introduced the experiment to them. Every participant was told to remember the point at which he or she was standing as the start of the route. Participants were then asked to walk from the start point to a currently unknown destination using specific landmarks. There were three types of landmarks in total (yellow, green, and blue). Participants were told the turn directions associated with each landmark colour. If the participant saw a blue landmark, they had reached their destination. Because the landmarks were either on the wall or on the floor, the participant was told to pay attention to the environment to find the landmark and to be attentive to areas around the landmarks while he or she was traveling. The author followed each participant at an appropriate distance in order to record the time they took to travel and provided assistance if he or she felt lost or otherwise uncertain. Before the participant actually began exploring the environment, the author asked him or her again to make sure there were no questions and all the directional information related to landmarks was clear.

3.4.2 Pointing back to the origin

The mechanism of this task is consistent with that of Bell and Saucier (2004) and Sholl (2000). Each participant stood at the same location, facing the same direction, and with 0° showing the position directly in front of the participant on a pointing device. The author measures the actual angle between the facing direction and the origin; hence, the absolute error between actual angle and the participant’s response will be recorded as the pointing error. All errors will therefore be in the range of 0° to 180 ° (Bell & Saucier, 2004).

When the participant arrived at the destination, he or she was congratulated for arriving at the correct place. The participant was then asked to use the compass to point to where he or she started. The participant stood at the point where the blue landmark was and faced the direction from which he or she came. The author stood away from the participant to create a pressure-free environment. The author asked the participant to speak aloud the number on the compass to which the pointer pointed once he/she had made their decision. Meanwhile, the author recorded the time each participant used to complete the pointing-back task. When the participant indicated he or she had estimated the angle to the origin on the compass, the author stopped the watch and wrote the number down on the data collection form.

3.4.3 Route Retracing

The pointing-to-origin task was followed by the route retracing task. For the first group, all the landmarks remained the same as those in the route learning section. For the second group, all the landmarks were changed to a generic type which indicated the intersections where participants had turned but all the directional information was lost. For the third group all the landmarks were removed.

Each participant was only informed at this point of the scenario to which they had been assigned (These scenarios were not previously described in any way). Participants in the first group were told to retrace the route and that all landmarks were left the same as those seen when they were traveling. Participants in the second group were asked to wait for about 4 minutes because there were some changes of the environment that needed to be made. When the author was back from changing all landmarks to blue, participants were asked to retrace the route and also informed that there were only blue landmarks at the choice points. For participants in the third group, the author told him or her to wait for about 4 minutes because there would be some changes made to the environment. When the author returned participants were informed that there were no landmarks in the environment anymore.

Once the participant started their return, the author started the stopwatch. The experimenter also followed each participant to record the route followed, including the route traveled and turn errors. The route retracing form was used for this purpose. A completed retracing form was used to measure any off-route travel. Another reason for the researcher to follow a participant was that when he or she had any uncertainty or felt lost the researcher could provide assistance.

3.4.4 Pointing back to the destination

Pointing back to the destination task used the same mechanism as the one in the pointing to origin task mentioned above and adapted from Bell and Saucier (2004). The participants stood at the origin, facing the same direction with 0° on the pointing device, and indicated the direction of the destination. The errors between actual angle measured by the experimenter and the participant's response would be recorded as the pointing error. All errors were between 0 ° and 180 °.

When the participant reached the origin, he or she was congratulated and asked to point on the compass to the place where he or she started retracing. The author recorded the time each participant spent to complete the pointing-back task. When the participant indicated he or she had decided the angle to the origin on the compass, the author stopped the watch and wrote the number down on the data collection form.

3.4.5 Questionnaire

A classroom in the Engineering Building was reserved to provide a quiet place for each participant to finish the questionnaire. Participants were led to this room after completing all wayfinding tasks. The classroom was located on the second floor of Engineering Building. Each participant finished the paper-based spatial ability tests, background information, wayfinding strategies, sketch map-drawing task, and task rating in the questionnaire successively.

Explanations and examples were provided to each participant before they began the spatial ability tests in order to be familiar with the questions introduced in the materials section in this chapter. The purpose of the wayfinding strategy section in the questionnaire was to obtain a subjective understanding of how participants solved their wayfinding problems. Each participant completed all experiments including the questionnaire in approximately 40 minutes.

IV

RESULTS

4.1 Introduction

Data from 60 qualified participants were incorporated into analysis. The overall goal of this study was to understand the development of our cognitive map and wayfinding strategies in a previously unknown large-scale environment. Particularly, these tests in this study addressed the following hypotheses:

1. The acquisition of survey knowledge in an unknown large-scale environment is as simultaneous as the development of landmark knowledge;
2. The role of landmarks in the development of our cognitive map is not as significant as an environment without landmarks;
3. The utilization of a landmark-based or survey-based wayfinding strategy is a combined manner depending on the participant’s familiarity with the environment.

In order to answer these questions, this chapter is divided into several sections, each of which emphasized one of the primary objectives including 1) wayfinding performance; 2) wayfinding strategies; 3) cognitive map development, 4) rating of task difficulty; 5) correlation analysis between Sense Of Direction (SOD) and navigational performances. In each section, a comparison between groups was processed to investigate group differences. The significance level for each statistical test is 0.05 in this study.

4.2 Wayfinding Performances

Most procedures that participants performed in this study were related to wayfinding performance. These included tasks from the basic, such as taking time to walk to the destination and return, to a higher level, like angular estimation of the relationship between the origin and destination (particularly once they had navigated on their own from the destination to the origin). These various tasks reveal the contribution of wayfinding experiences to the accurate construction of our cognitive map. In this section, all related data were divided into groups based on the 3 primary scenarios (the presence, modification or absence of landmarks on return). Most of the statistical analyses were based on the groups that participants had been assigned to.

4.2.1 Comparisons among groups

4.2.1.1 Travel Time

Each group spent less time walking back to the origin (WalkTime2) than walking to the destination (WalkTime1). The exact time each group used is shown in Table 1. As different environmental knowledge contributes to the development of cognitive map, it will not be unusual if no differences are found to exist between groups as the hypothesis. A one-way ANOVA was carried out to examine group differences on WalkTime1 (F (2, 57) = .135, p = 0.874) and WalkTime2 (F (2, 57) = 1.99, p = 0.146). The null hypothesis is that there is no difference of walking time between groups. No significant difference was found between groups, which retains the null hypothesis that different scenarios in the environment contribute equally to the wayfinding process, although they might result in different pointing accuracy, navigation performance, and development of environmental knowledge.

Table 1 Average travel time of participants in each group

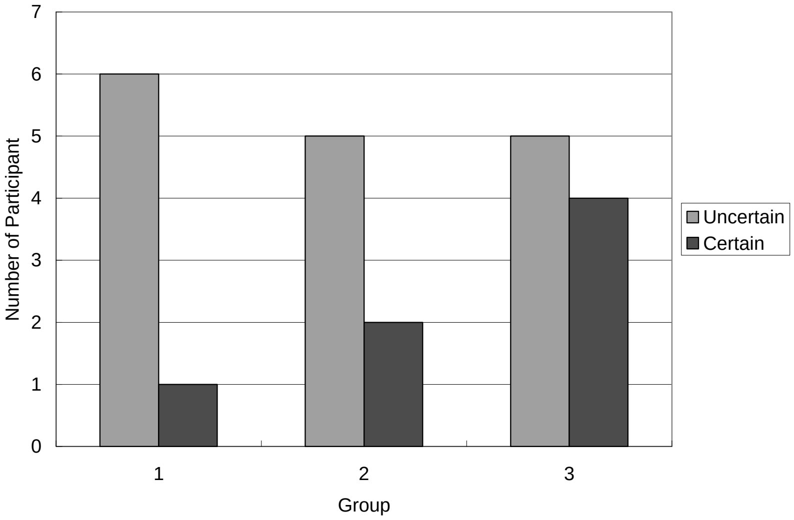
Group_#		WalkTime1	WalkTime2
1	Mean	03:10.15	02:47.75
	Min.	02:10.00	01:51.00
	Max.	04:10.00	04:14.00
	Std. Deviation	00:21.63	00:34.41
2	Mean	03:15.25	03:13.40
	Min.	02:00.00	01:54.00
	Max.	05:00.00	05:37.00
	Std. Deviation	00:47.56	00:47.32
3	Mean	03:14.30	03:12.20
	Min.	02:30.00	01:50.00
	Max.	04:01.00	05:19.00
	Std. Deviation	00:23.30	00:53.81

Note: WallkTime1 and WalkTime2 represent the time spent in route learning and in route retracing, respectively.

4.2.1.2 Off-route Travel

Once a participant reached the destination and completed the first pointing task, he or she was told to walk back to the start point. Participants were given freedom to walk a route on which they thought the best way for them by applying the environmental knowledge they acquired (landmark-, route-, or survey-based). This was a useful way to investigate differences of acquisition in different scenarios. When returning from the end point to the origin, some participants walked on a different path from the one they learned. In general, there were three situations reported by participants who walked off route. First, they had strong feeling of where the origin was and walked on another route (shortcut) towards it. Second, it was associated with their uncertainty with respect to the correct path (they were trying to retrace the correct path). They made guesses and walked without reporting to the researcher whether they felt lost. Third, they made guesses on the travel direction and felt lost. In this situation they indicated to the researcher that they were lost and were then led to the nearest intersection. The main difference between the second and third situations was that in the second situation participants did not indicate during route retracing that they felt lost. The composition of off-route participants in each group is shown in figure 3.

Figure 4. Composition of participants in off-route travel



Note: The uncertain category indicates off-route participants who asked for direction and who reported being unsure of heading direction on returning; certain category indicates participants who walked off-route with assured heading direction

It seems that as the directional information associated with landmarks becomes vague (i.e. landmarks lose directional information), more participants accomplished wayfinding based on their directional judgment and didn't feel lost. The number of participants in these two groups led by their sense of direction increased when static landmark information was unavailable.

Table 2: Off-route Travel Performance (Cm measured on map)

	Group	N	Mean (cm)	Std. Deviation
Turn_Error	1	20	1.80	2.707
	2	20	1.55	2.417
	3	20	2.30	2.755
Off_Route_Distance	1	20	17.075	34.712
	2	20	24.500	46.099
	3	20	27.500	43.169
Total_Route_Length	1	20	203.475	29.255
	2	20	219.750	41.621
	3	20	204.950	31.564

A Kruskal-Wallis Test was applied to examine the group differences associated with off-route travel since the errors were not normally distributed as many participants did not have off-route travel. The three dependent variables were turn errors on return, off-route distance on return, and total travel length on return. The purpose of this test is to test the null hypothesis that the environment plays a equal role on off-route traveling performance. No significant group differences were found on turn errors (H = 0.774, 2 d.f., p = 0.679), off-route travel distance (H = 0.736, 2 d.f., p = 0.692), and total travel length on return (H = 2.558, 2 d.f., p = 0.278). These results imply that the different scenarios of environment does not directly relate to the performances of off-route participants.

4.2.1.3 Direction Estimation

Each participant was required to accomplish two pointing-to-distant-object tasks, one of which was done when he or she just arrived at the end of route, while the other one was completed at the start point once the participant retraced the just learned route. An absolute degree of error (from 0 ° to 180 °) was obtained from the actual and estimated directions (from 0 ° to 360 °) at each pointing task.

The first comparison was made between the first (Pointing_Error1) and second pointing task (Pointing_Error2) within each group. The first pointing errors of each group are listed in Table 3. Group differences for each pointing task were also compared. A one-way ANOVA is carried out to test the null hypothesis that no difference in pointing errors between groups. As every participant learned the route in the same way, the first pointing error did not present distinct differences among groups ($F(2, 57) = 0.087$, $p = 0.916$), as expected. In addition, all angular estimations were significantly higher than a chance performance (90 °).

Table 3. Directional Estimation (Degrees)

Group_#		Pointing_Error1	Pointing_Error2
1	Mean	36.500	39.050
	S.D.	37.152	37.548
2	Mean	32.900	38.750
	S.D.	38.947	29.650
3	Mean	32.200	21.800
	S.D.	27.456	18.995
Total	Mean	33.870	33.200
	S.D.	34.341	30.322

The second pointing errors of each group are listed in Figure 4. The main purpose of this section was to test the null hypothesis that different environmental settings do not result in significant pointing errors, which compares the contribution of different environmental settings in construction of survey knowledge between any two groups. A univariate ANOVA was carried out between individual groups for Pointing_Error2. Among all three pairs there was a significant difference between group 2 and 3(F (1, 38) = 4.634, p = 0.038) and a marginally significant difference between group 1 and 3 (F (1, 38) = 3.361, p = 0.075). There was no difference between group 1 and 2 (F (1, 38) = 0.001, p = 0.978). The null hypothesis that differences in pointing errors exist between groups is rejected. As the groups only differed in the situation of the presence or absence of landmarks, the scenario with or without landmarks played an important role in the development of survey knowledge. For group 3 whose participants had no landmarks during their return, they exhibited the smallest pointing error among the three groups in the second pointing task. For groups 1 and 2, who returned with all landmarks present (locations only or locations and direction), the improvement of directional estimation was negligible.

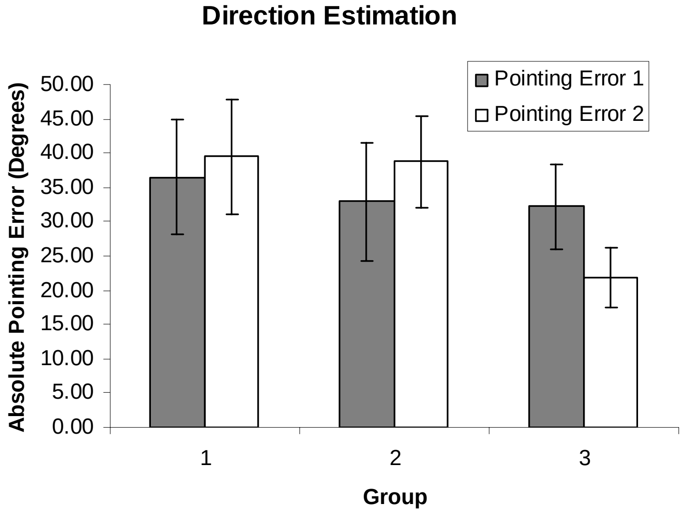


Figure 5. Absolute pointing errors made by group
Note: Pointing error 1 represents the absolute errors made at the end point after route learning, pointing error 2 shows the errors made at start point after route retracing.

4.3 Wayfinding Strategies

Two methods were used to assess participant's wayfinding strategies. The first one was participant's rating of twelve statements regarding the conformity of each type of wayfinding strategy they used. This was adapted from Lawton's wayfinding strategies (Lawton, 1994, 1996; Lawton & Kallai, 2002). Participants rated each statement with a scale from1 (least) to 5 (most) indicating the degree of agreement. These items are shown in the Appendix I. The second method was an open question on how participants found their way back to the start point. Participants wrote down brief descriptions of their general wayfinding strategies. Participant's responses to the aforementioned tasks were incorporated into the analysis.

4.3.1 Comparison among groups

A one-way ANOVA was carried out to test the null hypothesis that no difference on strategy rating exists between groups (Table 4). Statement 10 (Exhibitions and other signs along the paths I travelled in the building were helpful to me in finding my way) produced a significant difference between group 1 and 3 (p=0.049) which rejects the null hypothesis. Group 3 rated this statement higher than either group 1 or 2 (significantly more so than group 1). This significant difference indicated that when static landmarks became unavailable, although participants in this group made efforts to utilize survey-level knowledge, they seem to have paid additional attention to other environmental objects as alternative anchoring points. The fact that the rating of group 3 was higher than any other group suggests that participants in this group have a preference for landmark knowledge. Because the information used as landmark knowledge by group 3 was not as prominent as the experimental landmarks, on their return trip participants built survey knowledge as their dominant environmental knowledge. This is reflected in the analysis of second pointing error and following analysis of wayfinding strategies.

Table 4. Report of group rating

Group_#	Mean											
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12
1	1.45	1.80	2.05	2.10	2.30	2.35	3.25	1.75	2.75	4.00	2.85	2.35
2	2.05	1.85	1.55	2.30	2.65	3.20	3.30	2.15	2.50	4.45	3.35	1.60
3	1.95	1.70	1.80	2.55	2.55	3.00	3.45	2.55	2.30	4.65	3.20	1.85

The author sorted all participants' subjective responses into two categories: navigating by survey-based strategies and solely by non-metric strategies (landmark and/or route). Sorting was based on what a participant wrote indicating whether he or she employed strategies related to survey knowledge (e.g. "sense of direction," "configurational feeling"). Such a description was counted as using survey-based knowledge. The other descriptions were grouped into wayfinding by non-metric strategy (Table 5).

Table 5. Group cross-tabulation of subjective description by group (Count)

		Group			Total
		1	2	3	
Strategy	**With Non-metric environmental knowledge**	18	13	11	42
	With Metric environmental knowledge	2	7	9	18
Total		20	20	20	60

Note: The non-metric strategy indicates participants reporting landmark or route-based strategy, and metric strategy represents participants reporting survey-based strategies.

The data were all sorted based on the accounts of participants in a category. A Chi Square test is an appropriate option to examine differences between categories. A nonparametric 3 × 2 Chi Square test was carried out to test the null hypothesis that scenarios do not result in significantly different navigational strategies. The result, x^2 (2, N = 60) = 6.190, p = 0.045, rejects the null hypothesis implying that the three groups used different wayfinding strategies in the retracing test. In particular, with a decrease of landmark information, the number of participants who used survey-based knowledge in wayfinding strategies increased significantly.

In particular, 18 participants in group 1 used the experimental landmarks (e.g. “Remember landmarks and took the opposite path and directions from my first trip.” by the 12th participant, group 1). Two students used a combination of landmark-and survey-based strategies (e.g. “Used some landmarks in combination with general sense of familiarity with path. Also used signs to let me know I was on right path.” by the 18th participant, group 1) With the decrease of landmark information, more participants in group 2 (n = 7) and group 3 (n = 9) tended to use survey-based knowledge in their wayfinding strategy (e.g. “I tried to visualize in my mind the path backwards. I also recounted the display cases to help locate my position.” by the 8th participant, group 3). The full statements by all participants are sorted and listed in appendix V. Meanwhile, their descriptions show that they also utilized other environmental features when landmark information became vague. It was interesting to note that they combined different levels in wayfinding strategies.

4.4 Cognitive map development

The development of participants’ cognitive maps was additionally assessed using a sketch map drawing task. Three variables were coded including turn error on the map, distance error, and end point error. The turn error on the map was the number of wrong turns participant drew on the sketch map. The distance error was the error between the straight-line distance from the start point to the actual endpoint and the straight-line distance from the origin to the end point drawn by the participant. The end point error was the straight-line distance between the actual end point and drawn end point.

4.4.1 Comparison between groups

The three variables were analyzed across groups and their mean values are shown in Table 6. As a variable related to direction, the on-map turn error assesses the construction of directional knowledge reflected in map sketching, and the distance error and end point error were collected to assess the metric development represented in their sketched maps (Billinghurst & Weghorst, 1995). Group 1 had the highest errors in all three variables while group 3 made the smallest error in end point error, but group 2 outperformed the other groups in on-map turn error and distance error.

Table 6 Report of variables of cognitive map development (Measured on map)

Group_#	On_Map_ Turn_Error (count)	Distance_ Error (mm)	End_Point_ Error (mm)
1	6.80	20.2250	49.8250
2	4.90	14.1250	36.2000
3	5.20	15.5000	26.6500

To verify the group difference in map sketching, a one way ANOVA was applied to the three variables, On Map Turn Error: F (2, 57) = 0.862, p = 0.428; Distance Error: F (2, 57) = 0.473, p = 0.625; End Point Error: F (2, 57) = 1.295, p = 0.282 to test the null hypothesis that different scenarios contribute equally to map sketching errors. The retained hypothesis implies that different environmental settings may not result in different sketch-map drawing ability.

4.5 Correlation Analysis

4.6.1 Relation with sense of direction

In the questionnaire, participants rated their sense of direction on a scale from 1 to 100. Because one participant in group 3 did not rate his sense of direction, his record was removed from this analysis. Group 2 rated the lowest score (M = 69.05, SD = 16.00), group 1 had the highest rating (M = 76.15, SD = 9.896) while group 3 is situated in between (M = 70.79, SD = 23.637).

The correlation between sense of direction and Pointing_Error2 was calculated within each group to test the null hypothesis that the sense of direction does not correlate with the second pointing error: group 1 (r (18) = -0.37, p = 0.878), group 2 (r (18) = -0.003, p = 0.989) and group 3 (r (17) = -0.467, p = 0.044). Meanwhile, r (26) = -0.361, p = 0.059, and r (29) = -0.042, p = 0.822 were obtained in males and females. Only participants in group 3 had a significant correlation between sense of direction and second-time pointing error which rejected the null hypothesis. Negative correlation (r = -0.467) indicated that the higher rating of their sense of direction, the smaller pointing error participants estimated. The result here implies that wayfinding with no landmarks increases the accuracy of angular estimation if the sense of direction is already well developed.

To sum up, the significant correlation found between sense of direction and pointing error in group 3 signified the contribution of a better sense of direction in wayfinding performances. However, the reason that only group 3 generated significant correlation will be discussed in next chapter.

4.6.2 Relation with pencil-and-paper test

As suggested by previous studies, a pencil-and-paper test is a predictor of environmental abilities (Montello et al., 1999). Sex-related differences(t (58) = 2.083, p = 0.042) were also found in this pencil-and-paper test that male participants outperformed female students on mental rotation task. Besides, significant correlation was obtained between the mental rotation test and map sketching tasks including on-map turn error(r (58) = 0.268, p = 0.039), straight distance error (r (58) = 0.318, p = 0.013), and end point error (r (58) = 0.284, p = 0.028). It revealed positive correlation between mental rotation test and sketch map measures but not between mental rotation test and wayfinding performance.

V

DISCUSSION

The results from this experiment shed light on our understanding of human wayfinding behavior. Siegel and White's dominant framework (1975) was an important milestone in the understanding of human navigation and wayfinding behavior. Their classification of spatial knowledge—landmark, route, and survey knowledge—has provided geographers a clear model for the acquisition of environmental knowledge. The sequence of environmental knowledge acquisition suggested by the dominant framework has been central to this field for over three decades. While acknowledging its importance in the development of wayfinding research, questions concerning the sequence of environmental knowledge acquisition have emerged. A modified understanding of spatial knowledge acquisition has been defined by Montello's alternative framework (1998). In the new framework, the three levels of environmental knowledge are acquired with greater simultaneity when encountering an unknown environment for the first time. As the alternative framework is becoming increasingly accepted on a theoretical level and tested (Ishikawa & Montello, 2006). The objective of this study is to investigate this new framework with empirical results regarding 1) the existence of metric knowledge when we initially encounter a previously unknown environment; 2) the role that landmarks play in the formative stages of cognitive map development; and 3) the preferential development and utilization of the different levels of environmental knowledge in wayfinding conditions.

5.1 Metric Knowledge Development

The procedures for acquiring metric knowledge have been addressed by many studies in the past decades but suggest diverse conclusions. For example, one point of view was that metric knowledge could be developed earlier than non-metric knowledge (Hirtle & Hudson, 1991). Alternatively, it has been argued that survey knowledge only develops after the acquisition of non-metric environmental knowledge (Abu-Obeid, 1998). One possible reason that results have varied so much is the scale of the experimental space (Bell, 2002). In this study, all data were generated using an environmental scale in which the full environment could not be comprehended directly at any individual point, but required locomotion in order to develop a complete cognitive map (Montello, 1993).

To answer questions pertaining to the order of knowledge acquisition, the alternative framework based on the three types of environmental knowledge was used as a theoretical reference (Montello, 1998). In Montello’s theory, metric knowledge (survey knowledge) is acquired together with non-metric knowledge (landmark-or route-based knowledge) during the very earliest exposure to a new environment. This is the primary hypothesis that I intend to verify in this study. The purpose of the first pointing task is to assess participants’ development of survey knowledge instantly following their first exposure to the environment. Participants in this experiment were required to walk to a destination in the same environmental setting and conduct their first angular estimation immediately upon their arrival at the end point. The directional estimations found here are not consistent with dominant framework, but the alternative since they are more accurate than chance performance. In other words, participants acquired metric knowledge during their earliest exposure to an unknown environment. Meanwhile, although directional estimation was better than chance performance, its accuracy was still relatively coarse. An additional question then emerges: Should we continue to refine the accuracy of our survey knowledge with additional exposure, and does the nature of that exposure matter?

The second pointing test was designed to investigate the refinement of survey knowledge with additional travel experience and whether the nature of that experience played a role in the type of knowledge acquired and its accuracy. Participants were asked to return to the start point of the experiment in one of three different environmental situations: Landmarks with directional information, generic landmarks without directional information, and no landmarks. This design helps investigate the role of different environmental settings, particularly the presence and nature of important wayfinding landmarks in the development of survey knowledge.

The refinement of metric knowledge was not necessary for the navigational success of all groups. In particular, group 3, which returned with no landmark on route, faced the greatest challenge considering the explicit landmark information that had been present during route learning. In fact they produced the greatest increase in pointing accuracy; the accuracy of group 1 and group 2 changed non-significantly (with a slight decrease). The results indicated that experiencing the environment without landmarks resulted in more accurate survey knowledge (group 3), supported by more accurate pointing. Additionally, the environmental conditions of group 1 and group 2 resulted in similar performance. That is to say, landmarks (no matter with or without directional information) contributed similarly to the development of survey knowledge (improvement in survey knowledge was not obvious or substantial).

When interpreting these results, the decreased accuracy of group 1 and group 2 should also be clarified. By accepting the fact that at least some survey knowledge was obtained during early exposure (learning phase) to a new environment and a participant could develop adequate survey knowledge with additional traveling experience (Lovelace et al., 1999), it is logical to assume that the refinement of survey knowledge happens incrementally over time. Due to the coarse nature of survey knowledge as expressed by pointing accuracy during the first pointing task, the second travel experience seems to have been too short to improve the accuracy of survey knowledge dramatically (in the presence of the landmarks) unless an additional variable was added (such as the complete removal of landmarks). Furthermore, the participants in group 1 and group 2 had sufficient knowledge to solve their current navigational problems (return). Attending to information that was unrelated to the task at hand (returning the origin) was unnecessary. Consequently, the refinement of metric knowledge did not occur. Only the group traveling with no landmarks had a statistically significant improvement in metric knowledge.

The other factor that played a role in pointing accuracy was participant sense of direction. In the correlation between pointing errors and sense of direction, accuracy in the second pointing task had a significant relationship with participant's sense of direction in group 3. This suggests that in returning without landmarks, a participant's better sense of direction resulted in higher pointing accuracy (smaller pointing error).

Bringing these two pointing tasks together, a better understanding of participants' developing survey knowledge can be achieved. The development of survey knowledge is more likely to result in an incremental improvement in accuracy. Actively navigating an unknown route without being previously told that a pointing task would occur resulted in all groups making similar estimations in the first trial with better than chance performance. The retracing experience revealed different levels of improvement to survey knowledge, as the refinement of one group was significant and other two were not. It is also found that the development of survey knowledge is not a qualitative transformation of environmental knowledge from a low to high level as suggested by the dominant framework, but a quantitative refinement of survey knowledge from a less to more accurate standard.

The results are consistent with Montello's alternative framework (1998). The acquisition of survey knowledge in this experiment occurs during the initial exposure to an unknown environment and its development is a process of quantitative refinement. Furthermore, the improvement of survey knowledge appears gradual when initially developed environmental knowledge is sufficient to solve current navigational problems by metric knowledge or non-metric knowledge.

5.2 Role of landmarks

The different pointing errors among groups indicated that the refinement of metric knowledge resulted from their environmental surroundings, which only differed from each other in the appearance of landmarks during route retracing. As in our day to day life landmarks seem to be a readily available feature used in finding our way. The role of landmarks was intriguing beyond their effect on refinement of survey knowledge: how did it influence participants' navigation performance and cognitive map development?

In order to navigate in an unfamiliar environment, one has to build a local cognitive map to provide wayfinding support (Montello, 2005). Hence, an investigation of participants' wayfinding performance could be a reflection of their cognitive map. The contribution of landmarks in wayfinding was assessed by travel time and off-route travel measures. Regarding travel time, results showed that different environmental settings provided sufficient information for the return journey. The fact that cognitive mapping is a necessary process in wayfinding in a large scale environment, different environmental settings contribute to the construction of cognitive map, although those components differ.

The sketch mapping task measures included on-map turn error, distance error, and end point error based on the comparison between the actual route and the drawn map. Differences in cognitive map development were not supported by statistical testing, which also confirmed the earlier thought that different environmental settings contribute to the development of cognitive map; hence, the differences in map sketching tasks might lie in the accuracy. Group 1 was inferior to the other two groups in all variables, and group 2 and 3 obtained similar errors which were much smaller than group 1. For group 1 the remaining landmarks on route enabled participants to reach the start point without difficulties. They did not have to access, rely on, or develop additional configurational knowledge for direction and distance. The dominant knowledge of non-metric environmental knowledge contained in their cognitive maps appears to have been sequential information related to successive points along the path. It helped participants in this group return the start point but with no overt refinement of metric knowledge. However, it appears group 3 participants developed a cognitive map through the refinement of metric knowledge. Since the superior metric knowledge in their cognitive map seems to be dominant, participants were able to determine direction with higher accuracy. Traveling in an environment with landmarks showing only location, participants in group 2 could use those generic landmarks as anchoring points but had to determine the direction. Their cognitive maps consisted of both landmark and metric knowledge, which explained the mediocre performance of participants in group 2.

The role of landmarks in the development of our cognitive map could be drawn from the aforementioned performances. Firstly, they act as anchoring points for participants to locate exact positions. Then by embedding those points into a course-maintaining schema, a cognitive map dominated by landmark-based knowledge is developed. It helped participants change direction at a recognized location during travel and potentially keeps them on route (group 1). Secondly, comparing this cognitive map to the one developed from the landmark-absent condition when the configurational knowledge is the dominant knowledge, the environment without landmarks resulted in the greatest improvement in metric knowledge. This suggests the contribution of landmarks to survey knowledge is weak.

5.3 Wayfinding Strategies

Determining how participants made use of environmental knowledge in the retracing process was also one of the main objectives of this study. In addition to both Lawton's Wayfinding Scale (C. A. Lawton et al., 1996; Lawton, 1996) and Wayfinding Strategy Scale (Lawton, 1994), individual's description of their general wayfinding approach was also used to investigate wayfinding strategies. The questions discussed here were regarding route- and survey-based navigation and which type of integration was used by participants in wayfinding process.

The results showed that when navigating in an unfamiliar environment participants did not rely on one type of wayfinding strategy. In particular, when participants became unsure, a combination of non-metric and metric strategies was preferred. In the subjective descriptions of general wayfinding, participants in group 3 preferred to employ survey knowledge in their wayfinding strategy ("I find it most helpful to use an angle (roughly) to help me get back to where I started. Visual cues along the way helped me as well."

by the 14th participant, in group 3) Meanwhile, they also differed from the other groups in one wayfinding scale rating (using exhibition or signs along the path to find their way) on the indoor wayfinding scale (Lawton, 1996), indicating these participants used other environmental features to compensate for the removal of landmarks. This was indicated by the combination of route and survey strategies in the wayfinding process. Participants rated similarly in wayfinding scales based on landmark and configurational knowledge, again suggesting that they did not use one type of wayfinding strategy exclusively.

When considering a combination of strategies, how switching occurs is a topic of interest. Lawton suggested that individuals do not rely on a single wayfinding strategy but switch between different types of strategies depending on the context (Lawton, 1996). However, her suggestion that switching occurs exclusively from a route to a survey strategy was not supported by the current experimental results. Some participants in group 3 used a survey strategy followed by recalled environmental cues (exhibitions and signs but not the experimental landmarks) to find their way back. The switch from one strategy to another in this situation was from a survey to a route (non-metric) strategy. These experimental results indicate that the switch might be related to a wayfinder's familiarity with environmental knowledge, and that the switch was from a familiar-knowledge-based strategy to a less-familiar-knowledge-based strategy. Once a type of knowledge was sufficient to solve a wayfinding problem, a change of strategies would be unlikely. Since participants in group 1 had sufficient non-metric information (the landmarks or orders of landmarks) to determine the correct direction, their wayfinding strategies did not show an obvious transition from non-metric strategy to a metric strategy. This also explains the wayfinding performance of a person in the familiar environment, in which only a survey based strategy was used (Lovelace et al., 1999). Looking at the context of Lawton's work, its rationale is based on the dominant framework of spatial acquisition that route knowledge precedes survey knowledge, a situation that is generally not supported by the alternative framework (Montello, 1998) and the current experiment.

In conclusion, based on retracing performances, a participant's exhibited wayfinding strategy in an unfamiliar environment is likely to consist of a combination of route and survey strategies that transition from one to another. The switch between strategies moves from a type based on familiar knowledge to one based on less familiar knowledge. That is to say, when the current strategy was not adequate to make a wayfinding decision, a participant would switch to another strategy based on another type of knowledge as way to make a more accurate judgment. However, due to the limited exposure to the spatial environment, it is possible that a participant's environmental knowledge was cognitively distorted.

VI

CONCLUSION

The current study examined human acquisition of environmental information during navigation and wayfinding as well as the utilization of spatial knowledge in a new environment. The empirical results appear to support the alternative framework for spatial knowledge acquisition. First of all, the initial knowledge people obtain when they travel into a new environment is not only landmark knowledge, as the lowest level of spatial knowledge suggested by Siegel and White’s traditional framework (1975), but also metric knowledge, the latter being a substantially more complex level of knowledge. The sequence of environmental knowledge acquisition does not appear to follow a series of distinct steps from landmark, to route, to survey knowledge. Instead, the process of acquiring different levels of environmental knowledge starts simultaneously at the earliest stages. In this experiment, a participant’s metric knowledge, a higher level environmental knowledge hypothesized to occur after the construction of non-metric knowledge in the dominant framework, was found developing simultaneously with landmark and route knowledge during the earliest stages of acquisition.

It is also necessary to point out that the author does not disagree with the concepts in the traditional framework. In particular, the three categories of environmental knowledge have approached the understanding of human acquisition of environmental knowledge. The three levels of environmental knowledge occur as a result of acquisition of environmental knowledge. They facilitate our ability to solve all kinds of navigational and other spatial problems in our daily lives.

Allowing for the contribution of the traditional framework, this research focused on the sequence of knowledge developed within these three levels. For example, some previous studies found that the order of acquiring spatial knowledge was not consistent with the sequence in the traditional framework (Hirtle & Hudson, 1991). Montello (1998) proposed an alternative framework indicating that the acquisition of environment acquisition is simultaneous, and the three levels of environmental knowledge are obtained during the initial stages when visiting an unknown environment. The latter is supported by the experimental results from the current study. Participants here expressed more accurate directional estimation than chance performance after just one experience with the new environment.

Even though different levels of knowledge are developing simultaneously during one’s initial exposure to an unknown environment, it is important to acknowledge the relative coarseness of that metric knowledge. The improvement of survey knowledge relates to both environment information and the wayfinder. The greatest improvement of survey knowledge resulted from a wayfinding experience in an environment without previously seen and used landmarks. When a wayfinder had access to even part of the pre-acquired landmark information, the improvement of metric knowledge was not significant. The improvement of environmental knowledge is more likely a quantitative refinement than qualitative transformation. Since the initial exposure, a wayfinder acquires environmental knowledge on all levels but does not necessarily need to improve each at the same time. Greater experience or a specific navigational need ties to the corresponding refinement of a specific type of environmental knowledge. Additionally, it is found that a good sense of direction also contributes to the improvement of metric knowledge when traveling without landmarks. But on average, if the landmark knowledge is good enough to solve a navigational problem, a wayfinder does not seem to refine their metric knowledge of the unfamiliar environment over a short period, even if they have a strong sense of direction.

The most important role landmarks played in the wayfinding process is anchoring points for decision making, such as the location to change his or her heading direction, which enabled the wayfinder to follow a correct path. While acquiring landmarks in a certain order, participants were found to develop a local cognitive map based on this non-metric information. Hence, refinement of survey knowledge was not anticipated from this type of cognitive map development (groups 1 and 2). Results from this study highlight two factors that contribute to a more accurate metric knowledge: the first is that environment with no landmark facilitates high-paced refinement of survey knowledge. The second factor relates to a wayfinder's ability. If a person has a better sense of direction, he or she develops more accurate metric knowledge while traveling in an environment without landmarks. The contribution of landmarks to metric knowledge in cognitive map development is very weak. Besides the role of landmarks in cognitive map development, the mental rotation test is used as a predictor of differences in the cognitive map development between both sexes. If a participant has less error in mental rotation test a more accurate cognitive map could be developed.

Furthermore, the strategies one wayfinder uses to solve his or her wayfinding problem are mainly based on the knowledge they acquired. In the study of people's wayfinding in a familiar neighbourhood, wayfinders easily utilized a certain type of environmental knowledge to solve navigational problems (Lovelace et al., 1999). However, when wayfinders are in an unfamiliar environment, the process of solving wayfinding problems is different. The wayfinder uses a combination of non-metric and metric strategies as well as switching between the two as necessary. In particular, Contrary to Lawton's suggestion that the switching of strategies is from route-based to a survey-based (1996), these results indicate that strategy switching is from a strategy based on the most familiar type of environmental knowledge (route or survey) to a strategy based on a less familiar type of knowledge where necessary. However, when or how a wayfinder switches his or her wayfinding strategies is still in topic that requires further exploration.

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APPENDIXES

I: Participant sample questionnaire

II: Experimenter data collection form

III: Experimenter route retracing form

IV: Participant raw data collection

V: Subjective description of wayfinding strategy

I: Sample Questionnaire

Thank you very much for participating in our study. For the final component of the study please fill out the following questionnaire. (There is no right or wrong answer for each question or statement, so please write honestly).

A. Mental Rotation Test
Please go to the sheets the experimenter gives you.

B. Object Memory Test
Please go to the sheets the experimenter gives you.

C. Background Information
1. Gender: _______ 2. Age: _________ 3. Current Year of Study: _____
4. Major: _______ 5. First Language: _________
6. Are you left handed? ☐Yes ☐ No
7. Have you been to the Engineering Building before? ☐ Yes ☐ No
If yes, please indicate how many times you have been there.

____

8. Have you done one or both of the tests before?
Test A: ☐ Yes ☐ No Test B: ☐ Yes ☐ No

9. Do you often get lost when you are in a new place? ☐ Yes ☐ No
10. Are you good at giving directions? ☐ Yes ☐ No
11. In your day to day life are you very good at remembering places you've been and paths you have followed? ☐ ☐ Yes No

12. On a scale from 1 to 100, with 1 being poor and 100 being excellent please **choose one number** to rate your sense of direction. _________

13. How do you prefer to learn a new building? (Please choose only one)
   a. Use a map
   b. Have someone show you around
   c. Explore on your own
   d. Get someone to describe the building to you.

D. Wayfinding Strategies

I. Please give a brief description of how you found your way back to the origin of the path you just followed (return trip).

____

____

II. Here is a list of statements. Please circle a number following each statement on a scale of from 1 (least agree) to 5 (most agree), indicating which best reflect your real feeling or situation.

1. When I was in the building, I always kept in mind which direction I was moving (e.g. north, south, east, or west side of the building)

1 2 3 4 5
LEAST MOST

2. I tended to think of my location in the building or complex in terms of north, south, east, and west.

1 2 3 4 5
LEAST MOST

3. I kept track of where I was in relation to a reference point outside of the building, such as the center of Saskatoon, a campus building or near-campus location, or river. .

1 2 3 4 5
LEAST MOST

4. I knew which direction I was facing when I made turns.

1 2 3 4 5
LEAST MOST

5. I made a mental note of the distance I traveled on different sections of the path.

1 2 3 4 5
LEAST MOST

6. I visualized a map of the area in my mind as I went.

1 2 3 4 5
LEAST MOST

7. I kept track of the relationship between where I was and the next place where I had to change direction.

1 2 3 4 5
LEAST MOST

8. I knew the direction in which I was facing within the building without having to think about it.

1 2 3 4 5
LEAST MOST

9. It took a lot of mental effort for me to figure out my direction.

1 2 3 4 5
LEAST MOST

10. Exhibitions and other signs along the paths I travelled in the building were helpful to me in finding my way.

1 2 3 4 5
LEAST MOST

11. Labelled room numbers identifying parts of the building were very helpful in finding my way.

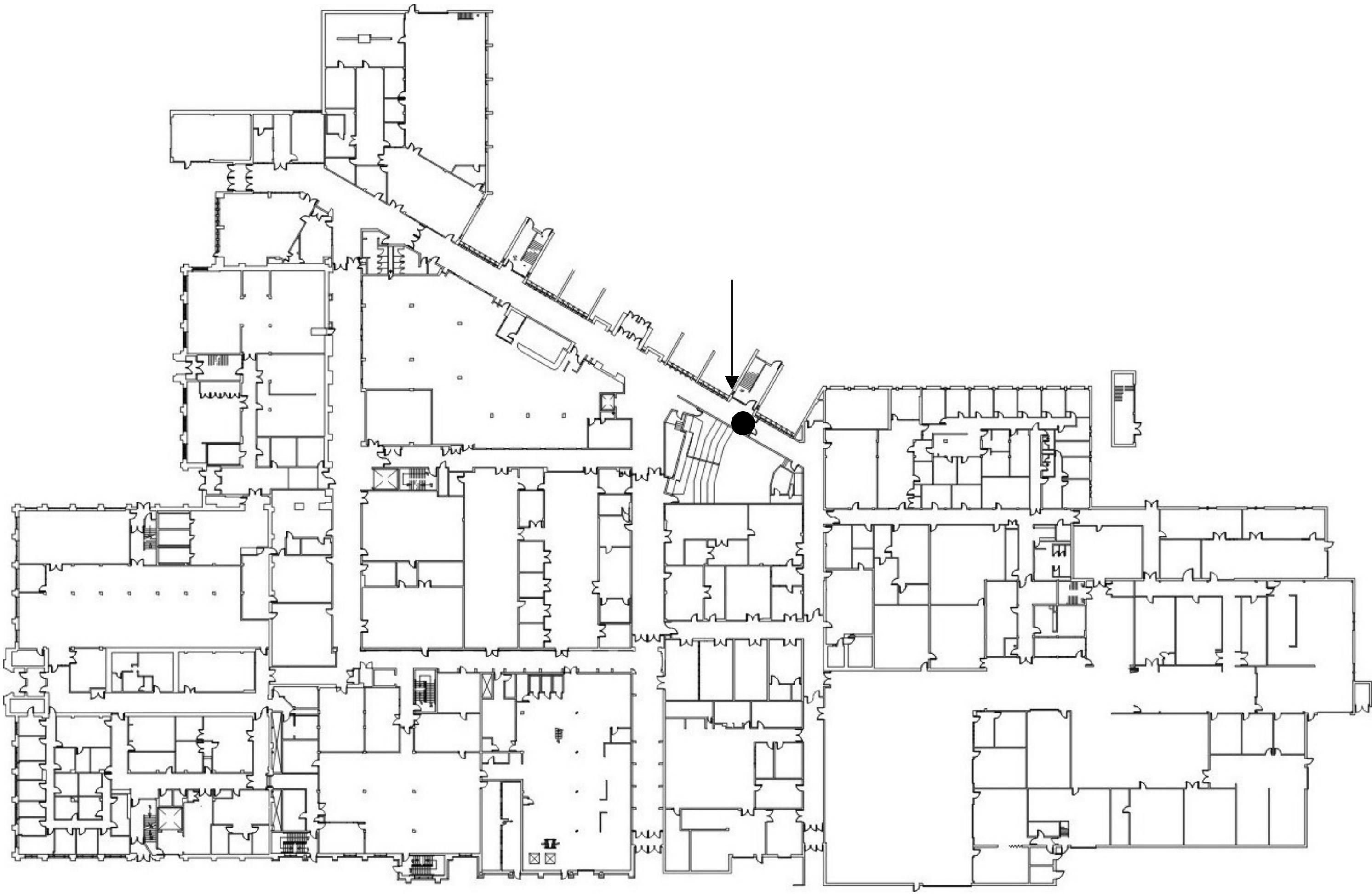
1 2 3 4 5
LEAST MOST

12. I found maps of the building, with an arrow pointing to my present location, to be very helpful.

1	2	3	4	5
LEAST				MOST

E. Route

Please try your best to draw the path you traveled on the sketch map. The black dot is the location where we started.



F. Task Rating

Please select from the options below to indicate which one you think was most difficult for you during the completion of the experiment.

☐ Walking to the end point ☐ Walking back to the start point

☐ Pointing to the start/end point ☐ Drawing the sketch map

☐ Other: ____

II: Data Collection Form

File No. _______________

Group _______________

Gender _______________

Walking time#1 _______________

Pointing time #1 _______________

Pointing angle #1 _______________

Walking time#2 _______________

Pointing time#2 _______________

Pointing angle#2 _______________

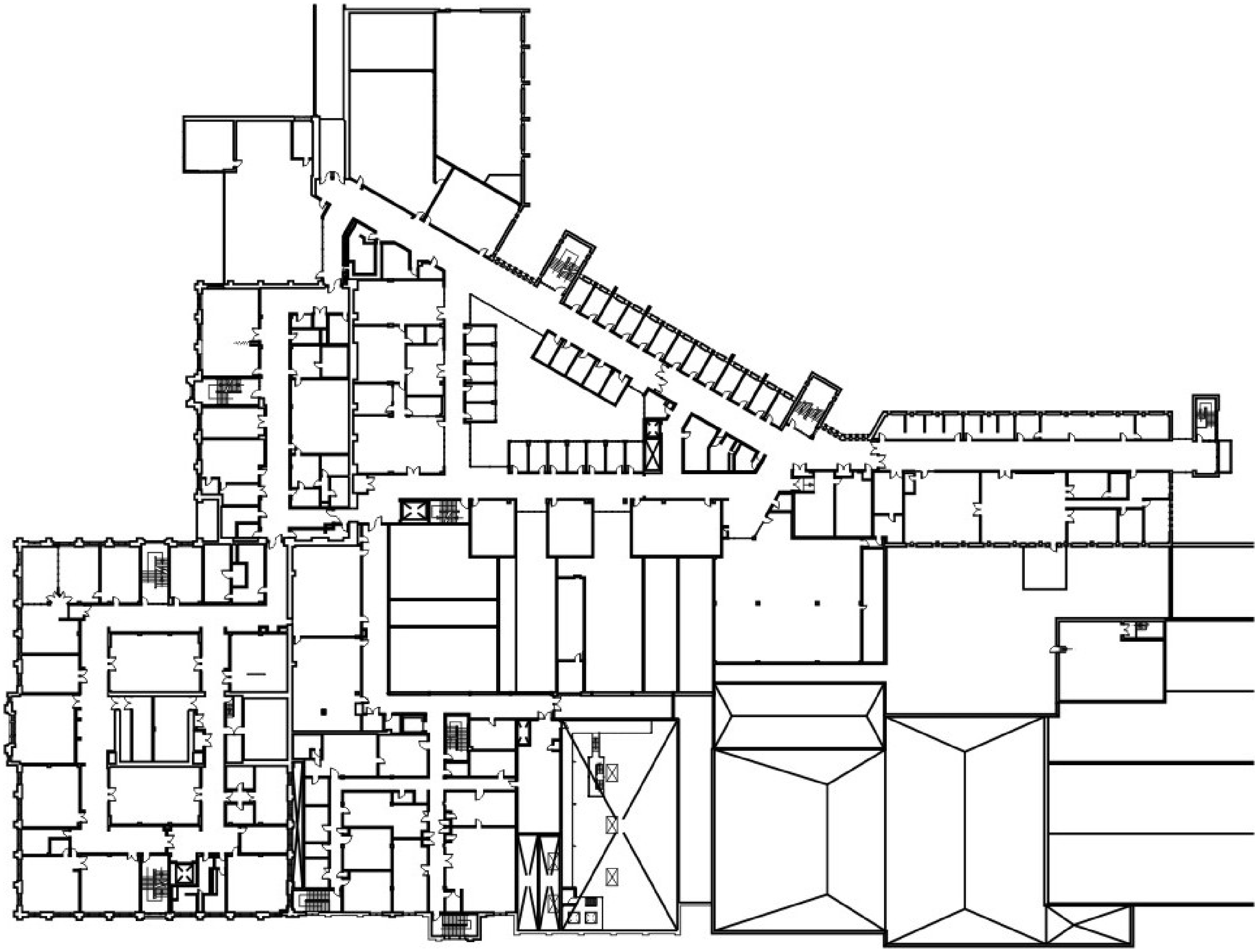
Questionnaire time _______________

Test A time: __________________________

Test B time: __________________________

Remarks:

III: Route Retracing Form



Turn errors: ___________________________________

Off-route travel measurement: __________________

Total Route length: ______________________________

IV: Raw data collection

Group_#	Gender	WalkTime1	WalkTime2	Pointing_Error1 (degrees)	PointTime2	Pointing_Error_2 (degrees)
1	0	00:03:31	00:02:48	26	00:01:10	6
1	0	00:02:48	00:02:30	26	00:00:11	76
1	0	00:02:52	00:02:49	86	00:00:16	19
1	0	00:03:10	00:02:46	4	00:00:25	66
1	0	00:02:10	00:02:43	34	00:00:12	154
1	0	00:03:31	00:03:00	96	00:00:31	14
1	0	00:03:11	00:03:50	36	00:00:52	9
1	0	00:03:10	00:04:14	46	00:00:07	14
1	1	00:04:10	00:02:59	6	00:00:04	24
1	0	00:03:10	00:02:36	16	00:00:04	4
1	1	00:03:10	00:01:51	4	00:00:25	19
1	0	00:03:10	00:02:57	9	00:00:13	76
1	1	00:03:10	00:01:52	4	00:00:07	14
1	1	00:03:10	00:03:09	36	00:00:31	6
1	1	00:03:10	00:02:17	36	00:00:17	19
1	1	00:03:10	00:03:02	6	00:00:13	76
1	1	00:03:10	00:02:23	116	00:00:09	34
1	1	00:03:10	00:02:25	16	00:00:24	46
1	1	00:03:10	00:03:17	11	00:01:27	71
1	0	00:03:10	00:02:27	116	00:00:06	34

Group_#	Gender	WalkTime1	WalkTime2	Pointing_Error1 (degrees)	PointTime2	Pointing_Error1 (degrees)
2	0	00:03:00	00:02:48	1	00:00:02	4
2	1	00:03:00	00:03:40	6	00:00:18	24
2	0	00:04:00	00:03:06	14	00:00:20	96
2	0	00:03:00	00:03:38	56	00:00:10	1
2	1	00:02:00	00:02:51	1	00:00:12	29
2	0	00:02:00	00:03:07	26	00:04:34	96
2	0	00:04:00	00:03:44	34	00:01:18	64
2	1	00:03:00	00:03:11	6	00:00:57	46
2	0	00:02:00	00:05:37	34	00:00:30	34
2	1	00:03:00	00:02:13	36	00:00:18	4
2	1	00:03:00	00:03:13	49	00:01:09	16
2	1	00:05:00	00:03:59	26	00:00:54	46
2	0	00:03:00	00:03:03	11	00:00:27	4
2	0	00:03:32	00:03:24	36	00:00:22	76
2	1	00:03:29	00:03:07	4	00:00:08	66
2	1	00:03:09	00:02:34	4	00:00:21	34
2	0	00:02:39	00:02:32	34	00:01:00	46
2	1	00:04:01	00:02:47	166	00:00:12	56
2	0	00:04:09	00:01:54	18	00:00:35	19
2	1	00:04:06	00:04:00	96	00:00:30	14

Group_#	Gender	WalkTime1	WalkTime2	Pointing_Error1 (degrees)	PointTime2	Pointing_Error1 (degrees)
3	0	00:03:35	00:05:19	4	00:00:30	24
3	1	00:03:54	00:03:10	14	00:00:11	66
3	0	00:03:29	00:02:44	116	00:00:03	14
3	0	00:03:19	00:02:32	16	00:00:17	4
3	1	00:03:13	00:02:46	36	00:00:05	6
3	0	00:03:29	00:03:08	26	00:00:19	6
3	0	00:03:04	00:04:08	21	00:00:08	24
3	1	00:02:57	00:02:28	16	00:00:28	14
3	0	00:03:00	00:03:59	31	00:00:01	1
3	1	00:02:47	00:02:31	26	00:00:07	14
3	0	00:03:24	00:03:12	6	00:00:16	24
3	1	00:03:22	00:04:59	34	00:00:24	26
3	0	00:02:55	00:01:50	16	00:00:06	14
3	1	00:03:24	00:03:08	36	00:00:53	16
3	1	00:03:04	00:02:25	11	00:00:20	9
3	1	00:04:01	00:04:17	66	00:01:09	66
3	1	00:03:27	00:02:55	16	00:00:31	14
3	0	00:03:16	00:02:31	46	00:00:06	9
3	1	00:02:30	00:03:02	81	00:01:03	51
3	0	00:02:36	00:03:00	26	00:00:16	34

V: Subjective description of wayfinding strategies (Metric Strategies highlighted)

Group 1

1. I would look for the coloured pieces of papers and go in the opposite direction. For example, yellow= left turn first time so on the way back I turned right.

2. Followed the papers again. On the way back yellow was ‘turn right’ instead of ‘turn left’ like it was on the original trip; green was ‘turn left’ instead of ‘turn right’. I looked for common objects (ex: pictures, washroom sign, etc.)

3. I used the opposite directions for each landmark. Ex. Instead of turning right on green, I turned left, and the same for yellow.

4. I envisioned that I did before so at a landmark, I would place myself as if I was approaching it the first trip and go that path.

5. I used landmarks such as pictures on the wall and displays. I also looked for the pieces of paper to make sure I was on the correct path.

6. Follow the papers, but with reverse directions. Use landmarks to verify that it is correct.

7. **Memorized directions taken then reversed course for way back, with occasional landmark used.**

8. First by looking at the signs (yellow/green), then by landmarks—the blue paint c/ beige lockers. Then by signage (library)

9. I looked at the landmarks and walked the direction they were facing.

10. Followed the colour coded paper.

11. I mostly looked for the coloured papers which had led me there in the first place.

12. Remember landmarks and took the opposite path and directions from my first trip.

13. By using the papers of colour as landmarks, class indicators.

14. I mostly looked for the coloured papers which had led me there in the first place.

15. As I walked on the way, I looked at my surroundings. On the way back, I really was lost, but little things that caught my eye on the route there took me into the right direction. For example, the recognized the big library and a sign pointing to wing C and wing D.

16. The coloured sheets and some landmarks.

17. I simply reversed the turning instructions of the colour coded sheets, so left became right, and right became left.

18. Used some landmarks in combination with general sense of familiarity with path. Also used signs to let me know I was on right path.

19. I was able to find my way back, because of the familiarity of the path I had followed before.

20. Following the papers in the hallways, I took a wrong turn at one of them but then saw the airplane and knew I was back at the beginning.

Group 2

21. I had recognized certain objects that would stand out from other places. I took note of posters on the wall, doors that I passed, display cases, and signs that were given.

22. The first couple of turns there were no options (eg: other hallways/routes) other than retracing my steps. A combination of the experimental landmarks (coloured paper) and the shades of lighting, wall composition and color, and specific pictures, doorways, etc. 2 remembered, 2 took a shortcut once we reached to main hallway as we had gone almost around in a square to begin with.

23. By recognizing either picture on the wall, staircases, displays, bathrooms, etc. Basically, I was looking for familiar objects. I also remembered some of the directions I took.

24. I remember that I have passed the library, the general office of Chemical Engineering and the exhibition at the end. Then I found those stuffs and followed them back. Afterwards, no special stuff in my memory. I lost.

25. I used landmarks like displays, posters, lockers, double doors, stairs, models, etc.

26. I used pictures on the walls and the colours on the walls.

27. As according to instructions given I used landmarks and colours of lockers, walls, different classrooms. I initially would take an overview of each corridor and then look for specific points to remember.

28. papers assisted, lockers (type/amount), library room

29. I remembered the attributes of the building at each change in direction point.

30. I look for signs and layout patterns that are familiar (eg. Rooms, walls).

31. On the way to the first endpoint I made route of the main entrance and the library. They were helpful in reaffirming. I was on the proper way back.

32. **I started from landmark and then used some short cuts back to the original path.**

33. Familiar corridor features: lockers (colour), windows to library, signs of labs and departments, blue papers to confirm that I was on the right track.

34. Looked for intersect pictures, bright green doors, trophies, ‘robotics’, and Saskatchewan pictures and plane on red cloth.

35. **Mainly by a mental sense of bearing, kind of a feel of what direction to go(right, left, etc.)**

36. **I understand these different landmarks and have a good sense of directions.**

37. **I used my sense of direction. I.E. I knew that where we had started was on the north side of this building. And then I tried to remember the things I went past on the way to the south side.**

38. Looked for things around the markers. Watched for which way the marker was facing. Looked for landmarks along way.

39. **I judged by the directions the papers were facing and by some landmarks. I partly went by intuition as well.**

40. Turned left at bathrooms in the Chemistry Engineering, turn right at the hallway with pictures (wall of distinction at the end), turned left at new addition, and turned left at last hallway, stopped at the plane.

Group 3

1. **From the direction I came from I knew which area I should end up. I looked fro both the pieces of paper and landmarks I saw on the way such as the ramp, bulletins in the glass cases, and walking past the library (behind it).**

2. I tried to remember objects on the walls and the types of intersections along with the turns I took on the way there.

3. **I took the shortest path I knew from my learning experience in the building.**

4. I recognized certain colours and locker patterns and pictures on the wall. And I made sure I didn't look at the things in any other halls so I would only know or recognize landmarks on my path.

5. I recalled the pictures on the wall, statues in the hall and door labels. I could usually tell which direction was familiar and which was not.

6. **A general feel for direction. Landmarks signs and objects helped to confirm location.**

7. **Used markers as general help. Remembered sign pointing to D wing. Knew starting point was airplane model. General sense of direction, followed angle.**

8. **I tried to visualize in my mind the path backwards. I also recounted the display cases to help locate my position.**

9. Remembered same places I passed on the way to end point, the path I took seemed like a well walked path.

10. I looked at my surroundings; I noticed all of the different coloured doors on the way.

11. **I remembered displays and room numbers. I also knew the direction I needed to go.**

12. Follow the sign, of course. Remember the objects easy to identify (pictures, statue, bathroom, etc.)

13. Kept an idea of where I had gone and figured out which were the major paths. If the colour of one hall was the same throughout and I saw that hall color again I assumed it crossed again.

14. **I find it most helpful to use an angle (roughly) to help me get back to where I started. Visual cues along the way help me as well.**

15. I think about which turn should I did. And I remembered some surroundings such as library, classroom.

16. I remembered the halls and some of the signs. There were different coloured doors and lockers that I remembered walking by.

17. Recognizable landmarks and familiar marking.

18. **Felt like the right ways to go, and sometimes using the surroundings.**

19. I used the visual cues that I paid attention to on my way to the destination.

20. **Memorized general direction of the paths also remembered classroom signs and big landmarks.**