# The science of navigation: An analysis of behavioural differences between good and poor wayfinders.

by

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**Author's Declaration**

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

## Abstract

Everyday experience suggests that certain people can find their way to a destination easily, while others have considerable difficulty. This dissertation focused on gaining a greater understanding of navigational strategies that can facilitate or hinder an individual's wayfinding performance. The first study was conducted to gain a broad idea of various factors that may influence navigational performance. Participants were guided through a building and then asked to find their way to a destination. It was found that good navigators made fewer errors in traversing a learned route than did poor navigators. They were also better at recognizing landmarks they had seen along the route, recalling the appropriate directions to be turned at each landmark, and at drawing the correct pathways on a map drawing task. A discriminant analysis revealed that the best predictor of determining navigational performance was the ability to form spatial relationships between landmarks. Results from the first study demonstrated that good navigators were better at determining spatial relationships between landmarks, but it did not address whether this was due to spatial relationships between distances and/or angles. The focus of the second study was to gain a greater understanding of the degree to which distance and angular information are used by good and poor navigators in determining spatial relationships between landmarks. Results showed that neither a distance nor an angular strategy were preferred in either group of wayfinders. An analysis of navigators initial heading angle error to a target location suggested that good wayfinders may be more efficient at finding their way because they appear to plan routes prior to initiating self-locomotion. Such pre-planning was confirmed by the fact that good wayfinders' initial heading direction error was significantly less than in poor wayfinders. Poor wayfinders appear to head in a random direction and then attempt to determine target locations. The use of landmark information may be useful in certain contexts, but this may not always be the most efficient strategy. The last experiment was aimed at determining whether good navigators adjust strategies used (landmark vs. street), depending on contextual factors. Differences in strategies used were not found, however the results suggest that good navigators appear to be more skilled at navigating in environments rich with streets compared to poor wayfinders. Good and poor navigators were equally skilled at navigating in environments rich in landmarks. It appears that the ability to determine spatial relationships between landmarks is the strongest predictor of navigational performance compared to a wide range of other navigational skills.

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## Table of Contents

**List of Figures**

**Study 1:**



**Study 2:**

**Study 3**

## List of Tables

**Literature Review:**

General Introduction:

Everyday experience suggests that certain people can easily find their way to a destination, while others have considerable difficulty (Kato & Takeuchi, 2003). Differences in navigational ability may arise because individuals focus on different types of information as they engage in wayfinding, such as landmark or cardinal direction cues. Various cognitive skills (memory, attention etc.) are necessary to successfully navigate, and thus identifying sources of variation in navigational ability is a challenge. It is often difficult to pinpoint these sources of individual differences since both internal and external factors contribute to individual differences in wayfinding ability. External factors include the characteristics of a situation or environment such as the availability of landmarks, and the pattern of streets and intersections. Internal factors include characteristics of an individual such as sex, familiarity with the environment, and strategies used to navigate (Lawton, 1996). There appears to be little agreement in the literature regarding which factors are the most important in predicting wayfinding ability. This dissertation is geared towards gaining a greater understanding of navigational strategies that can facilitate or hinder an individual's wayfinding performance.

In the past, individual differences have been examined by determining how they are related to psychometric tests of spatial ability. There are several psychometric tests that are often used, including tasks involving mental rotation of shapes, finding hidden figures and mazes (Caroll, 1993; Eliot & Smith, 1983; Lohman, 1988). Research by Hegarty, Richardson, Montello, Lovelace, & Subbiah, (2002), suggests that psychometric measures are weak predictors of environmental spatial performance. These tasks involve imagining the manipulation of small-scale space as opposed to visualizing one's own changing orientation and location in a large-scale space. The correlations with performance on these psychometric tests are typically not significant and rarely exceed an average of 0.3 (Hegarty et al., 2002).

Wayfinding Strategies:

Individuals often differ in the strategies they use, from using landmarks, to using a spatial layout or an internal map of the environment. Landmark, route and survey strategies are three types of approaches used to navigate (Prestopnik & Ewoldesen, 2000).

Landmark knowledge is often a foundation upon which more extensive spatial representations form. Landmark knowledge involves using spatial reference point locations that are well known. Route strategies involve using a sequence of instructions to navigate from one place to another. This strategy often involves navigating from one place to another using landmarks (Prestopnik & Ewoldesen, 2000). Using a route strategy involves the use of an internal mental representation of procedures that are required for locating a set of target locations in an environment. This type of strategy is inflexible since it forces the use of a specific direction from one place to another. Consequently, people who rely on route strategies become lost easily if they deviate from a learned route (Prestopnik & Ewoldesen, 2000). Route representations can preserve metric information regarding distances and directions between sets of locations, but they are more often conceptualized as preserving only topological information about proximity between locations. When using a route strategy, all information is encoded in terms of discrete sets of locations. This type of strategy does not allow a global simultaneous knowledge of all landmarks in an environment or their relative positions (Waller, 1999).

Survey strategies offer a more flexible approach to wayfinding. This type of strategy is often conceived as using a “map in the head” or “cognitive map” and involves the use of metric relations such as bearings. A cognitive map is a mental representation that corresponds to an individual's perception of the real world. Cognitive maps are often used while wayfinding and thus will be examined in several studies. Several studies will examine the role of landmark information, since it is involved in forming cognitive maps. This strategy does not simply involve knowing the locations between which a wayfinder has traversed. The focus with survey strategies is global, and such strategies rely on universal concepts that do not alter when direction or orientation changes. For example, survey strategies often involve using cardinal directions or the sun as reference points. Using a survey strategy is much more flexible than using a route strategy since survey knowledge allows the ability to find shortcuts that are different from the originally learned route (Prestopnik & Ewoldesen, 2000).

A study by Hund & Minarik (2006), examined the use of landmark and cardinal strategies as related to wayfinding performance. The results indicate that as a reliance on cardinal strategies increased, navigational efficiency also increased, suggesting that wayfinding strategies are related to navigational ability. It also appears that there is a correlation between wayfinding strategies and navigation efficiency. A reliance on cardinal strategies was associated with decreased navigation time (Hund & Minarik, 2006).

Successful wayfinding requires appropriate strategies and each type of strategy is associated with a certain reasoning process and spatial representation (Carlson, Holscher, Shipley, & Dalton, 2010). In order for a given strategy to be effective, an individual must be able to cope with the processing and representation demands of that strategy (Carlson et al., 2010). Individual differences in navigational ability arise from variations in strategies used. How successful a wayfinder is in a given environment is also influenced by the compatibility between the environment and the strategies an individual uses. Certain people may be better at navigating because they select appropriate strategies applicable to the type of environment they are in (Carlson et al., 2010).

According to Hund & Padgitt (2012), individuals with a good sense of direction report using more survey knowledge relative to route strategies compared to poor wayfinders. In this study, the effectiveness of wayfinding directions in a complex indoor environment was examined. Direction quality was measured using effectiveness ratings and behavioural indices. In previous studies, individuals with self-reported good sense of direction gave higher ratings to survey descriptions relative to those with a poor sense of direction (Hund & Padgitt, 2012).

Sex Differences:

There is little agreement on the issue of sex differences not only in wayfinding, but also in spatial ability generally. Previous studies examining navigational performance have found that men outperform women on paper-and-pencil tests of spatial ability, desktop virtual reality environments and real-world settings (Lovden et al., 2007). Individual differences due to gender are usually fairly small. Several studies have suggested that gender appears to play a minor role in the way in which environmental information is encoded (Sandstrom et al., 1998; Ward et al., 1986). When gender differences are found, they are often attributed to gender-related strategies. Males tend to rely more on cardinal directions while women are more to likely to use landmark information. Due to these differences in strategies men tend to rely more on survey knowledge. Women, on the other hand, are reported to rely more on route knowledge (Charleston & Zieles, 1996; Lawton, 1994). Females appear to have superior object location memory although this can depend on the type of objects and the extent of metric precision that is required (Hegarty & Wolvers, 2010).

Gender differences in performance on the use of landmarks have been found, but the results have been inconsistent. A study by Cutmore et al., (2000) suggests that both male and females use landmarks as navigational tools effectively (Cutmore et al., 2000). Conversely, a study by Parush & Berman (2004) suggests that the use of landmarks improves performance in females when used in conjunction with maps, but hinders performance in males (Parush & Berman, 2004).

Sense of Direction:

Another source of individual differences is an individual's sense of direction. Sense of direction is defined as knowledge of one's location in space. Individuals with a good sense of direction can provide a reliable reference bearing when they are registering the degree of a turn. Individuals with a good sense of direction can also accurately orient their mental representation of a configuration to match a scene they are viewing (Cornell, Sorenson & Mio, 2003).

The concept of sense of direction was developed in early analysis of navigation when an organism was observed to locate itself in unfamiliar territory. It appears that humans are capable of various methods of wayfinding depending on the type of information that is available to them. An individual's sense of direction could be important to all of these methods. For example, individuals with a good sense of direction may be more skilled at looking for areas likely to contain landmarks and can use the information to direct actions at intersections or routes. A good sense of direction can also provide an accurate reference bearing when wayfinders are registering a degree of a turn (Cornell et al., 2003).

Research on sense of direction has previously dealt with either the ability to maintain orientation while moving through space or the ability to point to unseen goals and draw maps

(Howard & Templeton, 1966). Individuals with a good sense of direction are skilled at determining spatial relationships beyond their immediate position and surroundings (Kozlowski & Bryant, 1977). According to several researchers, sense of direction involves the ability to mentally coordinate egocentric and imagined frames of references (Kozlowski and Bryant 1977; Sholl 1988, Montello & Pick, 1993). In a study by Bryant (1982), participants were asked to point to unseen objects at a university campus. The results indicate a strong correlation between self-reports of sense of direction and pointing error ($r = -0.63$) (Bryant, 1982).

Research by Kozlowski & Bryant (1977), suggests that individuals with a good sense of direction have a better mental representations of environments. In this study, participants were presented with a partial map of a university campus and asked to complete the map based on their cognitive map of the university. Individuals with a good sense of direction outperformed poor wayfinders (Kozlowski & Bryant, 1977).

Internal Neural Mechanisms:

Not only do external factors affect navigational ability, but internal neural mechanisms have an influence on individual differences as well. The neural networks supporting human wayfinding ability mainly involve the hippocampus, and prefrontal cortex. Individual differences due to sex may be attributed to the fact that men show activation in the left hippocampal region, whereas women show activation in the right parietal and right prefrontal areas during spatial navigation (Gron et al., 2000).

The ability to navigate effectively depends on the ability to successfully store navigationally relevant information. Differences in memory consolidation are also associated with variability in navigational ability. A study by Janzen, Jansen & Turennout (2008), suggests that the bilateral hippocampus, and parahippocampal gyrus are more active in good navigators in the presence of navigationally relevant information. In this study, memory consolidation of navigationally relevant landmarks after a route learning task was examined using event-related fMRI. The results indicate that there was increased activity in the bilateral hippocampus and parahippocampal gyrus in good navigators compared to poor wayfinders. The results from this study provide some evidence of the connection between memory consolidation and wayfinding ability (Janzen et al., 2008).

Functional magnetic resonance imaging studies have demonstrated differential neural activity in good and poor wayfinders. Findings one's way engages different cognitive processes than following a familiar route. A study by Hartley, Maguire, Spiers, and Burgess (2003), provides evidence of the importance of the anterio hippocampus and head of the caudate in wayfinding. Good navigators appear to have increased activation compared to poor wayfinders in the anterior hippocampus during wayfinding and the head of the caudate when following routes (Hartley et al., 2003).

Applications:

Understanding strategies used by good wayfinders can also have implications for behavioural geographers and cartographers. The construct of a sense of direction may play an important role in models of spatial decision making. The construct of sense of direction may also be important to models of spatial action and activity. It may be an explanation for why drivers prefer certain routes to others that are aligned within a cardinal grid. Lastly, greater insight of cognitive mechanisms involved in wayfinding may be important in assessing the aesthetics and effectiveness of maps (Cornell et al., 2003).

A greater understanding of sources of individual differences in navigational ability can be particularly helpful for establishing guidelines on designing buildings effectively. For example, routes can be designed to make navigating easier. This knowledge can provide insight into the type of environments that can be learned most quickly. Poor navigators may utilize an environment differently than poor wayfinders. A greater understanding of the strategies used by good and poor navigators is vital for a planner when designing environments suitable for both populations. Considering how good and poor wayfinders learn about space and how they handle spatial aspects of environments will also allow planners to develop maps that incorporate strategies used by both groups (Kitchin, 1994).

Research has found that poor hospital design is associated with increased environmental stress (Kitchin, 1994). This can be avoided by the application of navigational knowledge to designing clearer maps, and having directions at key decision points. Research concerning how good wayfinders navigate can provide information concerning the environmental needs of the elderly. Age-related decrements in navigational ability have an impact on quality of life. Environments can be designed to allow elderly individuals to learn their environments more quickly and with greater ease. These “optimum” environments may be more suitable as a living area and can be useful to architects creating spaces used mainly by elderly such as residential homes and hospitals (Kitchin, 1994).

## Study 1: Examination of navigational differences between good and poor wayfinders in large-scale environments

**Introduction:**

The present study attempted to determine whether people's appraisals of their sense of direction is a valid index of their ability to find their way in large-scale environments. This experiment examined individual difference variables that may be linked with self-ratings of sense of direction. Most research to date on large-scale spaces has focused on navigation in the horizontal plane. Vertical travel can disturb spatial cognition and often results in disorientation. Segmenting a building mentally into regions reduces cognitive effort and permits hierarchical planning. There have only been a few studies to date that have examined wayfinding in 3-dimensional large-scale environments (Passini, 1984; Foley & Cohen, 1984). Passini (1984), collected verbal protocols from individual's while navigating in a multilevel shopping center. Foley & Cohen, (1984), had participants determine distances between locations on various floors of a five-story building. In the current study, various components involved in navigating were examined in a 4-storey building. Participants were asked to construct and integrate representations of space located at different levels. A greater understanding of how individuals navigate in 3-dimensional spaces can provide useful insight into the optimal design of high-rise buildings.

Wayfinding errors can occur for a number of reasons and can be manifested in various forms. Movement errors can occur resulting from incorrect sensing of time, distance or velocity, which can result in an over or underestimate of distance. Errors can also occur due to a frame of reference that is distorted or poor perceptual recoding which can results in turn errors, direction errors or can cause a mismatch in choice points and turn angles. Navigational errors can also occur due to incorrect internal manipulations such as incorrectly integrating routes to form a layout, recognition errors such as incorrectly identifying a cue due to perspective changes or inadequate familiarity. Lastly, wayfindings errors can also occur due to the use of a distorted cognitive map, incorrectly implementing a correctly encoded behavior such as an angle or incorrectly decoding sets of spatial relations (Allen & Golledge, 1999).

This study was conducted to gain a broad idea of various factors that may influence navigational performance. Participants were guided through a building and then asked to find their way to a destination. In order to examine navigational strategies used by good and poor wayfinders, participants were asked to think aloud as they found their way to a target location. Participants also completed a series of questionnaires to assess their ability to (1) recognize landmarks, (2) remember directional information, (3) determine spatial relationships between landmarks and (4) form cognitive maps of environments. It was hypothesized that good navigators would outperform poor wayfinders at these questionnaires.

A think out loud method was used because it allows the simultaneous monitoring of a subject's mental activity as they navigate through an environment (Kato & Takeuchi, 2003). The ability to examine wayfinding behaviour on a temporal basis can provide important insight into wayfinding. The contents of verbal reports are analyzed by placing them in several different categories. These categories are based on commonalities in the statements to derive various similar "thought" categories. Examining these categories and their contents is a useful way of understanding a cognitive task and the strategies used. A drawback of verbal protocols is that they only give insight into processes that subjects are aware of or verbalize. Despite this disadvantage, verbal reports can assist in providing evidence to distinguish between competing models, such as psychometric tests, seeking to explain spatial cognition. The use of verbal reports as an attempt to acquire navigational information has been largely ignored in previous work (Spiers & Maguire, 2008).

In order to determine differences between good and poor navigators, the Santa Barbara Sense of Direction Scale was used to select participants that are skilled at navigating and those that have difficulty. Self-report measures such as the Santa Barbara Sense of Direction (SBSOD) scale are a more accurate approach of predicting spatial ability than paper-and-pencil tests of spatial ability. One likely reason for this may be due to the fact that their environmental cognitive abilities are utilized on a daily basis and there are real costs associated with having poor spatial abilities so people can easily think of situations in which these abilities (or the lack of these abilities) have come into play.

Examination of items loaded on this scale suggest that people rate their sense of direction based on judgments of their ability to remain oriented in an environment, learning layouts, using maps and by the ability to give and follow directions. Most items loaded on this scale involve ratings of the individual's own competency on navigational tasks that rely on survey or configurationally knowledge of environments. This self-report measure appears to be highly correlated with environmental knowledge that requires the ability to represent one's current orientation or heading in an environment.

Sense of direction and wayfinding are related notions, however they have different meanings. A sense of direction involves the ability to form an accurate cognitive map of an environment and to be able to orient oneself within this representation. Wayfinding refers to problem-solving abilities that are required to reach a destination. Orientating oneself with the use of a cognitive map is considered a source of information that is often used in this problem-solving process while wayfinding (Passini et al., 1998). The SBSD is a test of sense of direction and is related to tasks that involve updating location in space as a result of self-motion (Hegarty et al., 2002). This scale was used to examine wayfinding ability since orientating oneself with the use of a cognitive map is an important element of the wayfinding process (Allen & Golledge, 1999).

Participants:

Participants were undergraduate psychology students from the University of Waterloo. Participants had an average age of 20.25 (SD 1.42) and consisted of 20 females and 20 males. Sample sizes were determined using statistical power. Power calculations were conducted using $\pi = 0.80$ and a significance criterion of $\alpha = 0.05$.

Participants were selected based on their performance on the Santa Barbara Sense of Direction Scale (SBSD). An equal number of males and females with good and poor sense of direction were selected to eliminate a sampling bias since there appears to be a smaller sample of males with low SBSD scores in this population. The Santa Barbara Sense of Direction scale has been shown to predict actual wayfinding ability with reasonable accuracy and is internally consistent with good test-retest reliability (Hegarty et al., 2002). This is a 15-item scale that contains self-estimates of spatial ability, direction giving/ taking styles, and styles of exploration (Appendix A). In the SBSOD participants provide a rating of their agreement (on a scale 1-7) with various statements about their spatial skills (Epstein et al., 2005).

Items on the scale are phrased in such a way that half of the items are stated positively while the other half are stated negatively. An example of a positively stated phrase would be the following: “I am very good at judging distances” and an example of a negatively stated item consists of the following “ I easily get lost in a new city”. In this study and all subsequent studies, items on the scale were scored such that a higher rating indicates a good sense of direction  (i.e. the scores of positively rated items were reversed). Studies have shown that people are fairly truthful and accurate in estimating their navigational ability. Participants that scored at least one standard deviation above the mean of 1751 students were part of the good sense of direction group and those that scored one standard deviation below the mean were part of the poor sense of direction group. The focus of this dissertation was to examine differences between good and poor navigators, rather than average wayfinders and consequently only the extreme groups were selected. A double-blind procedure was used and the experimenter was not aware if the participant was part of the good or poor sense of direction group. Participants were given a participation course credit for taking part in the study.

**Method and Materials:**

The study took place at the Environment and Information Technology (EIT) building located at the University of Waterloo. This building was chosen because it had several landmarks and pathways to detect individual differences in wayfinding. If this environment had very few pathways even participants in the poor sense of direction group may not have committed any route errors, thus making it difficult to detect differences between the groups. This building contained numerous pathways and as a result the difficulty level of this task was appropriate for this type of study. This environment was also chosen because of a large foyer located in the center of the building, which can make it easier to form a cognitive map linking the different floors. Another aim of this study was to examine whether good and poor navigators differ in their ability to determine spatial relationships between landmarks located on multiple floors.

Determining spatial relationships of landmarks positioned on different floors requires an ability to synthesize information from various levels. The foyer in this building can facilitate participants in determining these spatial relationships since landmarks located on different floors can be viewed from a foyer. Lastly, this building was also suitable since most psychology participants had very little exposure to the building. Participants were asked to rate their familiarity with the building from 1-5 (1 not familiar, 5 familiar). Participant's who rated themselves 3 or below were included in the study. Results from a questionnaire confirmed that most participants were not familiar with the building. Data from the few participants who were familiar with the building were excluded from the analyses.

**Method:**

Participants were taken to an adjacent building on campus and upon arrival they were provided with a consent form. The meeting location was a place on campus adequately distant from the EIT building to prevent participants from visiting the building prior to the experiment. After completing consent forms participants were lead to the origin of a path through an alternate route so they could not acquire route information until they reached the starting location. Participants were then lead to the starting point of a route through tunnels on campus from a nearby building. The tunnels avoided the problem of bad weather and the reduced the ability of participants to determine their position by referring to exterior landmarks such as campus architecture or the sun. The route was arranged so it started at one exit on the north side and ended at another exit in the southern end of the building. The diagrams below illustrate the floor plan of each of the 4 floors (Figure 1, 2, 3, and 4). The line indicates the path, the starting positions are indicated by the arrows and each of the landmarks have been labeled.

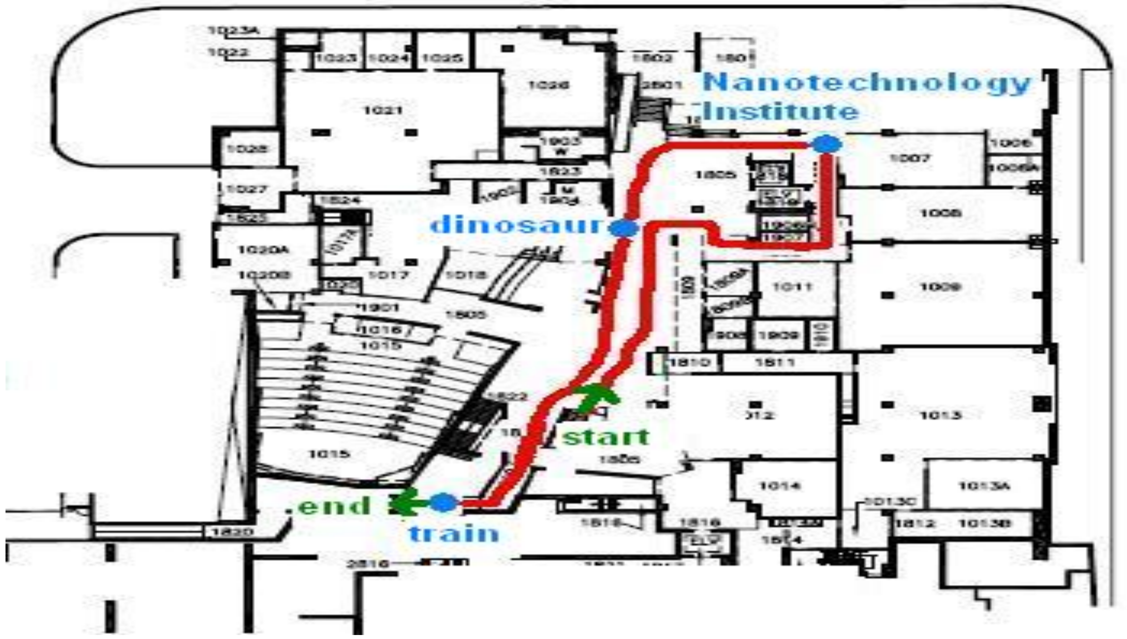


Figure 1: 1st floor layout

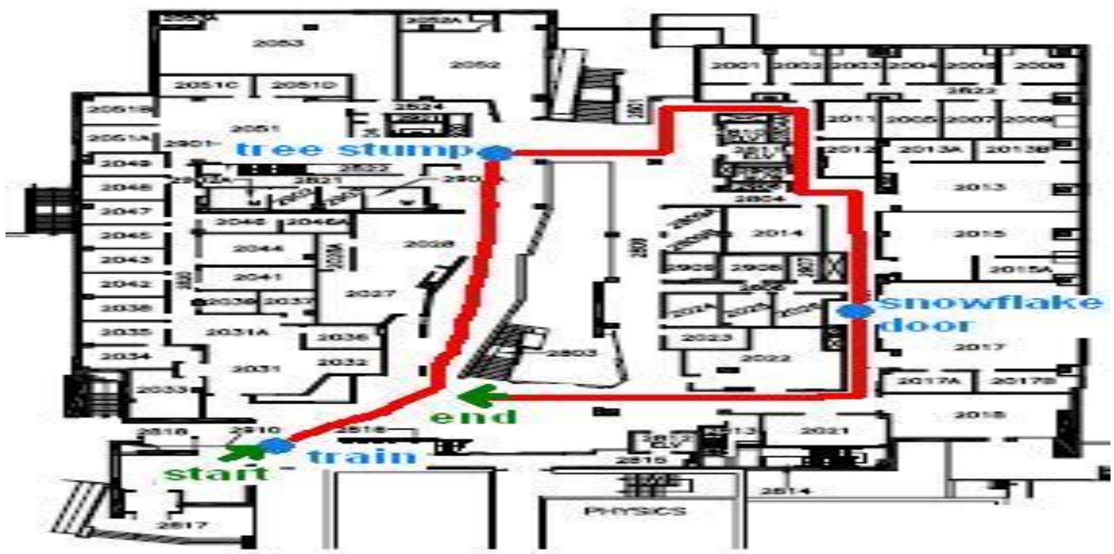


Figure 2: 2nd floor layout

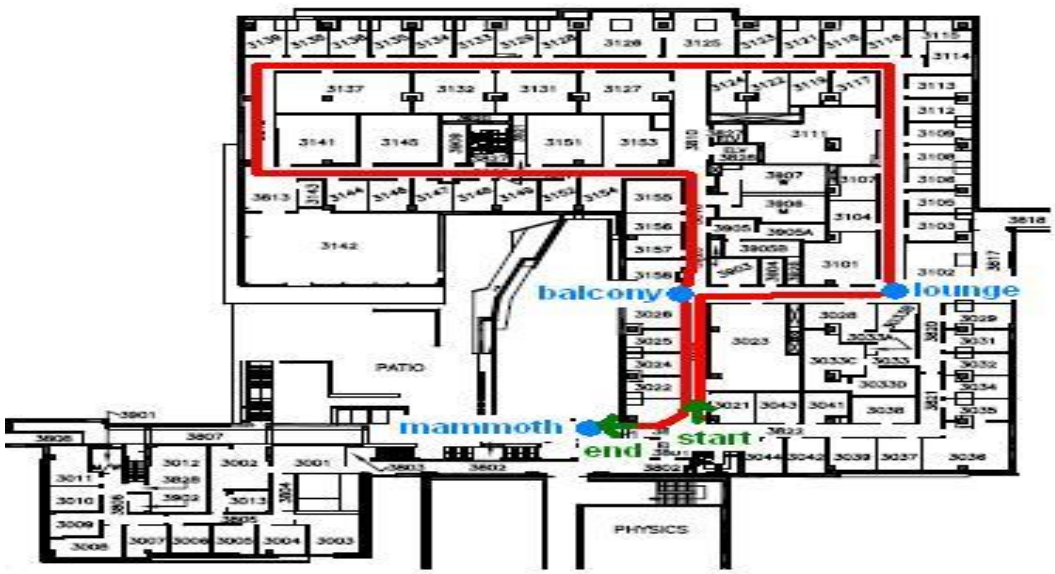


Figure 3: 3rd floor layout

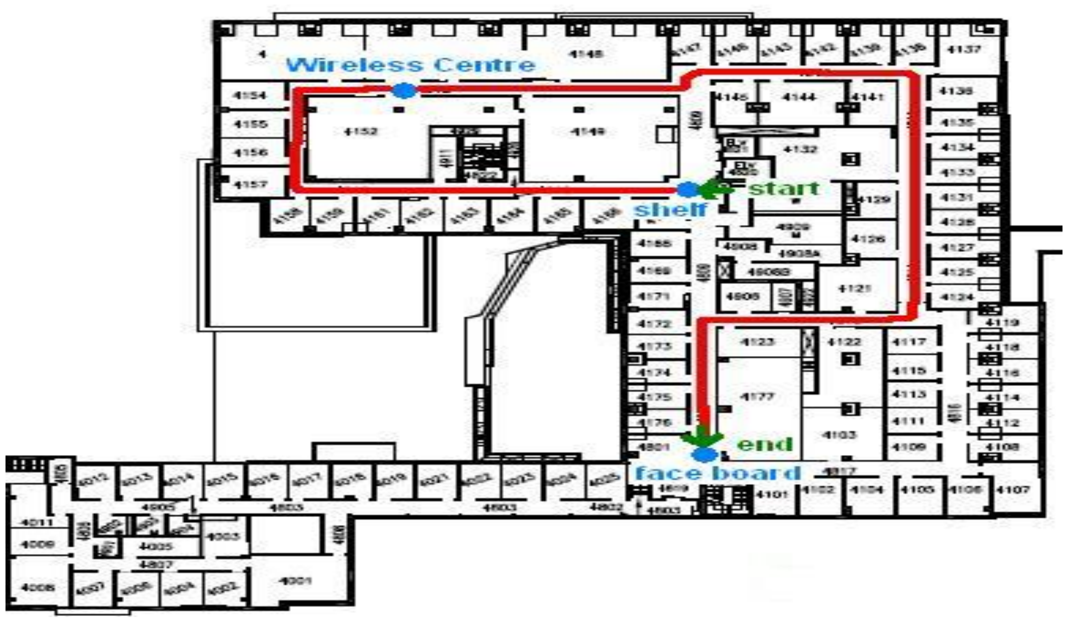


Figure 4: 4th floor layout

Upon entrance to the EIT building participants were asked to rate their familiarity with the building on a scale of 1-5, 1 being not familiar and 5 being very familiar (Appendix B). Participants were then guided through a multi-level (4 floor) route and asked to follow the experimenter in order to learn the route so they could retrace the path themselves in a second trial. Participants were asked to pay attention to the location of landmarks pointed out along the path. Each floor had 3 landmarks that participants were asked to remember (total # landmarks (4 floors x 3) =12). A picture of each of the 12 landmarks are provided in Appendix B. Participants were then asked to retrace the path taken without asking passers-by for assistance or referring to maps. As participants retraced the route they were asked to think aloud and verbalize anything that came to mind. As participants retraced the route they were video taped from behind. After retracing the route participants were asked to complete a series of questionnaires to assess their ability to (1) recognize landmarks, (2) remember directional information, (3) position landmarks on a map (4) assess spatial relationships between landmarks and (5) form cognitive maps of environments. Each participant completed the experiment in the same sequence. Firstly, participants learned the route of the $4^{th}$ floor by following the experimenter and then drew the route of the $4^{th}$ floor. After learning and drawing the $4^{th}$ floor, participants then learned and drew the $3^{rd}$ floor, $2^{nd}$ floor and lastly the $1^{st}$ floor. After learning and drawing each of the floors, participants were asked to retrace the entire route starting from the $4^{th}$ floor to the $1^{st}$ floor, without asking people for directions or the use of maps. After retracing the route, participants completed several questionnaires.

An area in an adjacent building was used to provide a quiet place to complete the questionnaires. The questionnaires were also completed in a different building to prevent participants from using environmental cues to answer the questions. Explanations and examples were provided to each participant to familiarize themselves with the questions being asked. The experiment took approximately 60 minutes to complete.

**Tasks:**

Route Drawing Task:

Participants were asked to draw the route taken on each floor (Appendix C). Maps were drawn on a 8.5 x 11 paper. Performance was measured by determining the percentage of paths that were drawn in the correct position. Paths had to be drawn according to the correct angle relative to other paths to be considered accurate (see appendix D for an example).

Path Pattern Identification:

The path on the 3$^{rd}$ and 4$^{th}$ floor are the same, but in the reverse direction. Participants were asked in an open-ended question if they noticed any similarities between the path taken on the 3$^{rd}$ and 4$^{th}$ floor (Appendix E). This question was designed to assess whether both good and poor navigators integrate spatial information by keeping track of spatial patterns of paths along different floors.

Landmark Recognition Questionnaire:

This questionnaire assessed participant's ability to recognize landmarks. Each question contained 3 photographs and participants were required to select 1 photograph that illustrates a landmark presented along a given path. The backgrounds behind all landmark photographs were cut out to prevent participants from using surrounding environmental cues to determine the correct landmark. The data were analyzed by determining the frequency of correct responses of each landmark.

Directional Information Questionnaire:

This questionnaire assessed participant's performance at keeping track of turns from landmarks while navigating (Appendix F). Participants were asked to indicate if they turned left, right or went straight once arriving at each of the 12 landmarks. The data were analyzed by determining the frequency of correct responses associated with each landmark.

Landmark Positioning Task:

Participants were presented with a map and they were required to indicate the position of each landmark on the map. The path taken on each floor was drawn on the map to reduce the influence of path memory in determining positional information of landmarks.

Spatial Relationship Questionnaire:

Participants were asked to identify a landmark's location relative to the other 2 landmarks positions by circling the "X" that best represents its location (Appendix G). Not all landmarks were on the same floor. The labeled "X''s represent the approximate position of 2 landmarks presented along the path.

Sample question:

1) Please circle the mammoth's position

**X**

X (Nanotechnology Institute)

**X** X (balcony) **X**

**X**

Verbal statements:

Participants were asked to verbalize their thoughts as they retraced the path. Verbal statements made were classified into 5 categories:

1) Landmark: Statements that make reference to landmarks.

2) Direction: Statements that make reference to turns.

3) Planning: Statements that make reference to planning a route before arriving at a destination. For example, "I'll turn left when I arrive at the 2$^{nd}$ landmark" This sentence would also be considered a "landmark", "direction" and "planning" statement.

4) Spatial Relationship: Statements that make reference to spatial relationships between paths, landmarks or the participant. For example "This path is parallel to the path I started from"

5) Uncertainty: Statements that indicate uncertainty. For example: "I'm not sure if I'm supposed to turn left from here".

Verbal statements made were only coded based on the words rather than intonation. Two raters categorized the statements and inter-rater reliability was determined.

Wayfinding Performance:

The frequency of wrong turns was used to determine wayfinding performance. If participants took a wrong turn, they were directed back to the correct turn in order to prevent a subsequent compounding of errors from the initial incorrect turn.

**Results and Discussion:**

Performance:

These results of this study indicate that the Santa Barbara Sense of Direction Scale is an accurate predictor of navigational ability (Figure 5). Poor navigators made more route errors ($F(1, 36) = 8.21$, $p = 0.007$, $\eta^2_{partial} = 0.186$). No significant sex differences in the average number of route errors were found ($F(1, 36) = 0.14$, $p = 0.705$, $\eta^2_{partial} = 0.004$) and there also was not a sex x ability (good vs. poor) interaction ($F(1, 36) = 0.04$, $p = 0.850$, $\eta^2_{partial} = 0.001$).

Poor navigators also made more pauses ($F(1, 36) = 9.26$, $p = 0.004$, $\eta^2_{partial} = 0.204$) than good navigators. No significant sex differences in the average number of pauses were found ($F(1, 36) = 2.5$, $p = 0.124$, $\eta^2_{partial} = 0.064$), and there also was not a sex x ability interaction ($F(1, 36) = 0.27$, $p = 0.603$, $\eta^2_{partial} = 0.007$). Pauses were noted when a participant made a complete stop of at least 2 seconds.

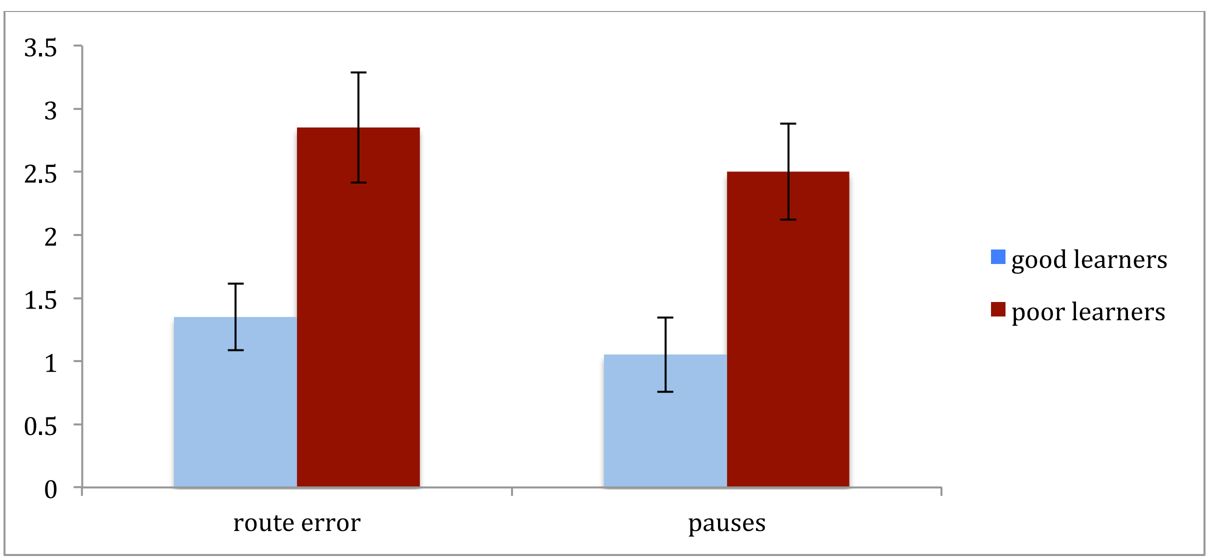


Figure 5: Average frequency of errors and pauses in good and poor wayfinders with standard error.

Landmark Recognition Task:

Good navigators outperformed poor wayfinders on the landmark recognition task (Figure 6). Results from the landmark recognition task indicate that good navigators were better at recognizing landmarks ($F(1, 36) = 6.6$, $p = 0.015$, $\eta^2_{partial} = 0.155$). No significant sex differences on this task were found ($F(1, 36) = 0.08$, $p = 0.777$, $\eta^2_{partial} = 0.002$ ) and there also was not a sex x ability interaction ($F(1, 36) = 0$, $p = 1.0$, $\eta^2_{partial} = 0$).

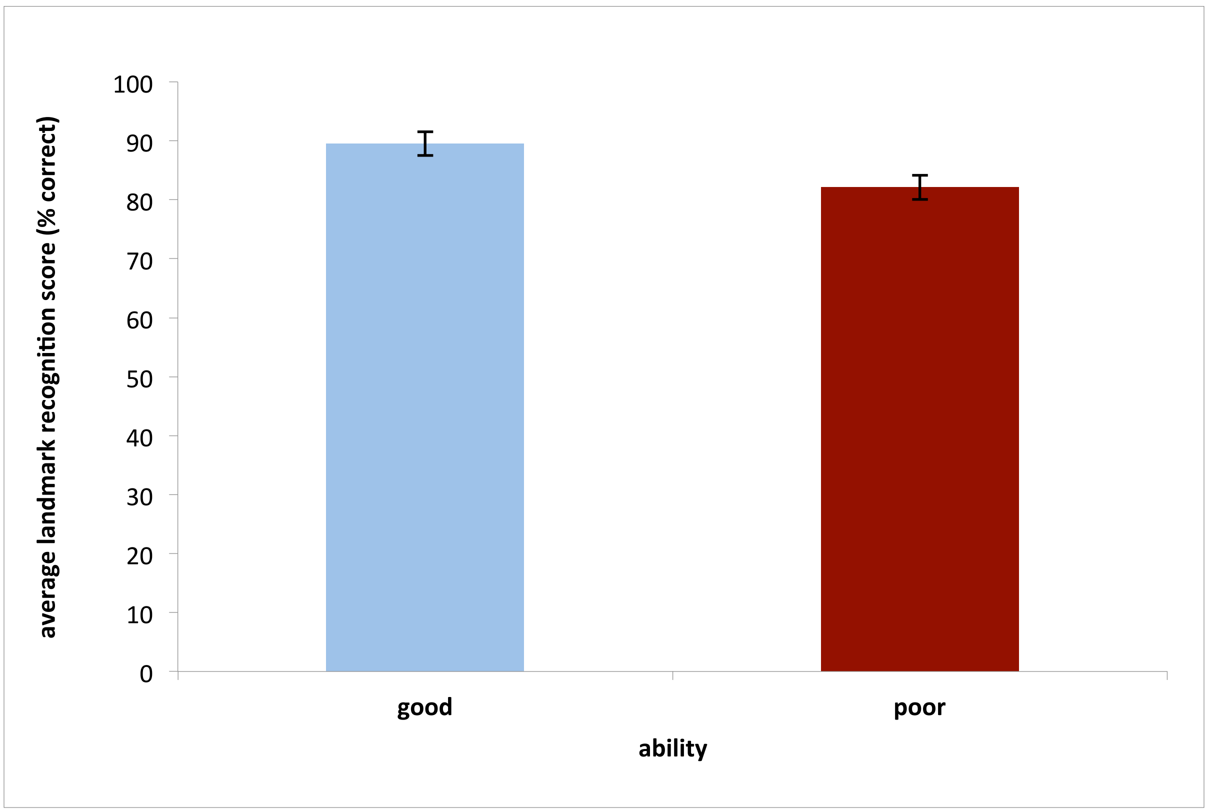


Figure 6: Average score on the landmark recognition task in good and poor navigators. Error bars represent standard errors of the mean.

Directional Information Questionnaire:

The results also indicate that good navigators are more skilled at assessing directional information from landmarks ($F(1, 36) = 4.80$, $p = 0.035$, $\eta^2_{partial} = 0.117$). Not only are good navigators better at remembering landmarks visually along a path, but they are also skilled at determining the direction they turned at these landmarks (Figure 7). No significant sex differences on this task were found ($F(1, 36) = 0.74$, $p = 0.397$, $\eta^2_{partial} = 0.021$) and there also was not a sex x ability interaction ($F(1, 36) = 1.099$, $p = 0.301$, $\eta^2_{partial} = 0.029$).

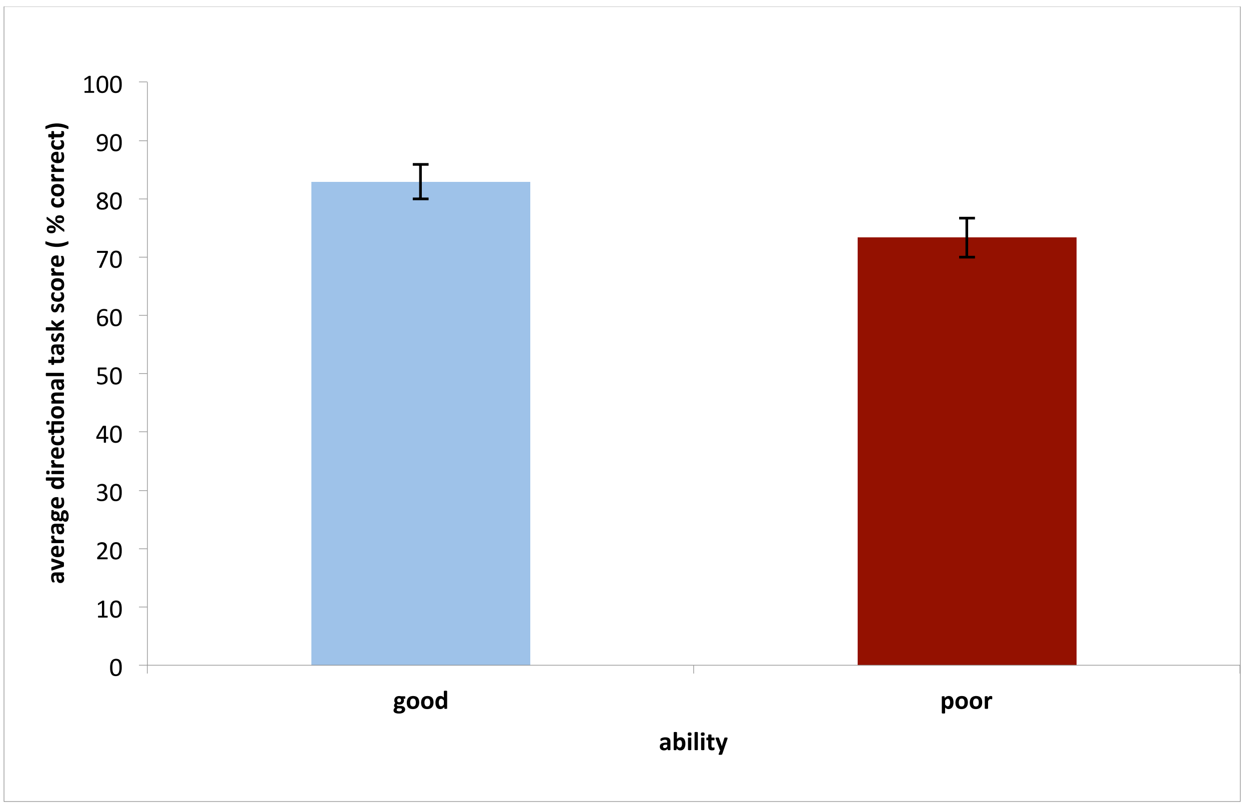


Figure 7: Average score on the directional task in good and poor navigators with standard error.

Landmark Positioning Task:

Results from the landmark positioning task (Figure 8) indicate that good and poor navigators did not significantly differ in their performance on this task. ($F(1, 36) = 3.29$, $p = 0.078$, $\eta^2_{partial} = 0.083$). No significant sex differences on this task were found ($F(1, 36) = 0.03$, $p = 0.857$, $\eta^2_{partial} = 0.0009$) and there also was not a sex x ability interaction ($F(1, 36) = 0.03$, $p = 0.857$, $\eta^2_{partial} = 0.0009$).

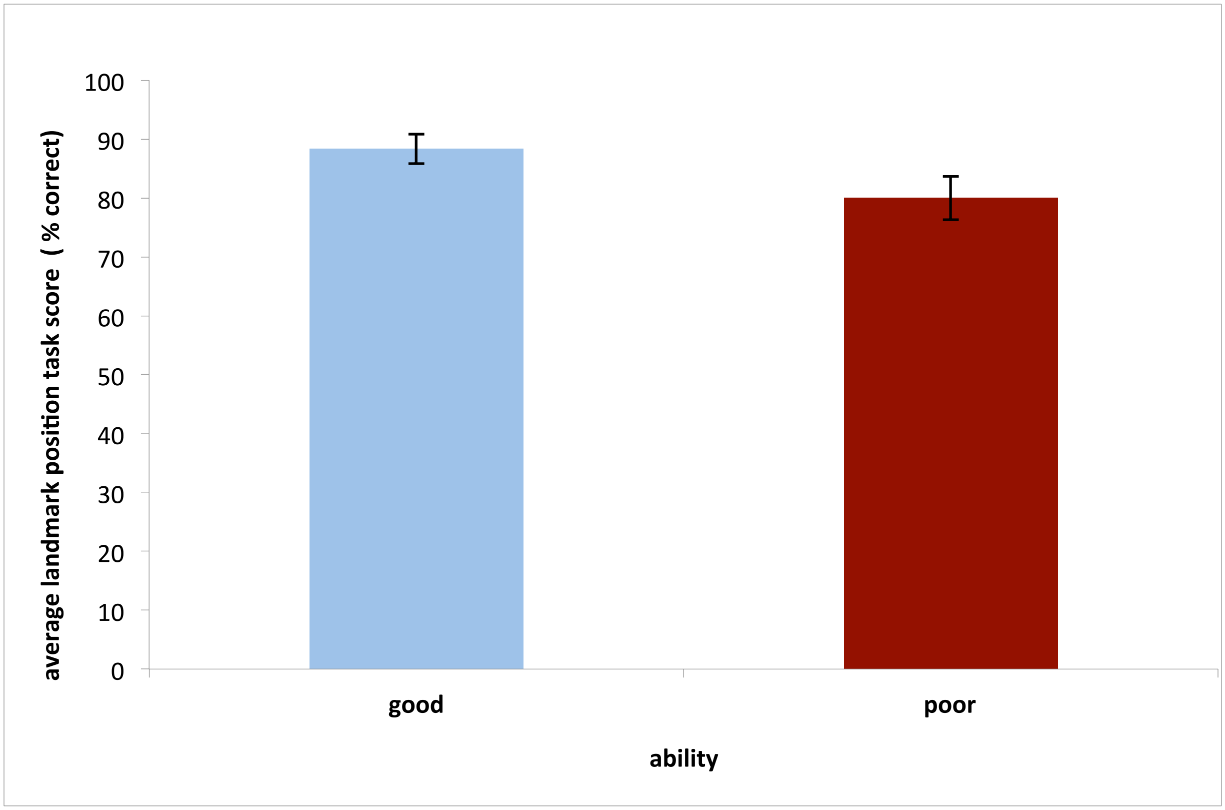


Figure 8: Average score on the landmark positioning task in good and poor navigators with standard error. A response was considered correct if the chosen location was within 2 cm of the actual landmark position on the map.

Map Drawing Task:

As illustrated in Figure 9, the findings from the map drawing task confirm that good navigators form more accurate cognitive maps than poor wayfinders ($F(1, 36) = 31.71$, $p < 0.001$, $\eta^2_{partial} = 0.468$). Performance on the map drawing task was quantified by the number of correct pathways drawn in the correct direction and angle relative to adjacent pathways. No significant sex differences on this task were found ($F(1, 36) = 0.81$, $p = 0.374$, $\eta^2_{partial} = 0.022$) and there also was not a sex x ability interaction ($F(1, 36) = 0.01$, $p = 0.941$, $\eta^2_{partial} = 0.0001$).

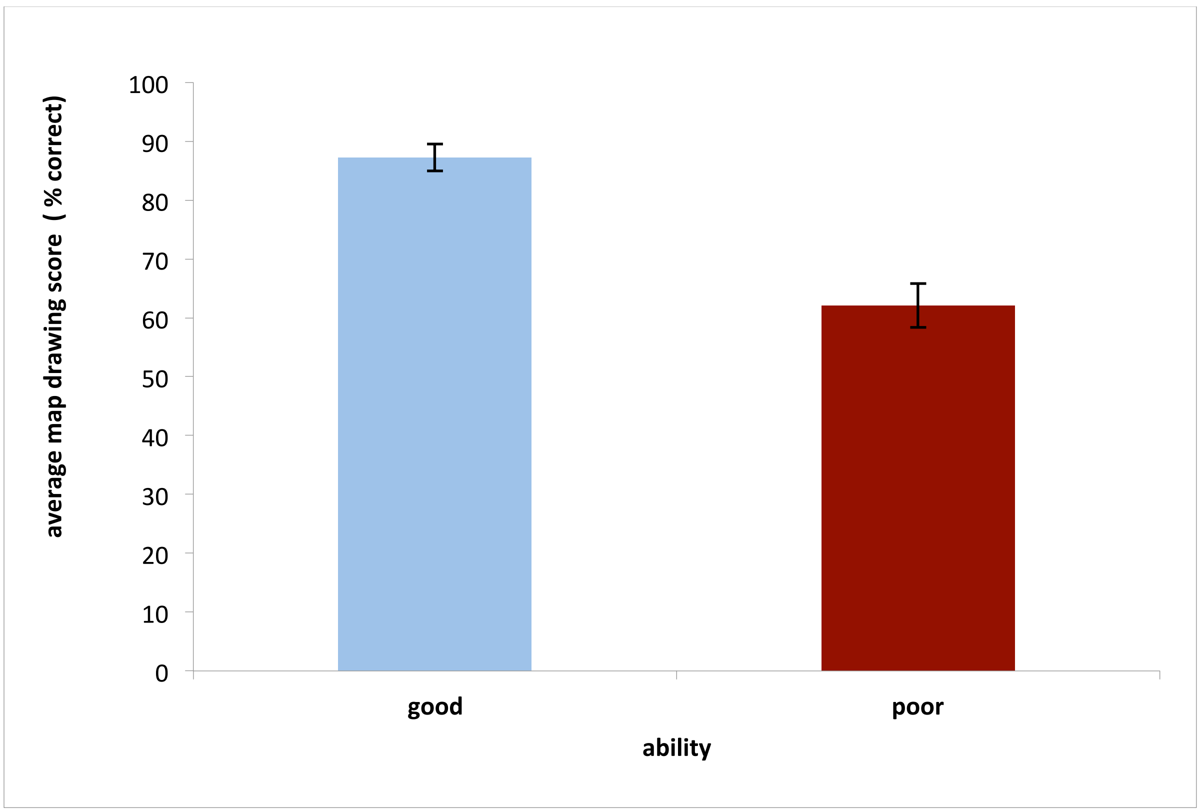


Figure 9: Average map drawing score in good and poor navigators with standard error.

Verbal Protocols:

Inter-rater reliability between the two raters was quite high ($r = 0.998$, $p < 0.001$). Poor navigators made significantly more uncertainty statements than good wayfinders (Figure 10: uncertainty: $F(1,36) = 47.80$, $p = 0.020$, $n^2_{partial} = 0.111$). No other differences between good and poor navigators were found in the other verbal categories (landmark: $F(1,36) = 23.51$, $p = 0.180$, $n^2_{partial} = 0.058$; direction: $F(1,36) = 22.01$, $p = 0.215$, $n^2_{partial} = 0.0547$; planning: $F(1,36) = 17.65$, $p = 0.340$, $n^2_{partial} = 0.044$; relationship: $F(1,36) = 14.22$, $p = 0.500$, $n^2_{partial} = 0.036$). These uncertainty statements demonstrate poor navigators low self-confidence in their navigational abilities and insufficient knowledge of the route.

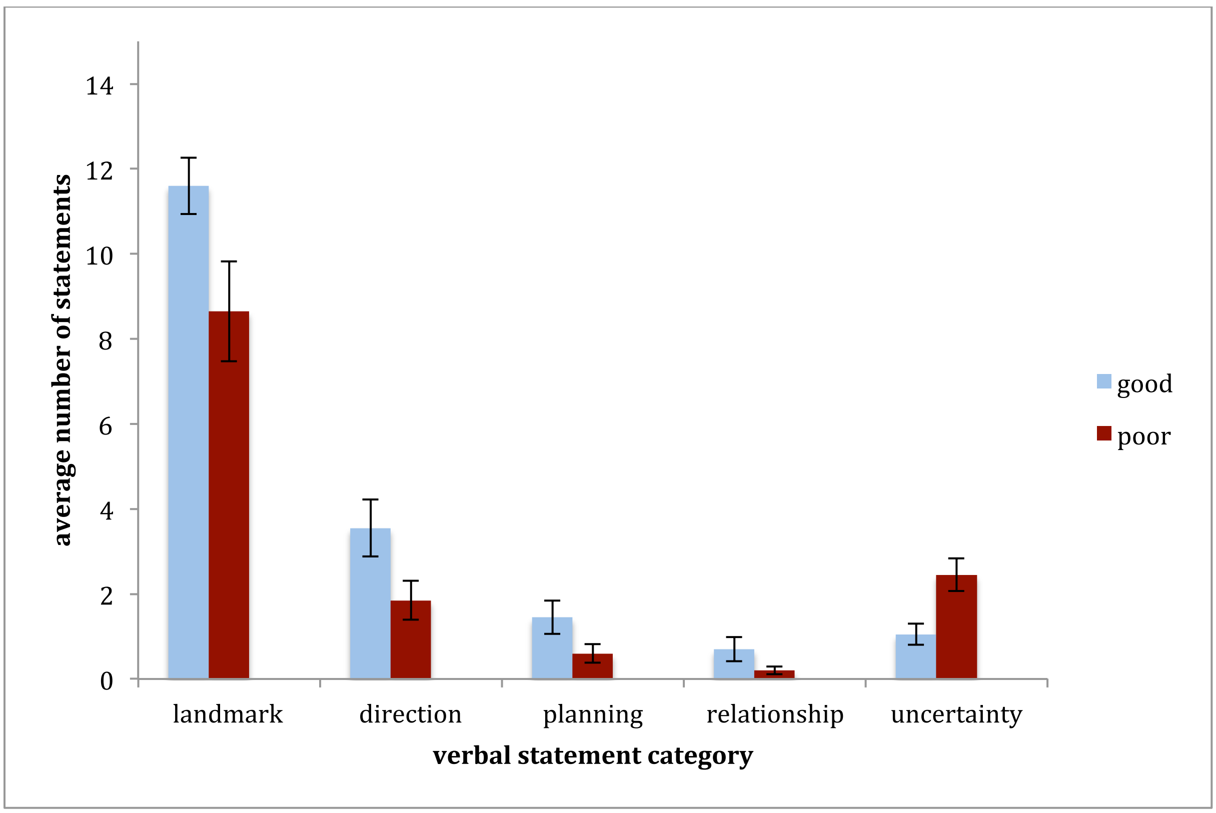


Figure 10: Average number of verbal statements in each category by good and poor wayfinders with standard error.

Cognitive strategies may not have been verbalized which may account for the lack of significant differences in some verbal statement categories. If an individual fails to make a verbal statement it may be that they are thinking, but just not verbalizing their thoughts. A disadvantage of verbal protocols is that certain individuals may be more talkative than others and may verbalize their thoughts more. In order to determine whether this may have had an influence, the number of verbal statements in each group was determined to examine if good and poor navigators made a significantly different number of total verbal statements. The total number of verbal statements made by good and poor navigators was not significantly different ($F(1, 36) = 0.01$, $p = 0.92$). These results indicate that the differences in verbal statements made were not due to the fact that good and poor wayfinders differed in how talkative they were.

Spatial Relationship Task:

As illustrated in Figure 11, good navigators also outperformed poor navigators at the landmark relationship task ($F(1, 36) = 51.78$, $p < 0.001$, $\eta^2_{partial} = 0.589$). No significant sex differences on this task were found ($F(1, 36) = 0.73$, $p = 0.399$, $\eta^2_{partial} = 0.019$) and there also was not a sex x ability interaction ($F(1, 36) = 0.134$, $p = 0.717$, $\eta^2_{partial} = 0.004$). These results suggest that participants with a good sense of direction are skilled at recalling several landmarks and use these objects effectively as landmarks for organizing successive environmental experiences into an overall configuration. Participants with a poor sense of direction appear to have difficulty in this area which may partly account for the greater number of route errors in this group.

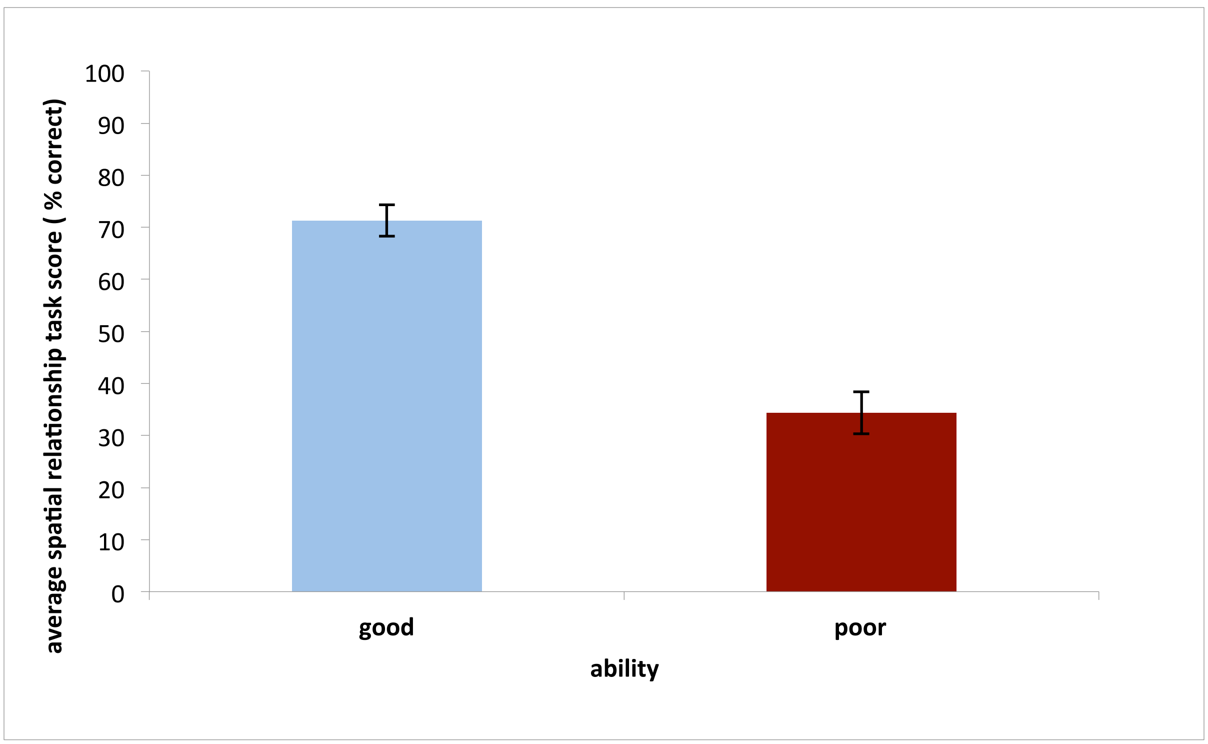


Figure 11: Average score on the spatial relationship task in good and poor navigators with standard error.

Path Pattern Recognition Task:

Participants indicated that the paths were similar because they were 1) the same but reversed, 2) both paths formed a square shape, or 3) they had similar landmarks. Alternatively, participants could indicate that there were no similarities between the paths. The results shown in Figure 12 indicate that good navigators are not better than poor navigators at integrating spatial information by keeping track of spatial patterns. No significant differences were found between good and poor navigators in their responses (reversed: $X^2 = 10.4$, df = 1, p = 0.40; square: $X^2 = 0.36$, df = 1, p = 3.04; landmark: $X^2 = 22.5$, df = 1, p = 0.12; none: $X^2 = 1.6$, df = 1, p = 2.12).

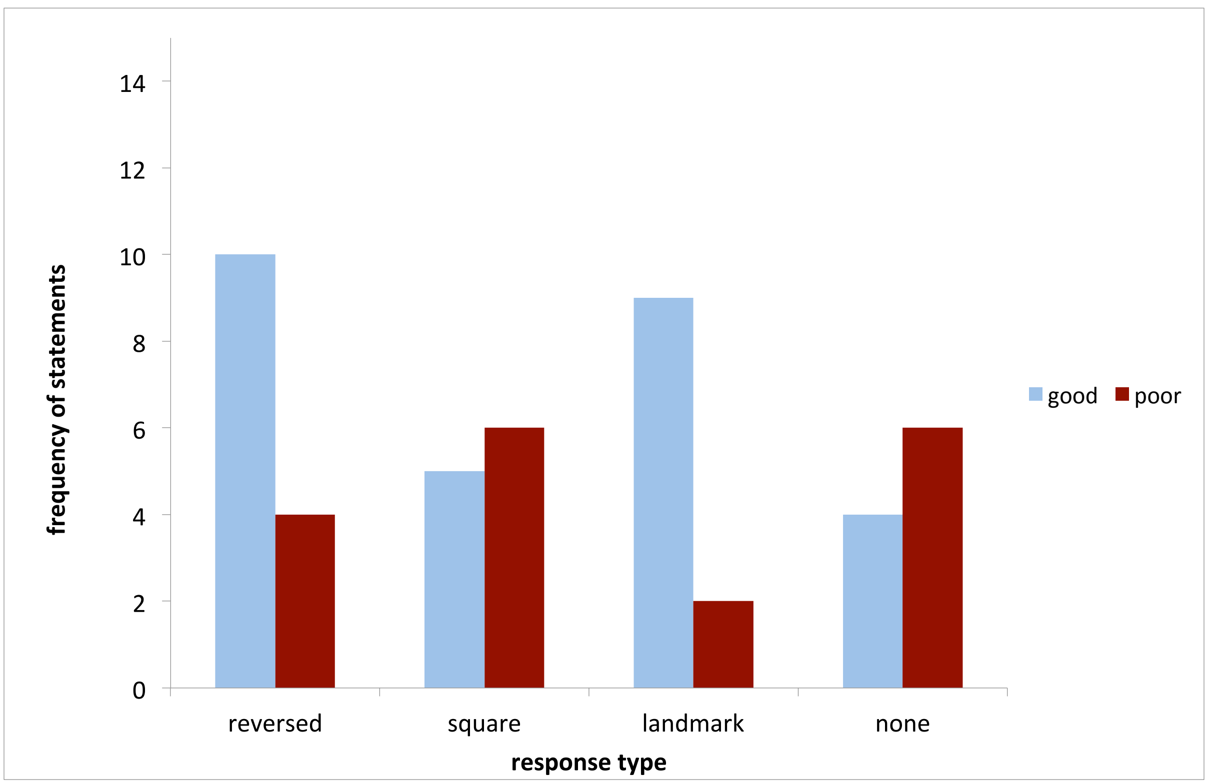


Figure 12: Frequency of statements in each type of response category on the path pattern recognition task.

A Discriminant Function Analysis was performed to determine whether any navigational tests in which significant differences were found could predict if individuals fall into a good or poor sense of direction group. Alpha levels were adjusted downward for multiple comparisons to ensure that the alpha level remains at 0.05. A discriminant analysis was used instead of a regression since the dependent variables (good vs. poor navigators) are categorical variables rater than continuous variables, which are required in a regression. The discriminant analysis was also used since it is a useful way of determining group category based on several independent variables. A stepwise procedure in SPSS (version 20) was used for entering the data in the discriminant analysis, which involves first selecting variables with the largest value of acceptance criteria. The discriminant analysis suggests the following predictive equation: $E = 0.732a + 0.576b + 0.222c + 0.067d$ (a = spatial relationship task score, b = map drawing score c = landmark recognition score, d = directional task score). The values indicate the relative importance of each factor. As illustrated, performance on the spatial relationship questionnaire was the most effective variable at discriminating between good and poor navigators.

Correlations between wayfinding performance and the various spatial tasks were also examined. The results indicate that there were individual differences between the groups. Wayfinding performance of good navigators was not significantly correlated with any of the spatial tasks (map drawing task: $r = -0.272$, $p = 0.221$; landmark recognition task: $r = 0.021$, $p = 0.926$; landmark positioning task: $r = -0.345$, $p = 0.116$; directional information task: $r = -0.285$, $p = 0.198$; spatial relationship task: $r = -0.017$, $p = 0.941$). Poor navigators differed from good navigators, and various significant correlations between wayfinding performance and several tasks were found. Significant correlations in poor wayfinders were found between wayfinding performance and the landmark recognition task ($r = 0.422$, $p = 0.064$), as well as in the landmark positioning task (r = 0.581, p = 0.007). Significant correlations were not found in the remaining tasks in poor navigators (map drawing task: r = -0.320, p = 0.169; directional information task (r= -0.375, p = 0.103; spatial relationship task: r = -0.075, p = 0.754). These results suggest that the ability to recognize landmarks and its position is associated with wayfinding performance in poor navigators, but not in good wayfinders.

**Discussion:**

Dividing participants into a good and poor sense of direction group gives an idea of the magnitude of performance effects. Selecting participants at least 1 standard deviations above and below the mean provided a suitable sample size and was an extreme enough criterion in selecting good and poor navigators. The results from this first experiment suggest that the lower and upper bounds chosen in this study were an accurate way of selecting good and poor navigators since good navigators performed better on most spatial tasks. It is unlikely that sampling participants using a more extreme criterion would have yielded different results since even with this selection good navigators outperformed poor wayfinders on several wayfinding abilities. Results from other studies also suggest that selecting participants 1 standard deviation above and below the mean is an extreme enough criterion. A study by Kato & Takeuchi (2003), also selected participants using this criterion, and found differences between good and poor navigators. According to Kato & Takeuchi (2003), good navigators show much better performance on route learning tasks compared to poor wayfinders.

The results from this study suggest that within the group of good wayfinders these spatial questionnaires do not account for variance in wayfinding ability. These findings also indicate that in poor wayfinders, the poorer the performance on these abilities the worse individuals are at navigating. Good wayfinders appear to be more skilled at recognizing the way landmarks look, and keeping track of the direction turned from them. These are important skills since simply recognizing a landmark is not sufficient for using it as a reference point, directional information is required to orient effectively while navigating. Good wayfinders accurate drawings of the paths also illustrate their accurate cognitive maps. Results from the spatial relationship task suggest that good wayfinders are also better at determining spatial relationships between landmarks.

A key finding from this study suggests that despite good wayfinders being more skilled at a wide range of navigational abilities, the ability to form spatial relationships between landmarks appears to be the strongest predictor of navigational ability. These results are unlikely to be attributed to the fact that poor navigators were bad subjects with low intelligence. Previous research suggests that there does not appear to be a significant association between wayfinding performance and intelligence. A study by Juan-Espinosa, Abad, Colom, & Fernandez-Truchaud, (2000) examined the relationship between intelligence and general processes in wayfinding (updating position, survey representation and route representation). The results suggest that wayfinding performance is not influenced by intelligence (Juan-Espinosa, 2000).

This study provides a greater understanding of how good and poor wayfinders navigate in 3D large-scale environments. One limitation of most controlled studies that have been conducted on wayfinding performance is that they have limited themselves to navigation in the horizontal plane on an isolated floor. Vertical travel can disturb spatial cognition and can often result in disorientation. Navigators often assume that different levels in a building have identical topology, which can lead to wayfinding impairments. It can also be difficult for wayfinders to properly align vertical spaces. There have only been a few studies to date that have examined wayfinding in 3-dimensional large-scale environments (Holscher et al., 2006).

The results from this study also replicate and extend research establishing the validity of self-ratings of sense of direction. Self-ratings of sense of direction were related to several different measures of route learning and wayfinding. The findings of this study suggest that a simple and inexpensive administration of the Santa Barbara Sense of Direction Scale can be used to accurately predict wayfinding performance (Cornell et al., 2003).

The results from this study can be used to assist with the design of training programs to boost wayfinding performance of poor wayfinders. Observations of hunter-gatherer cultures suggest that novice navigators are often instructed to look back when experienced travelers show them a route leading away from an important location. Pathfinders also look back in order to become more familiar with the locations and perspective of landmarks they encounter once they return along a route. Interesting experimental studies of modern urban children and adults that were trained on using this look-back strategy used by hunter-gatherers cultures have been conducted. The results indicate they were less likely to make errors at intersections when reversing a novel route than the group not trained (Cornell et al., 2003). The results of these studies suggest that poor wayfinders can be trained to navigate effectively and consequently the results of this study can be used to design appropriate training programs. Poor navigators should be trained to learn the relative locations of objects and paths rather than their absolute positions.

The current study provides a greater understanding of navigating and spatial learning in naturalistic environments. It is evident that further research is required to confirm the interpretation of the results described. For example, an important factor that may have influenced the results is the amount of information provided to participants before navigating through the environment. In the present study, participants were not given any prior information about the routes through which they had to navigate. In contrast, if participants were initially given some information about the routes they were to take, they may have employed different strategies (cognitive map versus route based strategies) to optimize their performance.

## Study 2: Examination of distance and angular information in the assessment of landmark configurations

**Introduction:**

Landmarks are an important part of an individual's cognitive map. Good navigation depends on developing an understanding of the environment and planning routes to locations that are not in an individual's immediate surrounding. The use of landmarks is imperative when navigating through environments. Landmarks are distinctive features in an environment that provide a wayfinder with a way of locating themselves and forming goals. According to Heft et al. (1979), there are two main ways landmarks can be used when navigating. Landmarks are memorable cues that are selected usually for recalling and remembering turns along a path. Landmarks also facilitate encoding of spatial relationships between paths and objects, which aid the formation of cognitive maps. In various types of environments, landmarks provide essential information about the relationship of objects, locations and paths. As illustrated landmarks provide vital navigational information and consequently a greater understanding of the use of landmarks can facilitate urban planners in designing appropriate environments (Heft, 1979).

Various spatial tasks require people to use landmarks to form a memory of their location (place memory) (Waller et al., 2002). A common place finding mechanism involves encoding entire arrays of landmarks as a configuration and to learn a location relative to this configuration (MacDonald et al., 2004). For example, an individual may establish a memory of a particular location by learning spatial relationships of several nearby landmarks (MacDonald et al., 2004). A location (cross in Figure 13 below) can be remembered in terms of its distance (Figure 13: d1,d2, d3) to nearby landmarks or by the relative angles (Figure 13: $\alpha1$, $\alpha2$ and $\alpha3$) in which those landmarks are positioned, or both (Waller et al., 2002). The focus of this study was to gain a greater understanding of the degree to which directional and angular information are used by good and poor navigators in determining spatial relationships between landmarks.

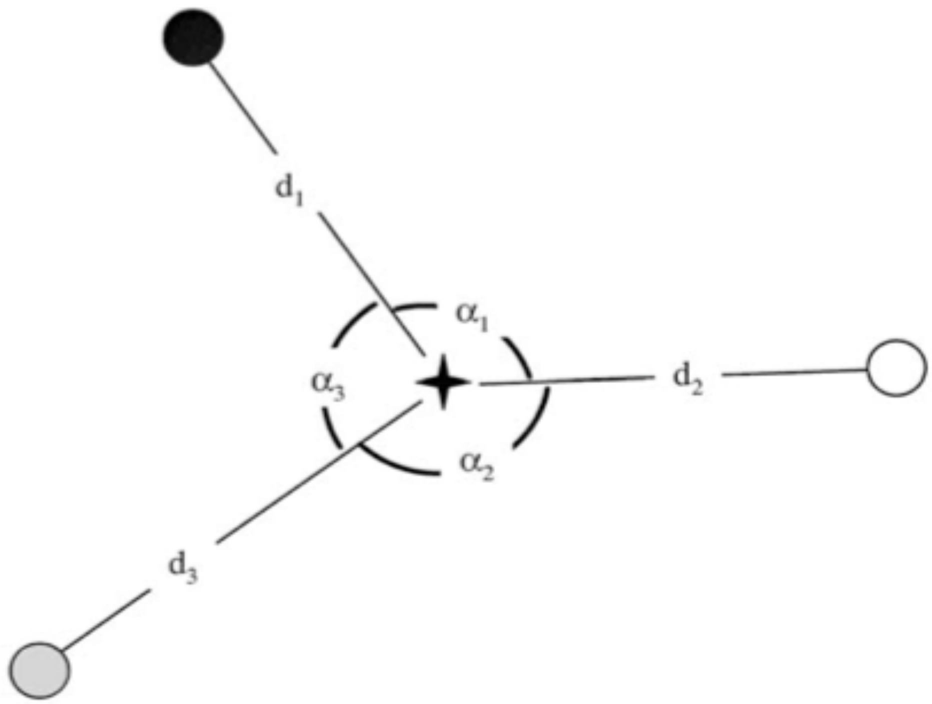


Figure 13: Target location (cross) determined by relative distances (d1, d2, d3) or relative angles (α1, α2 and α3).

The examination of place learning and landmark-based wayfinding in animals has been examined extensively. Cartwright and Collett (1983), trained bees to locate a food source that was posited at a particular distance and direction from an array of 3 landmarks. They then contracted and expanded the array. The bees searched closer to landmarks when the array was contracted and further away when the array was expanded, thereby maintaining the same compass direction from the landmarks. These results suggest that bees primarily use angular differences rather than distances between targets and landmarks (Cartwright & Collett, 1983).

This evidence suggests that animals can use distance information of landmarks, but it is of secondary importance and is only used when other information is ambiguous.

In humans however, it appears that distance information is more essential in place learning. Individuals often take distance information into consideration when learning locations. In an experiment by Spetch et al., (1997), participants were required to locate objects in a large grassy field that had been hidden in the center of an array consisting of 4 landmarks. In the learning phase this array of landmarks formed a square. The array was then altered after learning the location of the object and the array was expanded into an elongated rectangle. Rather than searching for the objects in locations that correspond to the absolute distances to the landmarks, people searched the center of the new rectangular array. Choosing the center of the array suggests that the relative distances rather than absolute distances from the landmarks were used by participants (Spetch et al., 1997).

Recently, several experiments (Bulthoff et al., 2008; Foo & Warren, 2007) have begun to examine place learning and landmark use, using virtual reality. These experiments have demonstrated that place leaning can occur in computer-simulated environments and this learning is similar to the principles of place learning that occur in animals. The development of virtual reality technology has allowed for a systematic and laboratory-based evaluation of navigational behaviour. A major advantage of virtual reality is that it allows an experimenter considerable control over visual features of an environment and allows route and landmarks to be perturbed (to assess the key features that participants use in wayfinding) – perturbations which would be difficult to effect in real world environments. A drawback of virtual reality is that it does not allow actual movement through space and consequently prevents participants from using kinesthetic, vestibular, and proprioceptive cues. Virtual reality only allows the assessment of navigational abilities that are visually based and does not allow input from other sensory systems. Despite the limitation of this technology, studies have shown that spatial knowledge acquired in virtual reality transfers well to real world environments (Moffat et al, 2001). Virtual reality studies on landmarks have been conducted to examine mental rotation and the ability to form cognitive maps (Bulthoff et. al, 2008; Foo & Warren, 2007). According to Bulthoff et al., (2008), cognitive costs of mental rotations are reduced when the viewpoint changes are caused from the observer's motion rather than the spatial layout or objects location. Foo & Warren (2007), conducted a virtual reality study examining the ability to form metric cognitive maps from path integration using landmarks. The results indicate wayfinders take novel shortcuts based on visual landmarks whenever they are available and reliable.

A study by Waller et al. (2000), examined the degree to which spatial relationships between landmark distances and angles are used. In this experiment, participants learned several locations, each relative to a different configuration of 3 distinct landmarks. They were then tested in an altered configuration of these landmarks and asked to return to the original location. Alterations were made such that one location preserved relative distance information and another location preserved angular differences. The altered configuration allowed an assessment of whether there was a preference for using relative distances or angles. The results indicate that relative distances between landmarks are used more than angular information.

Results from the first study demonstrated that good navigators were better at determining spatial relationships between landmarks, but it did not address whether this was due to the distances between landmarks and/or the angles between these landmarks. It is currently not known whether good navigators are better at assessing distances, angles, or both. It may well be that if one feature is particularly effective, good navigators may selectively focus on this particular feature and ignore the less effective metric.

Although distance information can provide useful information, angular information may be even more useful in certain circumstances. When 2 landmarks are separated by 180-degrees from a target location, encoding a line may be easier to encode in memory than distances. Individuals often determine their location by locating landmarks that are collinear with each other. Landmarks that are arranged linearly appear to be easily encoded and used (Franklin & Tversky, 1990). According to Franklin & Tversky, (1990), 90-degree angles are extremely well learned and are represented by the body's axes and thus easier to remember (Franklin & Tversky, 1990).

The current study manipulated the saliency of configurations that contain right angles and straight lines by altering the orthogonality of a learning configuration. Orthogonality in the current experiment was defined as the number of angle differences between adjacent landmarks that form a right or straight angle. We proposed that the orthogonality of a learning configuration may bias participants to either engage or avoid an angular based strategy. It was predicted that greater orthogonal angles would result in a preference for an angular strategy since they are easier to remember.

Good and poor navigators may also differ in their ability to determine spatial relationships because they focus on distance and angular information in different contexts. Previous studies have shown that individuals tend to use distance information when a target location is surrounded by 3 landmarks (Waller et al., 2003). This may not be the best approach in configurations with a greater number of surrounding landmarks. A large number of landmarks may make it difficult to remember several distances and perhaps keeping track of a configuration of angles may be a more efficient approach since it can be visualized easily. This study will also examine whether the number of landmarks surrounding a target location may influence the degree to which distance and angular information are preferred in good and poor navigators. In the present study the number of landmarks surrounding the target consisted of 3, 4, or 5 landmarks. Participants were then tested in an altered configuration in which one location preserved relative distances and the other angular differences. A preference for a location that preserves distance or directional information would provide an indication of the type of strategy preferred in good and poor navigators. This study also provided a greater understanding of the degree to which orthogonality may influence this preference in good and poor navigators.

**Method and Materials:**

Participants:

Participants were selected from a group of undergraduate psychology students from the University of Waterloo. 56 subjects participated in the study and they consisted of 28 females and 28 males with an average age of 20.19 (SD 0.98). Subjects were given a participation course credit for taking part in the study. Subjects were selected based on their performance on the Santa Barbara Sense of Direction Scale. Participants who scored at least one standard deviation above the mean of 1449 students were part of the good sense of direction group and those who scored one standard deviation below the mean as part of the poor sense of direction group. A double-blind procedure was also used for this study and the experimenter was not aware if the participant was part of the good or poor sense of direction group.

Apparatus:

Nine experimental stimuli were used along with nine control environments. Each stimulus consisted of a pair of configurations: a learning phase which consisted of a target location surrounded by 3, 4, or 5 landmarks, and an altered testing configuration that only contained the surrounding landmarks with the target removed. The diagram below (Figure 14), illustrates the environmental set up:

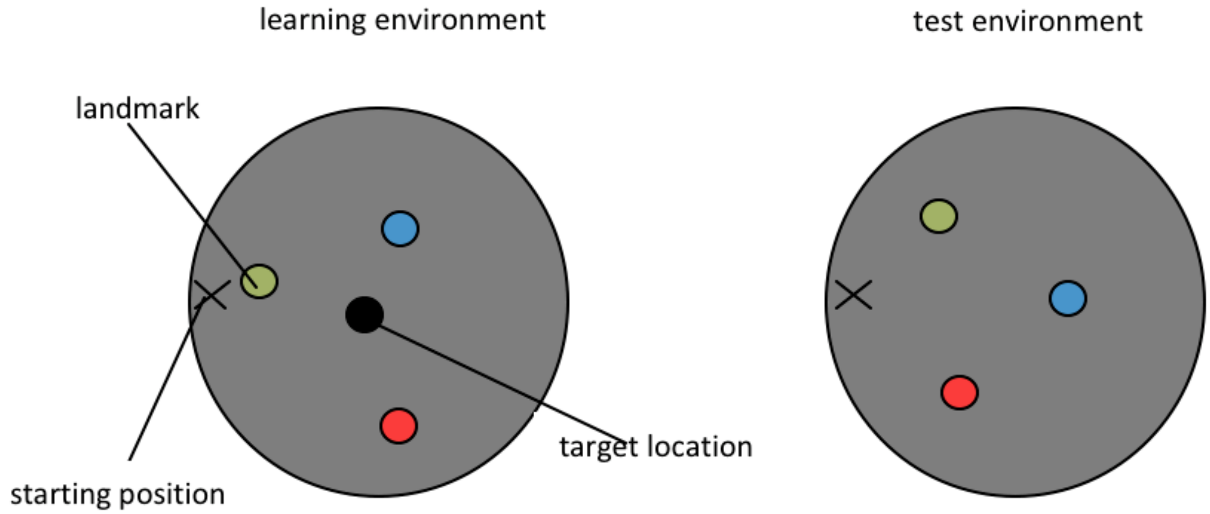


Figure 14: Learning and testing environments.

The testing configuration was altered so that one location preserved distance relationships and the other angular differences. In other words, at one particular location (D) in the testing configuration, the distances to the surrounding landmarks were the same as the distances from the target location to the surrounding landmarks in the learning configuration. Another location (A) preserved the same angular differences between the landmarks in the learning configuration.

Orthogonality and the number of surrounding landmarks were varied in the trials. Orthogonality was determined by the number of 90 or 180-degree angles. The learning configurations contained either 0, 1 or 3, 90 or 180-degree angles. The diagram below illustrates the number of orthogonal angles in each testing environment (Figure 15: 0 orthogonal angles; 1 orthogonal angle; 3 orthogonal angles).

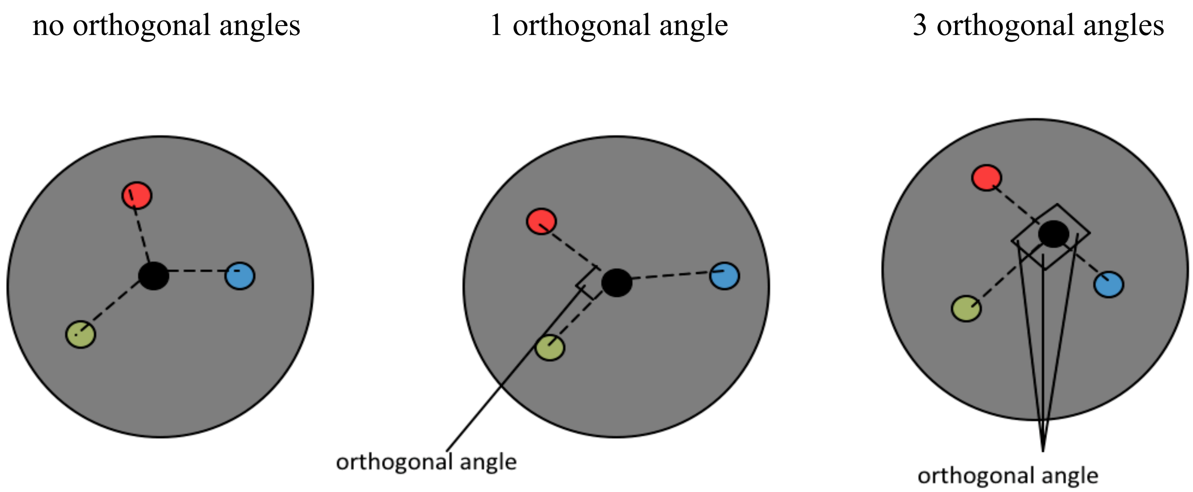

Figure 15: Configurations with 0, 1 and 3 orthogonal angles. The black pole represents the target location.

The number of landmarks surrounding the target was also manipulated so that each configuration consisted of 3, 4, or 5 landmarks. Nine additional control trials were used as foils and were not expanded or contracted. The control configurations were only rotated from the center of the landmark configuration. These control trials were blended with the experimental trials to reduce the likelihood that participants realize that the learning and testing configurations differed from the expansions and contractions. Figure 16, illustrates the environmental setup.

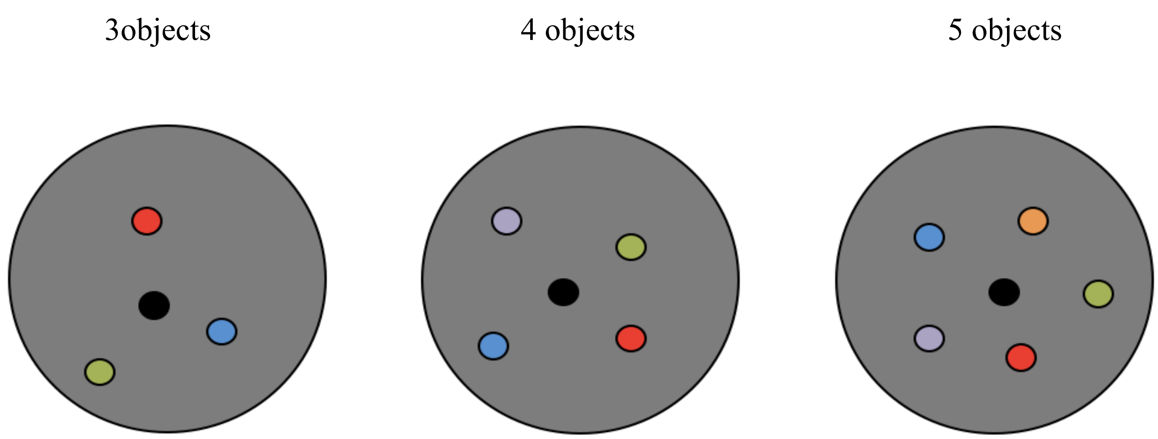

Figure 16: Configurations with 3, 4 and 5 surrounding landmarks. The black pole represents the target location.

The surrounding landmarks consisted of 3D cylinders (0.12 meter radius, 1.82 height) with 5 different colours (red, blue, green, orange and purple). The target location was marked using a black cylinder of the same dimensions as the surrounding landmarks. The environment consisted of a circular arena (2.5 meters in diameter) with a grey floor in order to create sufficient contrast between the landmarks and target pole. The ground and sky did not contain any patterns that could provide any location or directional information to participants. An immersive virtual environment was created using Google SketchUp 7.1 software. This program was exported to Vizard software. An optical tracker was used to monitor orientation and head position. Orientation and head position were sampled every 15 milliseconds. Participants interacted with the virtual environment using a nVIS head mounted display (HMD). The HMD had a 44 degree horizontal/35 degree vertical field-of-view. It had a video resolution of 1280 x 1024 pixels and a 60 Hz image refresh rate. The presentation of stimuli and the recording of positional and orientation information of participants were controlled using a Python programming script.

**Method:**

The experiment consisted of 18 trials (9 control and 9 experimental), which were comprised of a learning and a testing phase (36 total environments). Landmark configurations in the testing trials of the experimental conditions were rotated (30 or 50 degrees) from the center of the arena to ensure that the landmarks are placed in different positions from the learning trial. Table 1 indicates degree rotations in all the testing trials.

Table 1: Landmark configuration degreed rotations in each of the 18 experimental trials (A) and control trials (B).

A (Experimental Trials):

| # of orthogonal angles | # of surrounding landmarks | | |
|---|---|---|---|
| | 3 objects | 4 objects | 5 objects |
| **0 ∠** | 30 | 30 | 30 |
| **1 ∠** | 30 | 30 | 30 |
| **3 ∠** | 30 | 30 | 30 |

| # of orthogonal angles | # of surrounding landmarks | | |
|---|---|---|---|
| | 3 objects | 4 objects | 5 objects |
| **0 ∠** | 50 | 50 | 50 |
| **1 ∠** | 50 | 50 | 50 |
| **3 ∠** | 50 | 50 | 50 |

B (Control Trials):

| # of orthogonal angles | # of surrounding landmarks | | |
|---|---|---|---|
| | 3 objects | 4 objects | 5 objects |
| **0 ∠** | 30 | 30 | 30 |
| **1 ∠** | 30 | 30 | 30 |
| **3 ∠** | 30 | 30 | 30 |

| # of orthogonal angles | # of surrounding landmarks | | |
|---|---|---|---|
| | 3 objects | 4 objects | 5 objects |
| **0 ∠** | 50 | 50 | 50 |
| **1 ∠** | 50 | 50 | 50 |
| **3 ∠** | 50 | 50 | 50 |

Each trial began with a learning environment followed by a testing phase in which participants were asked to determine the location they believed matched the target location in the learning trial. The order of the trials was randomized for each participant. The first two trials consisted of practice trials and data from them was not collected. Participants entered the environment from a fixed starting position in the physical room and walked directly to the target. Participants moved in the virtual environment by walking with a head mounted display on. The headgear was attached to a computer by a cord, which prevented participants from walking into walls.

In the testing phase participants also entered the environment from a fixed starting position and were asked to determine the missing target location. Participants began each trial from a fixed starting position in the physical room and the virtual environment was rotated. Participants were told that they were viewing the learning configuration from a different viewpoint. In the control trials, the configuration of the test environment was only rotated and in the experimental trials they were rotated and altered. Rotating the configuration ensures that surrounding landmarks are not in the same positions as the learning condition, forcing participants to use target-to-landmark(s) relationships to complete the task (Waller et al., 2002). An equal number of landmark configurations were rotated clockwise and anticlockwise. Participants were asked to say the word "target" when they believed they had reached the missing target location. This target position was then recorded by the experimenter. At the end of the experiment, participants completed a simulator sickness questionnaire and they were asked if they noticed anything different about the learning and testing configurations (Appendix H).

The dependent variable in this study was determined using an approach by Waller et al. 2002. A preference for the distance location (PD) was defined as (DX – AX)/ DA. DX is the difference between the distance from X (chosen target location) to D (location that preserves distance relationships) and AX the distance from X to A (location that preserves angular differences). DA represents the distance between X (chosen target location) and A (location that preserves angular differences). The dependent variable (PD) can range from – 1 to 1. Positive values indicate an estimation of the target location closer to A and negative values an estimation closer to D. PD scores were compared to 0 (which indices no preference for either angles or distances) using a t-test in both groups.

**Results and Discussion:**

The results indicate that there were no significant differences in PD scores between good and poor wayfinders ($t(54) = 0.32$, $p = 0.75$) (Figure 17). Significant differences of PD scores from zero were tested in the analysis in good and poor wayfinders to determine if each group used a certain strategy. A score of zero indicates an equal preference for the distance and angular location. The results indicate that both good and poor navigators PD scores significantly differed from 0 in the negative direction, indicating a preference for a distance strategy in both groups (good: $t(27) = -4.31$, $p = 0$; poor: $t(27) = -3.90$, $p = 0.01$).

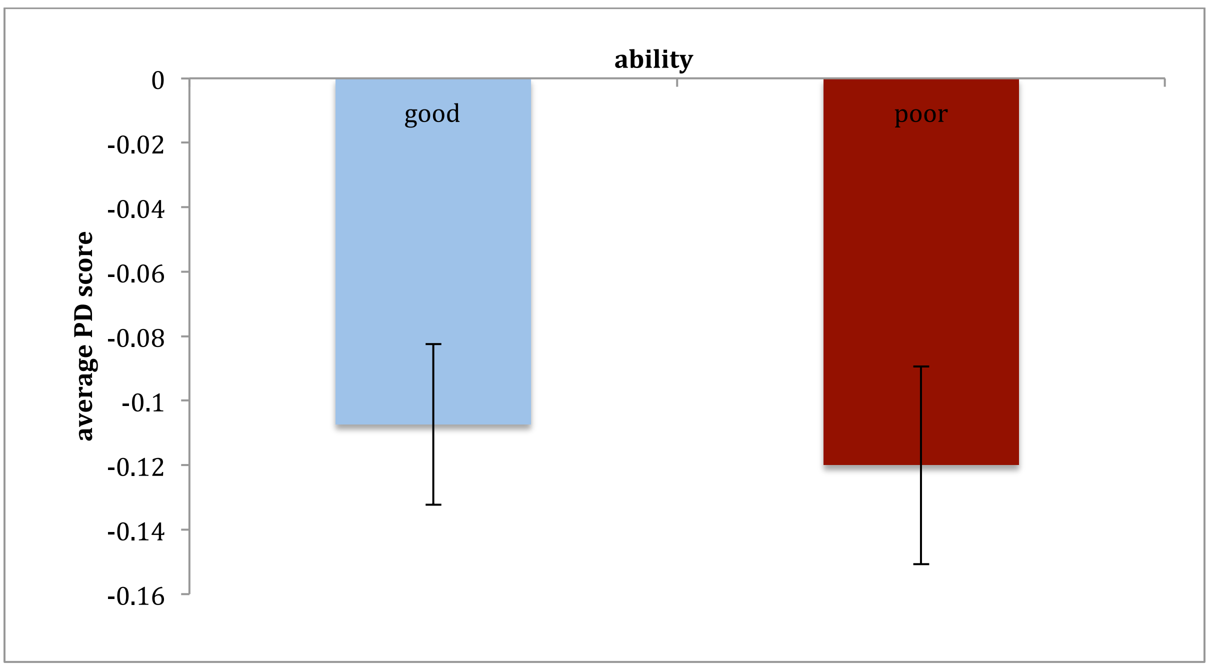


Figure 17: PD scores in good and poor navigators. The dependent variable (PD) can range from – 1 to 1. Positive values indicate an estimation of the target location closer to A and negative values an estimation closer to D. PD scores were compared to 0 (which indices no preference for either angles or distances). Error bars represent standard errors of the mean.

A repeated measures ANOVA was conducted do determine whether there was an effect of navigational ability (good vs. poor), number of objects (3, 4, or 5 objects), and orthogonal angles (0,1,3) on PD scores in the experimental trials. The results indicate an object x angle interaction ($F(4, 49) = 5.80$, $p < 0.001$, $\eta^2_{partial} = 0.100$), as illustrated in Figure 18 below.

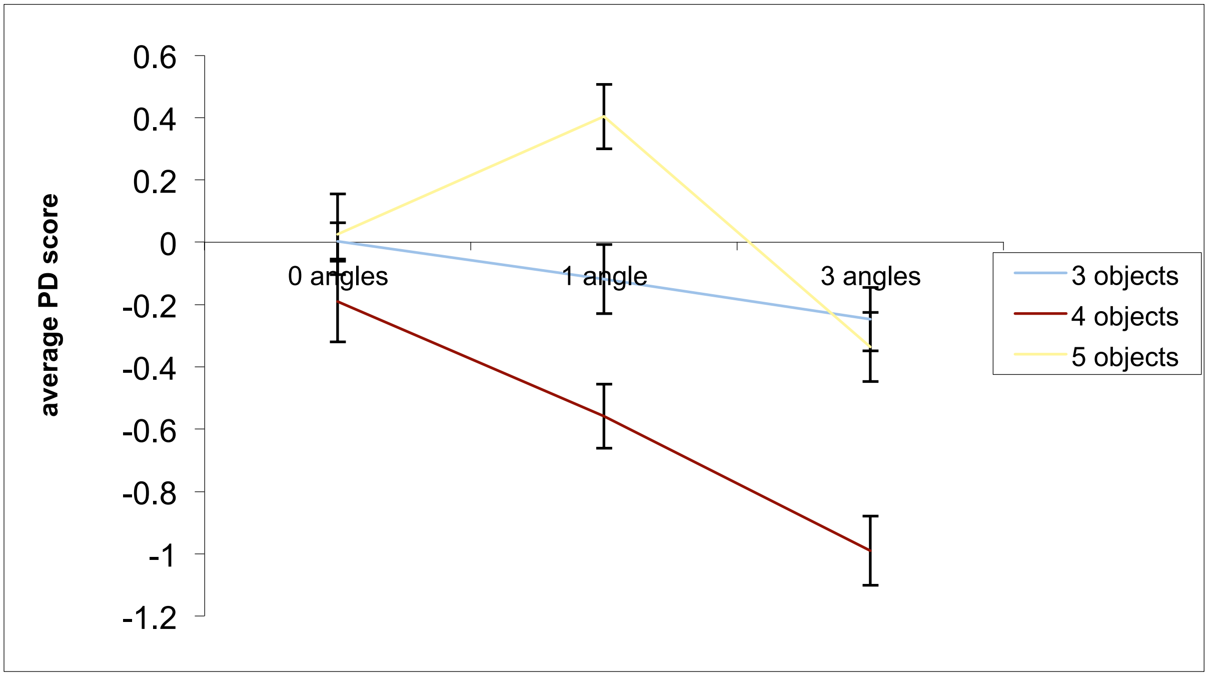


Figure 18: Average PD scores in configurations with 3, 4 and 5 objects and each of the orthogonal angles (0,1,3) with standard error.

The interaction suggests that in configuration with 3 objects, there was not a difference in strategy preference across the different angles (3 objects (0 vs. 1 angle: $F(1, 55) = 0.89$, $p = 0.351$, $\eta^2_{partial} = 0.016$; 1 vs. 3 angles: $F(1, 55) = 0.97$, $p = 0.329$, $\eta^2_{partial} = 0.017$; 3 vs. 0 angles: $F(1, 55) = 3.72$, $p = 0.099$, $\eta^2_{partial} = 0.063$). Strategy preference in configurations with 4 and 5 objects varied across different orthogonal angles (4 objects (0 vs. 1 angle: $F(1, 55) = 12.09$, $p = 0.001$, $\eta^2_{partial} = 0.180$; 1 vs. 3 angles: $F(1, 55) = 13.28$, $p = 0.001$, $\eta^2_{partial} = 0.194$; 3 vs. 0 angles:

$F(1, 55) = 35.79$, $p < 0.001$, $\eta^2_{partial} = 0.394$); 5 objects (0 vs. 1 angle: $F(1, 55) = 5.22$, $p = 0.026$, $\eta^2_{partial} = 0.086$; 1 vs. 3 angles: $F(1, 55) = 26.72$, $p < 0.001$, $\eta^2_{partial} = 0.327$; 3 vs. 0 angles: $F(1, 55) = 4.68$, $p = 0.035$, $\eta^2_{partial} = 0.078$).

No other effects or were found (number of objects: $F(2, 51) = 29.60$, $p < 0.001$, $\eta^2_{partial} = 0.362$; orthogonal angles: $F(2, 51) = 23.94$, $p < 0.001$, $\eta^2_{partial} = 0.315$; ability: $F(1, 52) = 0.09$, $p = 0.754$, $\eta^2_{partial} = 0.001$; sex: $F(1, 52) = 0$, $p = 0.99$, $\eta^2_{partial} = 1.344$; object x ability: $F(2, 51) = 2.12$, $p = 0.125$, $\eta^2_{partial} = 0.039$; object x sex: $F(2, 51) = 1.76$, $p = 0.18$, $\eta^2_{partial} = 0.032$; object x ability x sex: $F(2, 51) = 0.71$, $p = 0.495$, $\eta^2_{partial} = 0.013$; angle x ability: $F(2, 51) = 1.71$, $p = 0.19$, $\eta^2_{partial} = 0.031$; angle x sex: $F(1, 52) = 0.404$, $p = 0.67$, $\eta^2_{partial} = 0.007$; angle x ability x sex: $F(2, 51) = 3.30$, $p = 0.076$, $\eta^2_{partial} = 0.059$; object x angle x ability: $F(4, 49) = 1.04$, $p = 0.39$, $\eta^2_{partial} = 0.019$; object x angle x sex: $F(4, 49) = 1.43$, $p = 0.226$, $\eta^2_{partial} = 0.026$; object x angle x ability x sex: $F(4, 49) = 1.01$, $p = 0.401$, $\eta^2_{partial} = 0.019$).

According to Waller (2000), individuals use an angular strategy in configurations containing orthogonal angles; however the results from the current experiment differ (Waller, 2000). It was predicted that an increase in the number of orthogonal angles would result in a preference for an angular strategy as opposed to using distances, however the opposite was found. A distance strategy was preferred instead in configurations with more orthogonal angles. Differences between good and poor wayfinders were also not found. There may not have been an expected use of strategies because of the small environment. In this environment, the field was only 2.5 meters in diameter and consequently the locations that preserved distance and angular relationships were not very far apart. Expected differences in strategies may have also not been found because of the simple testing environment. These landmark configurations were fairly simple and only contained a few surrounding landmarks. Due to the simplicity of the environments, judging distances or angles can easily be determined. Previous research (Waller, 2000), and the current study suggest a distance strategy is preferred, and consequently there may not have been a switch to an angular strategy in configurations with more orthogonal angles because of the small scale of the environment in which distances can be easily judged.

Experiment 1 demonstrated that good wayfinders are better at determining spatial relationships among landmarks. It was initially hypothesized that good wayfinders may outperform poor wayfinders at this landmark task because they may rely on orthogonal angles in determining spatial relationships among landmarks; however this does not appear to be the case. Rather, it may well be that good wayfinders outperform poor navigators at determining spatial relationships due to a more accurate cognitive map (which was demonstrated by the accuracy in determining the target location), as opposed to using a more effective strategy of using orthogonal angles.

The control (non-altered) trials were examined to determine good and poor navigators performance at determining target locations. Participants may have chosen a target location because they prefer moving left or right. The data was also analyzed to determine if participants had a preference for turning in either direction. There does not appear to be any turning biases in the initial heading direction. An equal number of clockwise and counterclockwise turns in the initial heading direction were made ($X^2 = 1.75$, df = 1, p = 0.2). The results also indicate that good navigators were more accurate at determining the target location than poor wayfinders. For the control trials, a repeated measures ANOVA was also conducted to determine whether there was an effect of navigational ability (good vs. poor), number of objects (3, 4, or 5 objects), and orthogonal angles (0,1,3) on the error distance to the target location. The results indicate that there was an effect of ability ($F(1, 52) = 6.70$, $p = 0.012$, $\eta^2_{partial} = 0.114$), and an object x angle interaction was found ($F(4, 49) = 12.64$, $p < 0.001$, $\eta^2_{partial} = 0.273$).

The interaction (Figure 19) suggests that in configurations with 4 and 5 objects there is a decline in distance error to the target as the number of orthogonal angles increase (4 objects (0 vs. 1 angle: $F(1, 55) = 84.81$, $p < 0.001$, $\eta^2_{partial} = 0.606$; 1 vs. 3 angles: $F(1, 55) = 0.15$, $p = 0.696$, $\eta^2_{partial} = 0.027$; 3 vs. 0 angles: $F(1, 55) = 62.21$, $p < 0.001$, $\eta^2_{partial} = 0.530$); 5 objects (0 vs. 1 angle: $F(1, 55) = 2.44$, $p = 0. 123$, $\eta^2_{partial} = 0.043$; 1 vs. 3 angles: $F(1, 55) = 12.05$, $p = 0.001$, $\eta^2_{partial} = 0.179$; 3 vs. 0 angles: $F(1, 55) = 3.21$, $p = 0.079$, $\eta^2_{partial} = 0.055$). In configurations with 5 objects there is an increase (5 objects (0 vs. 1 angle: $F(1, 55) = 2.44$, $p = 0. 123$, $\eta^2_{partial} = 0.043$; 1 vs. 3 angles: $F(1, 55) = 12.05$, $p = 0.001$, $\eta^2_{partial} = 0.179$; 3 vs. 0 angles: $F(1, 55) = 3.21$, $p = 0.079$, $\eta^2_{partial} = 0.055$).

As demonstrated previously, there is a preference for an angular strategy in configuration with 5 objects compared to landmark arrays with 3 or 4 objects. It may be that using an angular strategy may not be as accurate, and may account for the increase in distance error as orthogonal angles increase

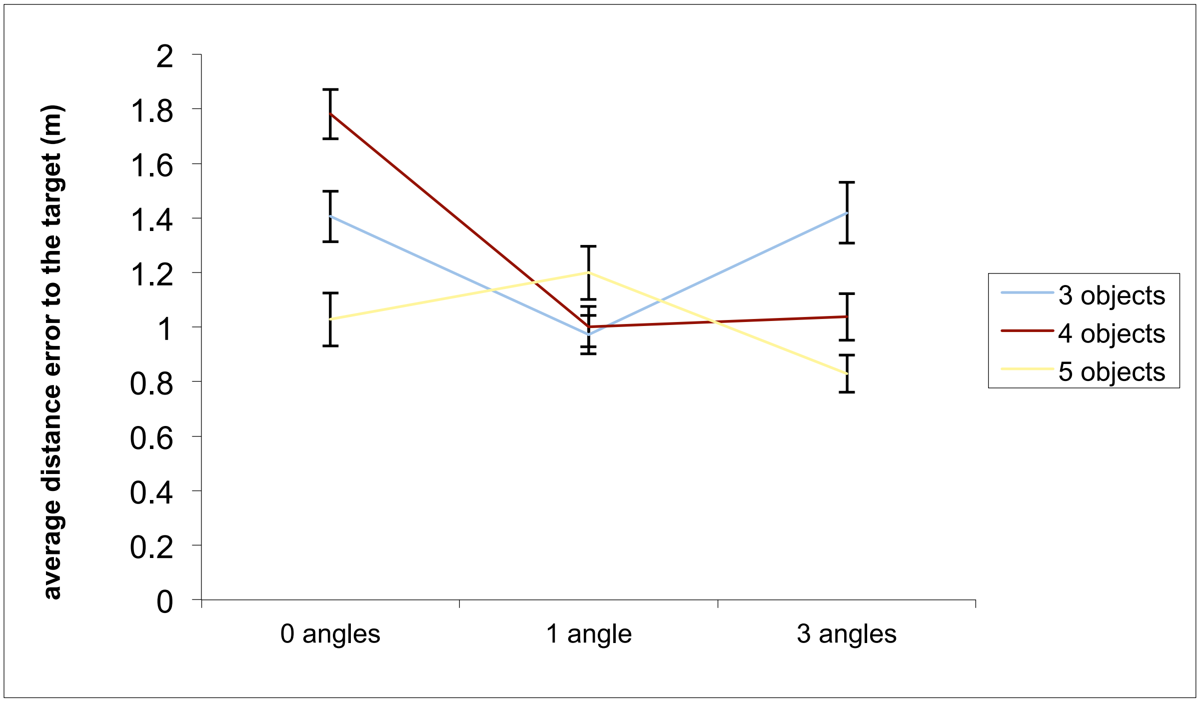


Figure 19: Average distance error in configurations with 3, 4 and 5 objects and each of the orthogonal angles (0,1,3) with standard error.

No other effects were found (number of objects ($F(2, 51) = 9.19$, $p < 0.001$, $\eta^2_{partial} = 0.151$); orthogonal angles ($F(2, 51) = 22.97$, $p < 0.001$, $\eta^2_{partial} = 0.309$); sex: $F(1, 52) = 2.01$, $p = 0.162$, $\eta^2_{partial} = 0.037$; object x ability: $F(2, 51) = 1.73$, $p = 0.183$, $\eta^2_{partial} = 0.032$; object x sex: $F(2, 51) = 1.41$, $p = 0.240$, $\eta^2_{partial} = 0.026$; object x ability x sex: $F(2, 51) = 0.19$, $p = 0.831$, $\eta^2_{partial} = 0.003$; angle x ability: $F(2, 51) = 1.67$, $p = 0.193$, $\eta^2_{partial} = 0.031$; angle x sex: $F(2, 51) = 0.79$, $p = 0.456$, $\eta^2_{partial} = 0.015$; angle x ability x sex: $F(2, 51) = 1.05$, $p = 0.309$, $\eta^2_{partial} = 0.020$;

object x angle x ability: $F(4, 49) = 1.66$, $p = 0.162$, $\eta^2_{partial} = 0.047$; object x angle x sex: $F(4, 49) = 1.55$, $p = 0.188$, $\eta^2_{partial} = 0.047$; object x angle x ability x sex: $F(4, 49) = 0.75$, $p = 0.558$, $\eta^2_{partial} = 0.021$)

As illustrated in Figure 20, good navigators were more accurate at determining the target location than poor wayfinders (ability: ($F(1, 52) = 6.70$, $p = 0.012$, $\eta^2_{partial} = 0.114$) . These results suggest good wayfinders are better at forming a cognitive map and determining spatial relationships between landmarks. The results from the first study indicate that poor navigators are not as skilled as good navigators at determining spatial relationships between landmarks on multiple floors. The results from this study indicate that poor wayfinders are also not as skilled at determining spatial relationships between landmarks at a smaller scale and on the same horizontal plane.

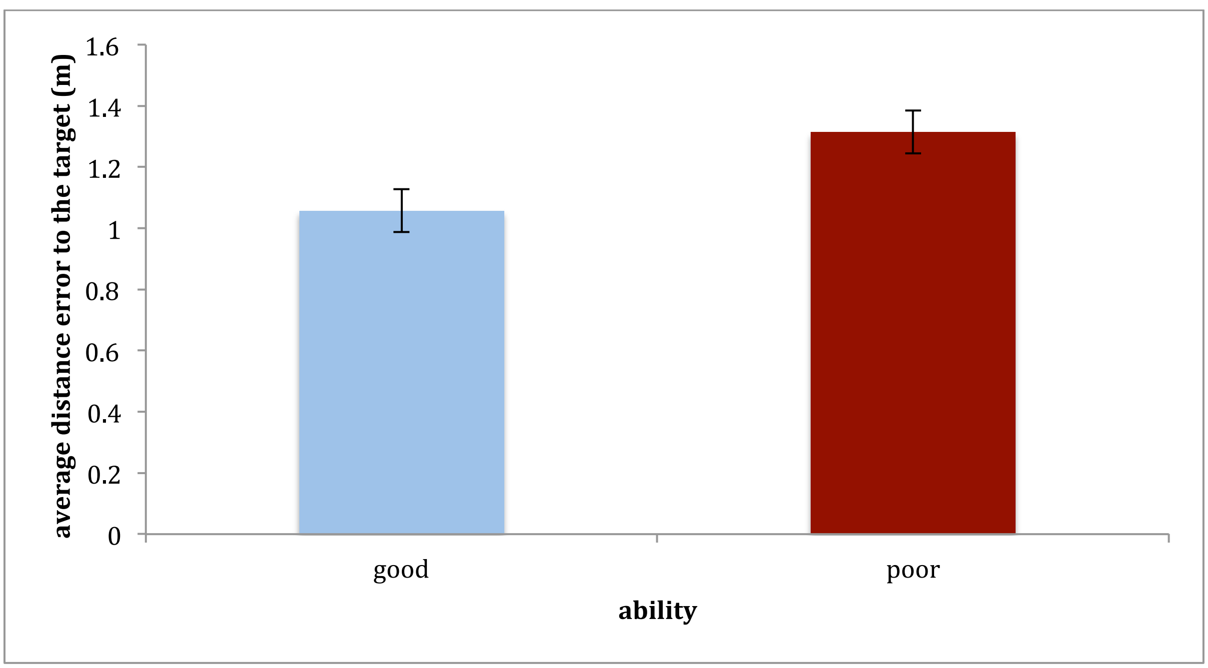


Figure 20: Average distance error (m) to the target location in good and poor wayfinders. Error bars represent standard error of the mean.

The diagrams below illustrate paths taken to reach the target (black pole) in good (Figure 21) and poor wayfinders (Figure 22) in a sample environment. As illustrated, the path taken by good wayfinders appears to be in the direction of the target location unlike in poor wayfinders.

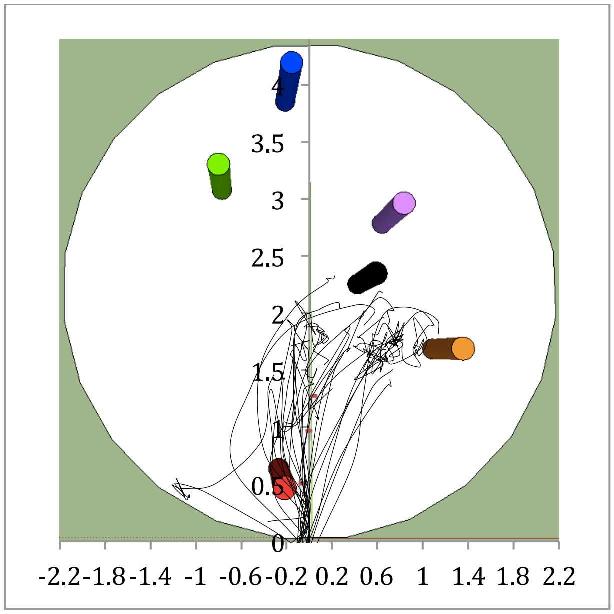


Figure 21: Path taken to reach the target (black pole) in good wayfinders.

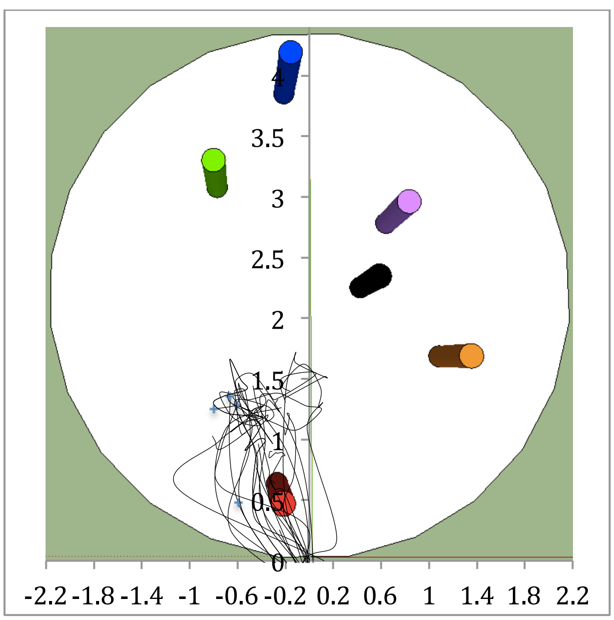


Figure 22: Path taken to reach the target (black pole) in poor wayfinders.

The standard deviation of the chosen target location was also determined to examine if there were any differences in variability between good and poor wayfinders. The data suggests that there were no significant differences in variability between good and poor wayfinders (Levene's test: $F(1,54) = 0.24$, $p = 0.625$). The scatterplot below (Figure 23), provides an illustration of the chosen target locations in a sample environment in good wayfinders (square dots) and poor navigators (diamond dots).

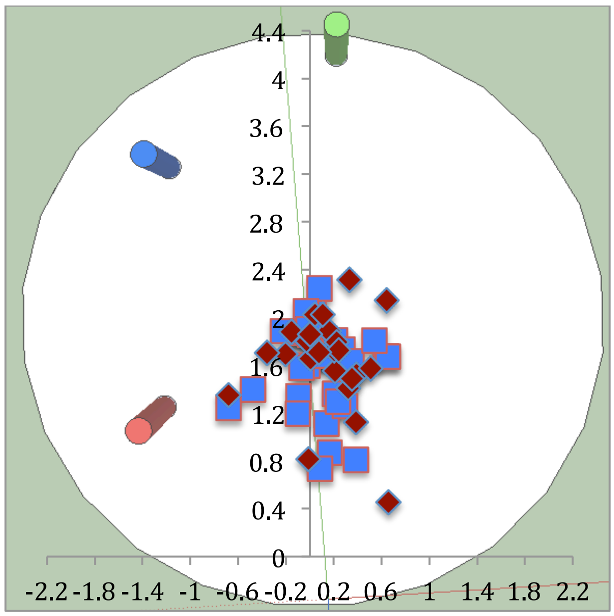


Figure 23: Illustration of the chosen target locations in a sample environment in good wayfinders (square dots) and poor navigators (diamond dots). The black point indicates the location that preserves the relative angles while the white represents the distance location. The numbers represent meters.

Participants may have used body-based coordinates to determine the target location, which would involve choosing a target location based on the movements used during the learning trial. It is unlikely that participants are using body-based coordinates to move to the perceived goal since there appears to be considerable variability in the chosen target location. If participants were using body-based coordinates to move to the target location, they would have converged to a single incorrect point based on the movements that brought them to the target location in the training trial.

A statistical analysis was also conducted to determine whether participants used the same movements to get to the target location on the test trial as they did on the training trial. Distances (error distance) of the chosen target location from the body-based location of the target were calculated and compared to 0, to determine if there were any differences. Participants do not appear to be choosing the same location since a significant difference in the distances was found ($t(55) = 45.57$, $p < 0.001$).

The results from the control trials indicate that good wayfinders were better at determining the target location. Good navigators may have been better at determining the target location because they oriented themselves toward the target location early on. This strategy is referred to as the "least angle strategy" and involves choosing a path that is closest in terms of angularity to a direct line between their current position and the goal.

Heading direction has been examined by Mou & McNamara (2004), in which spatial updating in a familiar environment was investigated. Participants learned locations of objects in a room and then walked to the center and turned to appropriate facing directions prior to making judgments of relative direction (e.g. "Imagine you are standing at X and facing Y") or egocentric pointing judgments ("You are facing Y. Point to Z"). The results indicate that pointing performance was best when the imagined heading was parallel to the learning view. The results from McNamara (2004) suggest that individuals are capable of updating their position and determining heading direction, however the results from the current study indicate how good and poor navigators differ in this ability.

In order to determine initial heading orientation, the angle of the path within the first 0.5 meters was determined in both good and poor wayfinders. Heading angle error was also examined by determining if there was an effect of navigational ability (good vs. poor), number of objects (3, 4, or 5 objects), and orthogonal angles (0,1,3). The results indicate that the following interactions were found: object x ability ($F(2, 51) = 22.04$, $p < 0.001$, $\eta^2_{partial} = 0.297$); angle x ability ($F(2, 51) = 8.90$, $p < 0.001$, $\eta^2_{partial} = 0.146$) and an angle x object interaction ($F(4, 49) = 26.55$, $p < 0.001$, $\eta^2_{partial} = 0.337$).

No other effects were found (ability ($F(1, 52) = 100.62$, $p < 0.001$, $\eta^2_{partial} = 0.659$; number of objects ($F(2, 51) = 6.56$, $p = 0.002$, $\eta^2_{partial} = 0.112$; orthogonal angles ($F(2, 51) = 33.51$, $p < 0.001$, $\eta^2_{partial} = 0.391$; sex: $F(1, 52) = 0.17$, $p = 0.682$, $\eta^2_{partial} = 0.003$; object x sex: $F(2, 51) = 0.47$, $p = 0.627$, $\eta^2_{partial} = 0.008$; object x ability x sex: $F(2, 51) = 0.23$, $p = 0.774$, $\eta^2_{partial} = 0.004$; angle x sex: $F(2, 51) = 1.20$, $p = 0.309$, $\eta^2_{partial} = 0.022$; angle x ability x sex: $F(2, 51) = 0.69$, $p = 0.500$, $\eta^2_{partial} = 0.013$; object x angle x sex: $F(4, 49) = 0.63$, $p = 0.640$, $\eta^2_{partial} = 0.012$; object x angle x ability x sex: $F(4, 49) = 0.77$, $p = 0.542$, $\eta^2_{partial} = 0.014$).

Figure 24 suggests that in configurations with 4 and 5 objects, as the number of orthogonal angles increases, heading angle decreases (4 objects (0 vs. 1 angle: $F(1, 55) = 12.11$, $p = 0.001$, $\eta^2_{partial} = 0.180$; 1 vs. 3 angles: $F(1, 55) = 22.33$, $p < 0.001$, $\eta^2_{partial} = 0.289$; 3 vs. 0 angles: $F(1, 55) = 10.60$, $p = 0.002$, $\eta^2_{partial} = 0.161$); 5 objects (0 vs. 1 angle: $F(1, 55) = 3.70$, $p = 0.060$, $\eta^2_{partial} = 0.063$; 1 vs. 3 angles: $F(1, 55) = 18.50$, $p < 0.001$, $\eta^2_{partial} = 0.251$; 3 vs. 0 angles: $F(1, 55) = 6.36$, $p = 0.015$ , $\eta^2_{partial} = 0.103$). There was an increase in landmark arrays with 3 objects (3 objects (0 vs. 1 angle: $F(1, 55) = 67.84$, $p < 0.001$, $\eta^2_{partial} = 0.552$; 1 vs. 3 angles: $F(1, 55) = 29.32$, $p < 0.001$, $\eta^2_{partial} = 0.347$; 3 vs. 0 angles: $F(1, 55) = 19.23$, $p < 0.001$, $\eta^2_{partial} = 0.259$).

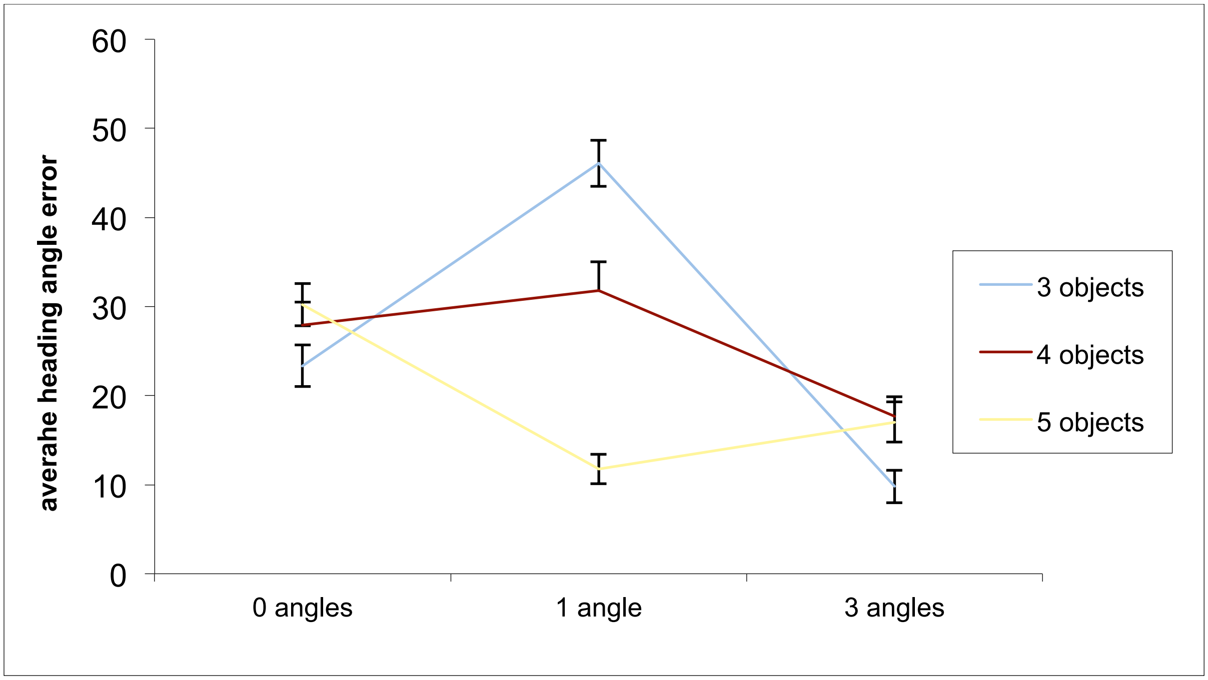


Figure 24: Average heading error in configurations with 3, 4 and 5 objects an8d each of the orthogonal angles (0,1,3) with standard error.

The ability x angle interaction (Figure 25: $F(2, 51) = 8.90$, $p < 0.001$, $\eta^2_{partial} = 0.146$) suggests that in good navigators, an increase in orthogonal angles is associated with a decline in heading error (good navigators: (0 vs. 1 angle: $F(1, 27) = 1.43$, $p = 0.295$, $\eta^2_{partial} = 0.041$; 1 vs. 3 angles: $F(1, 27) = 28.50$, $p < 0.001$, $\eta^2_{partial} = 0.513$; 3 vs. 0 angles: $F(1, 27) = 53.31$, $p < 0.001$, $\eta^2_{partial} = 0.663$). In poor navigators, there is an increase in heading error with 1 orthogonal angle and then a decline in heading error with 3 orthogonal angles (poor navigators: (0 vs. 1 angle: $F(1, 27) = 28.75$, $p < 0.001$, $\eta^2_{partial} = 0.515$; 1 vs. 3 angles: $F(1, 27) = 90.79$, $p < 0.001$, $\eta^2_{partial} =$

0.770; 3 vs. 0 angles: $F(1, 27) = 6.54$, $p = 0.016$, $\eta^2_{partial} = 0.194$). It may be that poor navigators are not acknowledging the orthogonal angles until there are at least 3 of them. Heading error improves in poor navigators when there are at least 3 orthogonal angles.

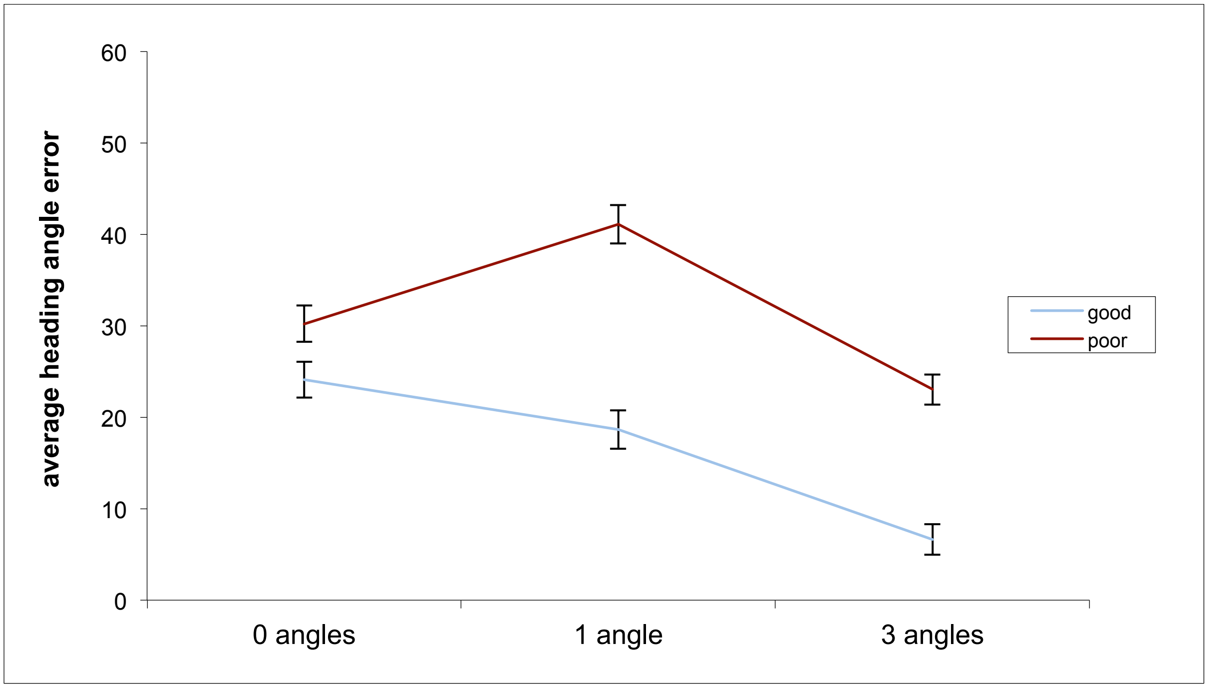


Figure 25: Average heading error in configurations with 0, 1 and 3 orthogonal angles in good and poor navigators, with standard error.

The ability x object interaction (Figure 26: $F(2, 51) = 22.04$, $p < 0.001$, $\eta^2_{partial} = 0.297$), suggests that in good navigators an increase in the number of objects is associated with an increase in heading angle error (good navigators: (3 vs. 4 objects: $F(1, 27) = 2.90$, $p = 0.100$, $\eta^2_{partial} = 0.097$; 4 vs. 5 objects: $F(1, 27) = 2.21$, $p = 0.075$, $\eta^2_{partial} = 0.148$; 5 vs. 3 objects: $F(1, 27) = 9.149$, $p = 0.005$, $\eta^2_{partial} = 0.253$). In poor navigators, it is the opposite and an increase in the number of objects is associated with a decrease in heading angle (poor navigators: (3 vs. 4 objects: $F(1, 27) = 13.88$, $p = 0.001$, $\eta^2_{partial} = 0.339$; 4 vs. 5 objects: $F(1, 27) = 3.07$, $p = 0.091$,

$\eta^2_{partial} = 0.102$; 5 vs. 3 objects: $F(1, 27) = 41.57$, $p < 0.001$, $\eta^2_{partial} = 0.606$). These results suggest that in good navigators an increase in objects makes it difficult to determine heading angle, but in poor wayfinders the objects may be being used as an additional navigational cue in determining heading angle.

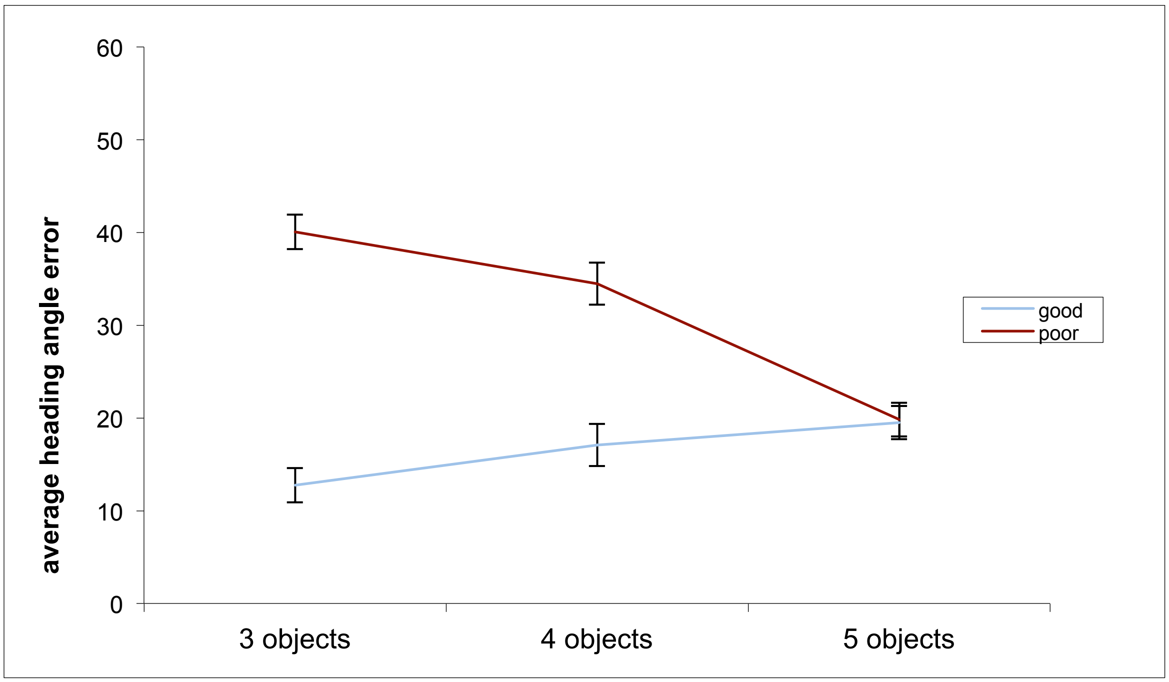


Figure 26: Average heading error in configurations with 3, 4 and 5 objects in good and poor navigators, with standard error.

As illustrated, good navigators heading error was smaller than poor wayfinders. These results suggest that good navigators determine the target location early on and plan their paths accordingly. Planning of routes in good navigators suggest that there may be certain areas of the brain that are being activated in these wayfinders. A study by Fincham, Carter, Veen, Stenger and Anderson, (2001) examined neural mechanisms involved in planning. It appears that regions activated during goal-processing operations include the right dorsolateral prefrontal cortex [(Brodmann's area (BA 9)], bilateral parietal (BA 40/7) and bilateral premotor areas (BA 6)

(Fincham, et al., 2001). The results of the current study suggest a connection between planning and activation of these regions of the brain in good navigators.

This "least angle strategy" that involves planning a route can be applied to an unknown environment if the target can be seen directly from the navigator at the beginning of a route. In these environments, the target pole could easily be viewed from the starting position in the arena. If the target cannot be viewed during the navigation process, decisions are based on the believed directions, which can cause inaccurate wayfinding decisions. This strategy used by good wayfinders may account for their ability to effectively navigate in environments. Good navigators appear to be piloting where they are heading in advance and choose an appropriate path accordingly. The results also suggest that poor navigators walk aimlessly initially and then choose a target location once they get closer to their destination. Planning a path ahead of time can be an efficient strategy since it allows navigators to plan shortcuts. When navigators do not plan routes ahead of time this can cause them to choose inappropriate paths initially which can then make it difficult to get back on track when an incorrect path has been selected. The results from this study suggest that good navigators appear to use a least angle strategy when determining routes, which may partially account for their ability to successfully navigate in environments (Hochmair & Frank, 2002).

In order to use the least-angle strategy an individual must have a good mental representation of their environment. When utilizing the least-angle strategy, a navigator constructs a cognitive map, which contains directions, angles and vectors (Hochmair & Frank, 2002). The use of the least-angle strategy by good navigators further confirms that they are better at forming cognitive maps compared to poor wayfinders. Cognitive maps are mental representations that are used to make spatial decisions. Essentially, cognitive maps are a mental representation of environmental knowledge. Cognitive maps include knowledge of spatial relations and include the integration of information in an environment (Kitchin, 1994). The task in these experiments requires the knowledge of spatial relationships between landmarks rather than their absolute positions since the landmark configurations were rotated in the test trial. Good navigators use of the least angle strategy further confirms that they are better at forming cognitive maps than poor wayfinders.

In summary it appears that both good and poor wayfinders appear to use a distance strategy rather than angles. The results from the control trials indicate that good navigators were better at determining the target location. The results from the first study indicate that poor navigators are not as skilled as good navigators at determining spatial relationships between landmarks on multiple floors. The results from the control trials of this study indicate that poor wayfinders are also not as skilled at determining spatial relationships between landmarks on the same horizontal plane and at a smaller scale. Lastly, the heading error results suggest that good navigators appear to plan where they are heading in advance and choose an appropriate path accordingly. The use of this least angle strategy used by good wayfinders may partially account for their ability to effectively navigate in environments.

## Study 3: Analysis of the influence of contextual factors on the use of landmarks and streets in good and poor wayfinders

**Introduction:**

The ability to determine spatial relationships between landmarks is the strongest predictor of determining navigational ability (study 1). Good wayfinders may be more skilled at this task because they compute their initial heading direction to target locations in advance (study 2). This route planning may be why good navigators are less likely to get lost since choosing an appropriate path in advance can prevent taking a wrong turn or a longer route. As illustrated by the previous experiments in this thesis, good wayfinders appear to be skilled at using landmark information (spatial relationships and computing initial heading direction) when navigating. The use of landmark information may be useful in certain contexts, but this may not always be the best strategy. The next experiment is aimed at determining whether good navigators alter the strategies they use depending on contextual factors.

Tom and Denis (2004), compared the effectiveness of route directions based on references to either landmarks or street names. The results suggest that street-based descriptions were less effective during navigation than landmark-based descriptions in several respects. Participants following the street-based instructions stopped more frequently to check information in the environment, indicating that they experienced more hesitation when they were using instructions of this type. Furthermore, each stop or checking episode lasted longer in the street-based than in the landmark-based condition. As a result, it took longer to reach the end-point using street-based instructions compared to using landmarks. Participants using landmark-based instructions were also more confident during navigation, since they stopped and checked less often and for less time, even when ambiguous landmarks were involved (Tom & Denis, 2004).

In the Tom and Denis (2004) study, using landmarks rather than street names was an effective approach, but this may not be the most effective strategy in environments rich in landmarks. In environments containing several landmarks (e.g. downtown New York City), providing route descriptions using landmarks may not be an effective approach because of the overwhelming number of landmarks that can be used. Individuals may not rely on one particular strategy and may switch between strategies instead. When considering a combination of strategies, the reasons why switching occurs is a topic of interest (Lawton, 1996). Individuals who use an orientation strategy often use route strategies in environments rich in route information and landmark distinctiveness (Bethellfox & Shepard, 1988). Conversely, individuals who use route strategies often switch to orientation strategies when route information is lacking (Bethellfox & Shepard, 1988). Research on mental rotation performance has further illustrated that individuals often alter the strategy they use as they become more familiar with a particular type of problem (Kyllonen et al., 1984). It is possible that individuals may also switch strategies as they become more familiar with environments. Route knowledge often precedes configurational knowledge of an environment and it is likely that individuals shift from a route to an orientation strategy as they become more familiar with their surroundings. In line with the assumption that route knowledge often precedes configurational knowledge, research has shown there is often a switch from a route strategy to an orientation strategy as people become more familiar with an environment (Lawton, 1996).

Research has been done on differences in strategy use in relation to personal attributes such as sex and age. Sex differences in spatial cognition suggest that males are better than females in spatial information processing. Males tend to use Euclidean spatial cues such as direction and distance while females are more likely to use landmarks (Kato & Takeuchi, 2003).

Euclidean strategies can provide an advantage in contexts in which the navigator has left a specified route, such as when a wrong turn has been taken. In these situations, individuals using Euclidean strategies can utilize cardinal directions to orient themselves to determine their position, whereas navigators using landmarks may become disoriented. This disorientation can lead to anxiety, which may persist throughout subsequent navigation (Saucier et al., 2002).

The above research provides a greater understanding of various aspects of the role of strategies, but it does not address the relationships between an individual's performance in navigating and their spontaneous use of strategies. The aim of this study was to examine differences in strategies used by participants with good and poor sense of direction. Good navigators may continually renew their knowledge of an environment and try to find the best strategy at each navigational stage. Unlike the previous experiments, this study is aimed at gaining a greater understanding of the use of landmark and street strategies in different contexts. This study also differs from previous studies since only a route or landmark strategy can be used in these environments, while other extraneous variables such as smells, sounds, elevation are excluded unlike in the first real world study.

The virtual environment in this study consisted of a landmark and street dominant region. The landmark dominant region consisted of several landmarks at each intersection (4 landmarks) and fewer streets. The street dominant region consisted of several streets, however fewer landmarks at the intersections (1 landmark), compared to the landmark dominant region. Using a street strategy in the landmark dominant region would be a more efficient strategy due to the overwhelming number of landmarks. Conversely, using a landmark strategy would be more efficient in the street dominant region due the abundance of streets. It was predicted that good navigators will alter the strategy they use based on the type of region they are in (street or landmark dominant), while poor wayfinders would not.

Dwell times spent at intersections in the landmark and street dominant regions were used to determine the type of strategy used. In the learning trials participants learned a route in the environment and in the test trials they were transported to intersections and asked whether they went left, right or straight. The landmarks were switched in the experimental intersections of the test trials to determine the relative reliance of the use of landmarks or streets in each region. If participants are relying on a landmark strategy, the switch would cause confusion and result in a longer dwell time at the intersection. Landmarks were not switched in the control intersections of the test trials.

If good wayfinders use a landmark strategy in the street dominant environment, there would be a difference between dwell times in the control and switch (experimental) conditions (longer dwell time in the switch condition). If good navigators use a street strategy in the landmark dominant region, there would not be a difference in dwell times between the control and switch conditions. Lastly, if poor navigators constantly rely on a street strategy, they would show no differences in dwell times between the control and switch trials in either environment.

Another aim of this study was to examine how wayfinding strategies and anxiety are related to spatial ability. Although the goal of navigating is to reach a specific destination, navigation speed and accuracy can also play an important role. Navigating quickly and accurately can mean the difference between arriving on time or being late for an important meeting, which can create anxiety.

It is predicted that in certain types of environments using one strategy and not switching strategies may be associated with higher rates of anxiety when navigating. If an individual who only relies on landmarks is in an environment with very few landmarks it's likely they would feel anxious about getting lost since they do not use other strategies based on contextual factors. It is predicted that individuals who alter strategies are less likely to feel anxious about finding their way in a novel environment since they alternate the strategies they use and can more easily find their way in new contexts.

This study will also examine the possibility that there is an association between wayfinding ability and anxiety. The relation between spatial anxiety and performance is unclear. Spatial anxiety refers to anxiety caused by uncertainty or failures in wayfinding and was measured according to the scale provided in appendix I (Hund & Minarik, 2006). Spatial anxiety and wayfinding ability could be linear in nature, or more complex, such as curvilinear relations between anxiety and performance. (i.e. optimal performance at midlevel's of anxiety). It is predicted that there will be a linear correlation between wayfinding ability and spatial anxiety based on previous findings reported in the literature (Hund & Minarik, 2006). Spatial anxiety may have a negative effect on navigational ability by reducing attention to features in an environment (Saucier et al., 2002).

This study was conducted using a virtual environment as opposed to a natural setting due to various reasons. Several studies conducted, especially ones in real environments provide subjects with a wide range of additional navigational cues, such as geographical slant, and ego motion information that can be used to determine metric relations by path integration. Due to the wealth of information provided from these environments, it is often difficult to determine navigational strategies used. The use of virtual reality controls these extraneous variables and allows a greater understanding of navigational strategies utilized. In this study, the landmark dominant and street dominant environment only differed in the number of landmarks and streets and other features were not altered. Another key advantage of conducting this study in virtual reality is that it allows the creation of inconsistent environments. In this study, landmarks were moved around which would be difficult or even impossible in natural environments.

**Method and Materials:**

Participants:

Participants were selected from a group of undergraduate psychology students from the University of Waterloo. 28 participants took part in the study, 14 good navigators and 14 poor wayfinders with an average age of 20.5 (SD 1.07). Of the 28 subjects, 14 were given a participation course credit and 14 were provided $10 for taking part in the study. Subjects were selected based on their performance on the Santa Barbara Sense of Direction Scale. Participants who scored at least one standard deviation above the mean of 1017 students were part of the good sense of direction group and those who scored one standard deviation below the mean as part of the poor sense of direction group. A double-blind procedure was also used for this study and the experimenter was not aware if the participant was part of the good or poor sense of direction group.

Materials:

Environments created in this experiment were designed using Google Sketchup 7. This is a walkabout 3d software that allows users the ability to explore layouts as a full screen real-time walkthrough, to simulate walk-paced movement through the simulated environment. The eye level for all trials was set to a height of 1.60 meters. Participants moved in the virtual environment by clicking and holding a mouse button to move forward. Participants were allowed to hold the mouse in the hand and position they felt most comfortable with. Heading direction was changed by rotating the HMD.

A rectangular grid was used to create two environments that differed only in the number of landmarks/paths rather than by the kinds of intersections (Y, T, X etc.). This layout prevents the type of intersections from becoming a confounding variable between the two environments. A rectangular grid would also make learning the task a lot easier. A more organic environment may make it difficult for poor wayfinders to solve the task, which may result in random responses. Figure 27 below, illustrates the virtual environment:

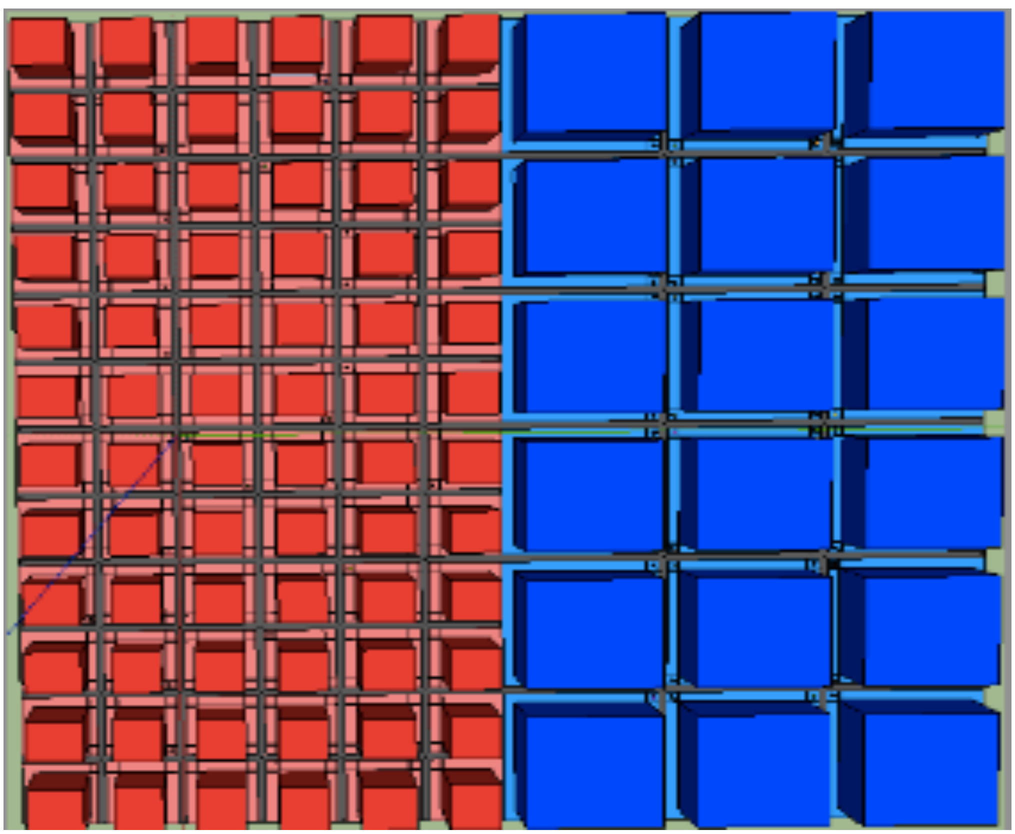

Figure 27: Diagram of the virtual environment. The left region represents the road dominant region and the area on the right, the landmark dominant region.

Objects that are typically found outdoors were chosen as landmarks. A list of landmarks is provided in Appendix J. Landmarks consisted of objects that were the same height and were placed at the same distance from the centre of the intersection. The landmarks were also surrounded by a wall to prevent them from being viewed from adjacent intersections. This was done to ensure that landmarks in a particular intersection could only be used as local landmarks. Local landmarks are only visible from a short distance and are used as reference points to intermediate goals along a route. Local landmarks can be used either for guidance, such as reference points to intermediate goals or as pointers to direct a navigator onwards from an intermediate goal. In contrast, global landmarks provide a large-scale frame of reference and are visible from a far distance (Steck & Mallot, 2000). The barriers that encased the landmarks ensured that landmarks could only be used as reference points for that particular intersection and could not provide additional cues when participants were at other locations.

All intersections along the path contained street names labeled on a pole. All street names were written in black on a white signboard to make it easily visible. The pole was placed in the centre of the intersection to make them more noticeable to participants. All street names consisted of four letter words. Names were kept brief and consisted of one-syllable words to make them easier to remember. Street signs were not considered landmarks since they were not a visually distinctive feature in the environment. Every intersection contained the same type of street sign, consisting of a white board attached to a grey pole. Street signs also only consisted of names of people and did not refer to any objects.

The spatial anxiety scale measures anxiety levels when navigating in unfamiliar environments. This is an 8-item questionnaire designed to assess spatial anxiety in several different wayfinding situations (Appendix I). Level of anxiety is rated using a 5-point scale, ranging from Not at All to Very Much. Anxiety levels are determined by summing up the ratings for the 8 items. The higher the total number, the more anxiety the participant reports when navigating in unfamiliar environments. A score of 8 is associated with the lowest level of anxiety and 40 the highest (Hund & Minarik, 2006). The anxiety scale was administered at the end of the experiment, after being immersed in the virtual environment.

**Method:**

Participants learned 4 different routes in a virtual environment by following arrow markings on the ground. Each route consisted of 6 turns, 3 in the landmark dominant area of the environment and 3 in the street dominant section. Each of the 4 routes consisted of the same distance. An equal number of routes began from the landmark dominant area and the street dominant region. The stop point of a path was indicated by a red bar positioned on the floor of the environment. This approach of following the arrow markings to learn a path allows for participants to actively engage in the route learning process. Alternative techniques such as presenting participants with a video, allows the opportunity to learn the environment without paying much attention. The approach used in this study forces participants to be more aware of their environment and where navigation decisions are to be made. Figure 28 illustrates the arrow marking participants were asked to follow.

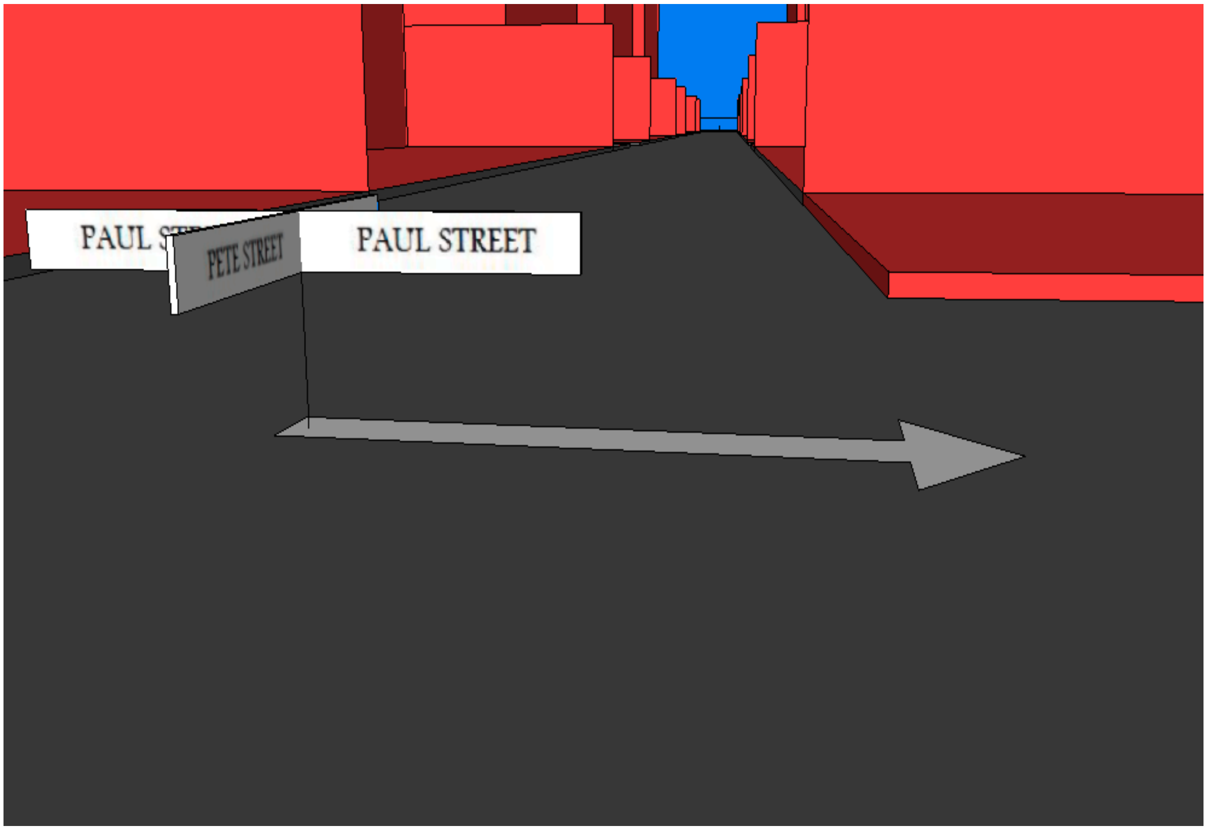


Figure 28: 3D view of the virtual environment.

Upon completion of learning one route, participants engaged in a series of test trials. On the test trials participants were transported to 4 out of the 6 turns along the route, and asked to turn either left or right. Two turns were in the landmark dominant area and two in the street dominant section. Participants were transported to one intersection prior to the turning position so they could locate themselves within the environment. At that starting point participants were asked to walk straight to the next intersection, and then to go either left, right or straight depending on the arrow marking. The turns made and the dwell time at the testing intersections were recorded. A turn decision was recorded once a participant passed a barrier wall of the intersection to turn into a road. The routes contained an equal number of left and right turns.

In the testing trials, the landmarks were switched to create a discrepancy in the turn decision points. The discrepancy was made to gain insight into the type of strategies used by good and poor wayfinders. If participants use a landmark strategy their decision time at the testing intersections could be delayed due to confusion from the switched landmarks. If participants were using a route strategy their dwell time would be reduced since the switch in landmarks would not have an influence on their decision speed since they are focusing on the roads as opposed to the landmarks. In 2 out of the 4 experimental test trials, the landmarks were switched while in the other 2 control trials the landmarks were not switched.

In the experimental switch trials the landmarks were replaced with previously viewed landmarks that were encountered during learning trials rather than with a novel landmark. This was done to reduce the likelihood that participants noticed the switch. Landmarks within the landmark dominant environment were switched with landmarks also within the landmark dominant area and landmarks within the street dominant environment were switched with landmarks in the street dominant area. This was done since the number of landmarks in the landmark dominant environment consisted of 4 landmarks per intersection and only 1 in the street dominant environment. Switching 1 landmark in the street dominant environment with 4 landmarks in the landmark environment would make the switch fairly noticeable, and consequently landmarks were switched within the same environment type.

Dwell time at each intersection was determined by the duration spent within the barrier walls by the software. The time interval began once a participant passed a barrier wall at an intersection and ended once they exited the intersection by walking past another wall.

The study took approximately 60 minutes to complete and at the end of the experiment participants were asked to complete a simulator sickness questionnaire. Participants were also asked if they noticed a discrepancy between the learning and testing trials. Any participants that noticed that the landmarks were replaced were excluded in the analysis since no proper decision can be made if this difference is observed.

**Results and Discussion:**

A repeated measures ANOVA was conducted to examine whether there was an effect of navigational ability (between variable: good vs. poor), sex (between variable), region (within variable: landmark vs. street dominant) and condition (within variable: control vs. experimental) on dwell time at the intersections.

The result indicate a significant condition x region interaction ($F(1, 24) = 4.66$, $p = 0.041$, $\eta^2_{partial} = 0.162$). There was also a significant difference in ability ($F(1, 24) = 8.95$, $p = 0.006$, $\eta^2_{partial} = 0.271$). There were no other effects or interactions that were found (condition ($F(1, 24) = 4.03$, $p = 0.056$, $\eta^2_{partial} = 0.143$); sex: $F(1, 24) = 0.64$, $p = 0.431$, $\eta^2_{partial} = 0.026$; region: $F(1, 24) = 0.43$, $p = 0.517$, $\eta^2_{partial} = 0.017$; condition x ability: $F(1, 24) = 2.11$, $p = 0.159$, $\eta^2_{partial} = 0.081$; condition x sex: $F(1, 24) = 0.86$, $p = 0.363$, $\eta^2_{partial} = 0.034$; condition x ability x sex: $F(1, 24) = 0.03$, $p = 0.873$, $\eta^2_{partial} = 0.001$; region x ability: $F(1, 24) = 2.66$, $p = 0.116$, $\eta^2_{partial} = 0.099$; region x sex: $F(1, 24) = 0.38$, $p = 0.542$, $\eta^2_{partial} = 0.015$; condition x region x sex: $F(1, 24) = 0.03$, $p = 0.873$, $\eta^2_{partial} = 0.001$; condition x region x ability x sex: $F(1, 24) = 0.26$, $p = 0.618$, $\eta^2_{partial} = 0.011$)

The results indicate that good wayfinders did not switch strategies as was predicted since an ability x condition interaction was not found ($F(1, 24) = 2.11$, $p=0.159$, $\eta^2_{partial} = 0.081$). If good wayfinders used a landmark strategy in the street dominant environment, there would be a difference between dwell times in the control and switch (experimental) conditions (longer dwell time in the switch condition). If good navigators used a street strategy in the landmark dominant region, there would not be a difference in dwell times between the control and switch conditions.

Lastly, if poor navigators constantly relied on a street strategy, they would show no differences in dwell times between the control and switch trials in either environment.

These results do not provide evidence that good and poor navigators differ in their ability due to the switching of strategies in environments dominant in streets or landmarks. There are various strategies that are used when navigating, such as the use of cardinal directions. Even though good and poor navigators did not differ in the use of street or landmark strategies in this environment, there may be other strategies that good wayfinders are using that poor navigators may not be.

Good navigators' overall longer dwell times compared to poor wayfinders suggest that they may take a longer time to make a decision because they may be observing their surroundings more thoroughly (ability ($F(1, 24) = 8.95$, $p = 0.006$, $\eta^2_{partial} = 0.271$). In the first experiment pauses were considered to be a sign of wayfinding difficulty, however in this experiment longer dwell times is a sign of wayfinding finesse. In the first experiment there were no discrepancies between the learning and testing environments, however in the third experiment there were alterations. Longer pauses in the first experiment were associated with wayfinding difficulty since participants are taking longer to process the same spatial information presented in the learning trial. In this experiment in which the environment is altered, confusion is associated with recognizing a discrepancy between the learning and testing environments, and thus a sign of wayfinding finesse.

There was also a significant condition x region interaction ($F(1, 24) = 4.66$, $p = 0.041$, $\eta^2_{partial} = 0.162$) (Figure 29 below). These results suggest that in the landmark dominant environment there were no differences in dwell time between the control and experimental conditions (landmark (control vs. experimental: $F(1, 27) = 0.222$, $p = 0.642$, $\eta^2_{partial} = 0.0089$). In the street dominant environment however, there was an increase in dwell time in the experimental intersection from the control trial (street (control vs. experimental: $F(1, 27) = 4.37$, $p = 0.046$, $\eta^2_{partial} = 0.139$). These results suggest that even though there was not an effect of ability (good versus poor), overall individuals appear to be using a landmark strategy in the street dominant environment. Both good and poor individuals are capable of using appropriate strategies.

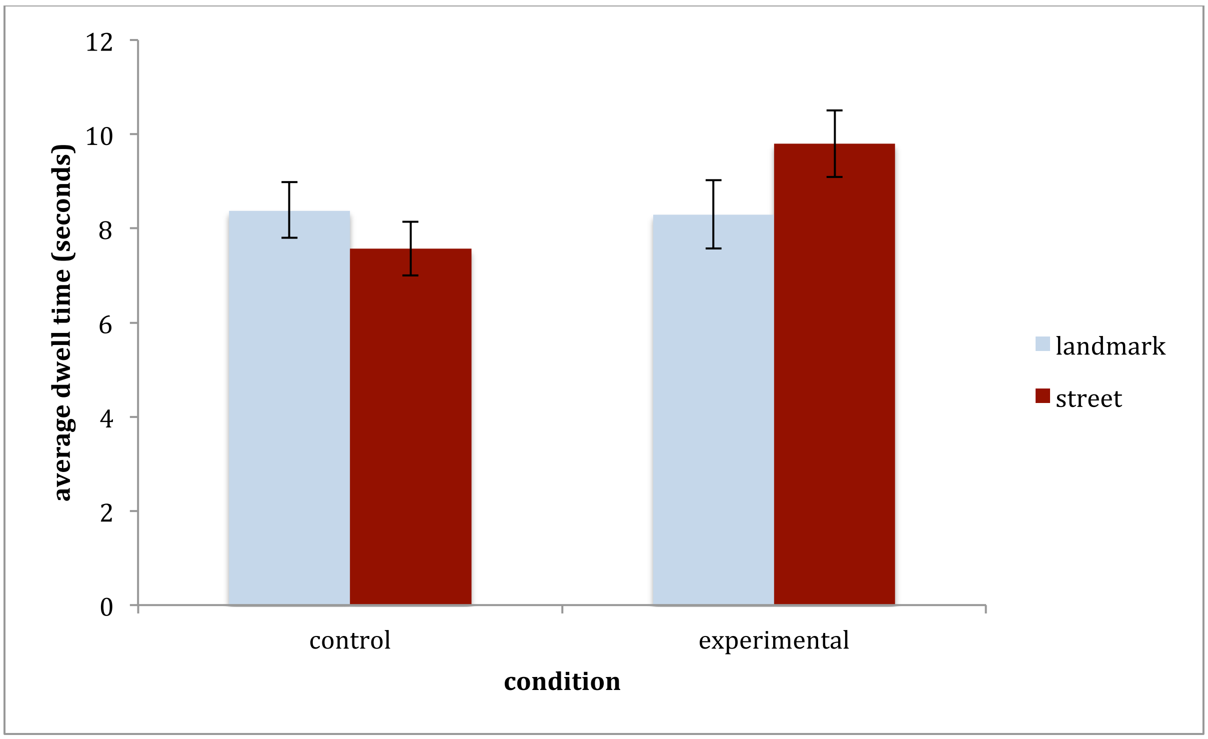


Figure 29: Average dwell time (seconds) in the landmark and street dominant regions, with standard error.

A repeated measures ANOVA was conducted to examine whether the average number of correct turns in the control trials (non-switched trials) were affected by navigational ability (good vs. poor), sex, and region (landmark vs. street dominant).

An ability x region interaction ($F(1, 24) = 5.76$, $p = 0.025$, $\eta^2_{partial} = 0.193$) was also found (Figure 30). Good navigators made significantly more correct turns than poor navigators in the street dominant region (street: (good vs. poor: $F(1, 27) = 13.00$, $p = 0.001$, $\eta^2_{partial} = 0.666$), however good and poor navigators made the same number of correct turns in the landmark dominant areas (landmark: (good vs. poor: $F(1, 27) = 0.183$, $p = 0.672$, $\eta^2_{partial} = 0.993$). These results suggest that good navigators appear to be more skilled at handing an overwhelming number of streets compared to poor wayfinders. Good and poor navigators are equally skilled at navigating in environments rich in landmarks.

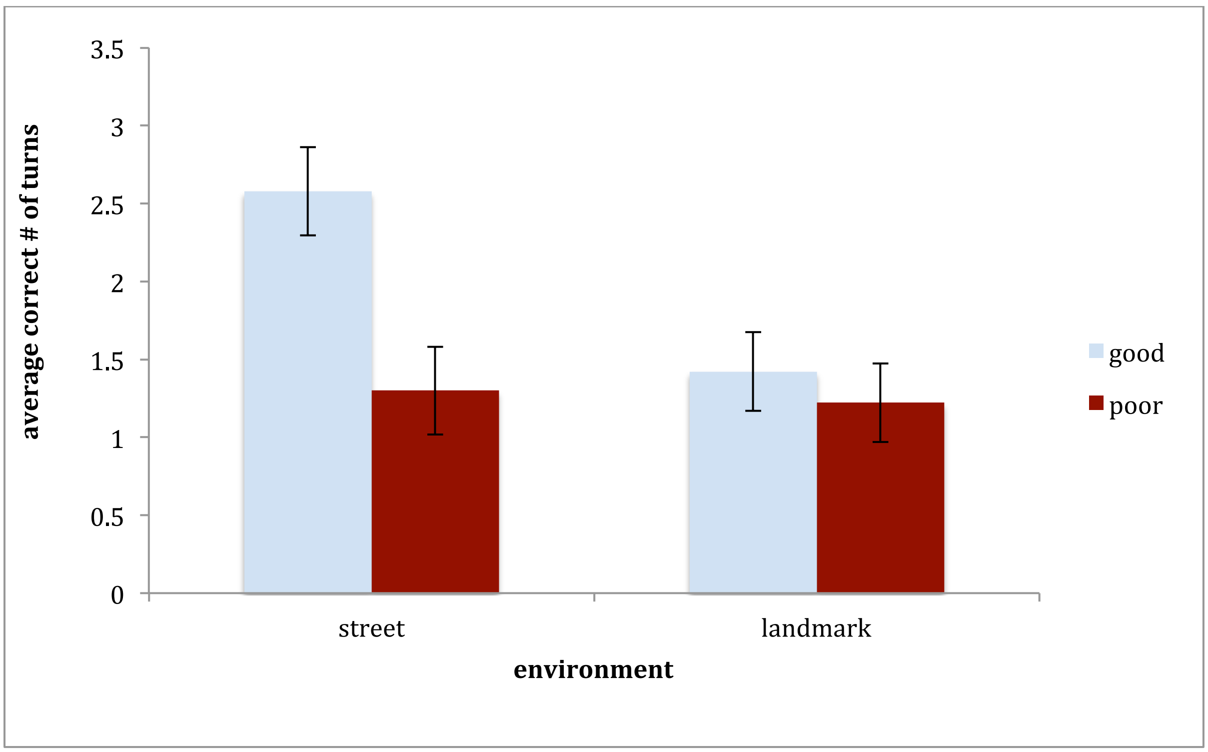


Figure 30: Average correct number of turns by good and poor navigators in the street and landmark dominant regions, with standard error.

The were no other significant main effects or interactions (ability: $F(1, 24) = 5.87$, $p = 0.023$, $\eta^2_{partial} = 0.196$; sex: $F(1, 24) = 0.02$, $p = 0.90$, $\eta^2_{partial} = 0.001$; region x sex: $F(1, 24) = 1.13$, $p = 0.298$, $\eta^2_{partial} = 0.045$; region x sex x ability: $F(1, 24) = 1.60$, $p = 0.219$, $\eta^2_{partial} = 0.062$)

Good and poor navigators did not differ in their self-reports of anxiety ($F(1, 24) = 0.42$, $p = 0.520$, $\eta^2_{partial} = 0.017$). It was initially expected that good navigators would report less anxiety since they are less likely to get lost because of their ability to alter strategies. It may be that poor navigators have become adapted to becoming lost, and it no longer is a source of anxiety. There also does not appear to be a significant effect of sex on anxiety ($F(1, 24) = 0.22$, $p = 0.642$, $\eta^2_{partial} = 0.009$). A sex x ability interaction was also not found ($F(1, 24) = 0.34$, $p = 0.568$, $\eta^2_{partial} = 0.013$).

Good and poor wayfinders did not have varying levels of simulator sickness ($F(1, 24) = 0.80$, $p = 0.378$, $\eta^2_{partial} = 0.003$). Males and females also did not report different levels of simulator sickness ($F(1, 24) = 1.81$, $p = 0.191$, $\eta^2_{partial} = 0.007$). There was also not an ability x sex interaction of simulator sickness ($F(1, 24) = 0.02$, $p = 0.894$, $\eta^2_{partial} < 0.001$). These results indicate that the findings from this study were not influenced by varying levels of anxiety or simulator sickness.

**Discussion:**

Few studies to date have examined wayfinding in large-scale spaces in terms of the strategies participants use to navigate. In Heft's (1979) field study, participants were taken for a walk along a route consisting of 22 intersections and after completing the walk they were instructed to retrace the route and asked to indicate the type of strategy they used at each intersection point. The results suggest that participants alter the strategy they use depending on the characteristics of the environment. Participant's level of performance must be closely related to their ability to flexibly use different strategies (Heft, 1979; Kato & Takeuchi, 2003). The current experiment unlike Heft's (1979) study, provides a greater understanding of the way in which two particular strategies (landmark versus road information) are used and whether switching of these strategies occurs in good and poor wayfinders. The results of this study indicate that landmark and street strategies are not ways good and poor navigators differ in their strategy selection. Even though good and poor navigators did not differ in the use of street or landmark strategies in this environment, there may be other strategies that good wayfinders are utilizing that poor navigators may not be.

The results from this experiment also further expand on the findings from Tom & Denis's (2004) study. According to Tom and Dennis (2004), individuals rely more heavily on landmark information as opposed to roads. The current study indicates that this does not always occur, and strategies used can change depending on contextual factors. Even though there were no differences between good and poor navigators, the results from this study indicate that individuals switch to a landmark strategy in the street dominant environment, however this does not occur in landmark dominant environments.

These results from the correct number of turns suggest that good navigators appear to be more skilled at handing an overwhelming number of streets compared to poor wayfinders ($F(1, 24) = 5.76$, $p = 0.025$, $\eta^2_{partial} = 0.193$). Good and poor navigators are equally skilled at navigating in environments rich in landmarks.

**General Discussion:**

The results indicate that good navigators are skilled at a wide range of abilities compared to poor wayfinders. Good wayfinders are better at recognizing landmarks and determining their directional and positional information. The results also confirm that good wayfinders form more accurate cognitive maps, which is suggested by their performance on the spatial relationship tasks. Lastly, the results confirm that the Santa Barbara Sense of Direction Scale is an accurate predictor of wayfinding performance, which was demonstrated by good wayfinders path retracing performance. Good navigators performance was also verified by their verbal protocols, which contained fewer route errors. As illustrated, good navigators appear to be skilled at a wide range of navigational abilities. Good navigators appear to be more skilled at recognizing landmarks, and determining their directional and positional information. It also appear that one of the best predictors of determining navigational performance is the ability to form spatial relationships between landmarks when compared to a wide range of other abilities.

It also appears that a distance or angular strategy is not preferred over the other in good and poor wayfinders. Both strategies are used by both groups and determining distance or angular information does not appear to be why good navigators are better at determining spatial relationships between landmarks. The results from the control trials indicate that good wayfinders were better at determining the correct target location. The results further suggest that good wayfinders form more accurate cognitive maps than poor navigators. It appears that good wayfinders may be more efficient at finding their way because they appear to plan routes prior to initiating self-locomotion. Such pre-planning was confirmed by the fact that good wayfinders' initial heading direction error was significantly less than in poor wayfinders. Poor wayfinders appear to head in a random direction and then attempt to determine the target location. Good wayfinders on the other hand, determine an initial heading direction that is in line with the target location. This strategy can prevent individuals from taking a wrong turn and getting lost. Preplanning routes in advance can assist in taking short cuts, and reduce the chance of taking a wrong path.

Lastly, the results indicate that individuals appear to switch to a landmark strategy in street dominant environments, but this does not occur in landmark dominant environments. The results from the correct number of turns suggest that good wayfinders appear to be more skilled at navigating in environments rich in streets compared to poor navigators. Good and poor navigators are equally skilled at navigating in environments rich in landmarks.

A cognitive map is an internal representation of spatial information (Tolman, 1948). Tolman (1948) used rats to describe how humans utilize these mental representations. According to Tolman (1948), humans construct a mental representation within the nervous system that is used to guide movements. According to Golledge and Timmermans (1990), cognitive maps are various knowledge structures that develop with age and education. These knowledge structures have different levels of detail and integration. Different knowledge structures are combined using process relating to perception, storage and retrieval to form a cognitive map (Golledge & Timmermans, 1990).

The results from these studies indicate that good navigators appear to be better at forming cognitive maps since they were able to determine the relative location of landmarks in the first study using mental trigonometry, and they were more accurate at determining the target location in the second experiment which required the ability to mentally rotate landmark configurations.

The ability to determine spatial relationships between landmarks involves the use of cognitive maps, which allow individuals to form a holistic view of environments. Such maps allow for relative locations of landmarks and pathways to be determined. This ability to determine spatial relationships may be one of the main reasons good wayfinders are better at navigating while others have considerable difficulty. Using a cognitive map to determine relative locations as opposed to remembering locations by their absolute position can have various benefits. Use of this configurational knowledge can assist in getting back on track when an individual is lost. If poor navigators are only learning the absolute locations of landmarks than it can be difficult to get back on track if they get lost since they are not aware of the relative positions of other nearby landmarks that could be used to find their way. If good navigators get lost, and are unable to find a particular landmark along a route, they can determine the relative positions of surrounding landmarks to determine where they are. When individuals determine spatial relationships between objects they are able to update their position as they move and consequently it makes it easier for them to get back on track if they get lost.

In all types of environments whether it is a networked space or an open terrain, landmarks provide essential information about the relationships of locations and paths. According to Heth et al. (1997), there are two ways landmarks can be used when navigating. Landmarks are memorable cues that are chosen along a path, particularly when leaning turning points along a path. Landmarks also assist in encoding spatial relationships between objects and paths. This distinction can also be descried in two kinds of relationships, landmark-goal relationships where landmarks are used as cues along a path to a goal, and landmark-landmark relationships, which provide a global understanding of the environment. Landmark-goal knowledge can be used in active navigation, and landmark-landmark knowledge may be more essential in determining orientation (Heth et al., 1997).

Good navigators are better at determining both types of the relationships described by Heth et al. (1997). Good navigators are better at determining spatial relationships between landmarks (study 1: landmark-landmark information) and between landmarks and goals (study 2: landmark-goal information). Both these abilities are interrelated and can play an important role in navigating. Good navigators may be better at finding their way because they are better at active navigation and determining landmark-goal relationships effectively. This was demonstrated by their accuracy at determining the correct target position in the control trials in study 2, which required the ability to determine a goal location (target), in reference to a landmark (surrounding landmarks in the configuration). When individuals are actively navigating through an environment, they also need to orient themselves effectively, which landmark-landmark relationships can assist with. Good navigators displayed this ability in study 1 in which they were required to determine spatial relationships between landmarks. In summary, good wayfinders may be better at navigating because they are effective at determining target locations in reference to landmarks and they are also better at orienting themselves appropriately.

The results from these studies suggest that poor navigators have difficulty in recognizing landmarks, remembering directional information and determining spatial relationships between landmarks. Buildings should have open concept styles, which can facilitate poor navigators in learning the relative location of landmarks, rather than their absolute positions. Open concept environments may make it easier for individuals to make mental connections between landmarks and pathways. Buildings should also be designed with more foyers since they facilitate the ability to determine spatial relationships between landmarks on multiple floors. Lastly, buildings and cities can be designed in ways that make it easier for poor wayfinders to determine their initial heading direction to a target location more easily. For example, tall towers that can be seen from various vantage points can assist in determining initial heading direction more easily.

Designing buildings optimally is a challenging process since individuals with varying levels of navigational ability may prefer using certain strategies rather than others. A building designer needs to take into consideration the navigational needs of poor wayfinders, average navigators and those with superior abilities. As mentioned, the results of these studies suggest that there are various ways in which buildings can be designed more effectively to assist poor navigators. Buildings should be designed that meet the needs of both poor and good navigators by having more foyers and being more open.

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# APPENDIX

Appendix A

**<u>Santa Barbara Sense of Direction Scale</u>**

**This questionnaire consists of several statements about your spatial and navigational abilities, preferences and experiences. After each statement, you should circle a number to indicate your level of agreement with the statement. Circle "1" if you strongly agree that the statement applies to you, "7" if you strongly disagree, or some number in between if your agreement is intermediate. Circle "4" if you neither agree nor disagree.**

1. I am very good at giving directions.
strongly agree 1 2 3 4 5 6 7 strongly disagree

2. I have a poor memory for where I left things.
strongly agree 1 2 3 4 5 6 7 strongly disagree

3. I am very good at judging distances.
strongly agree 1 2 3 4 5 6 7 strongly disagree

4. My ''sense of direction'' is very good.
strongly agree 1 2 3 4 5 6 7 strongly disagree

5. I tend to think of my environment in terms of cardinal directions (N, S, E and W).
strongly agree 1 2 3 4 5 6 7 strongly disagree

6. I very easily get lost in a new city.
strongly agree 1 2 3 4 5 6 7 strongly disagree

7. I enjoy reading maps.
strongly agree 1 2 3 4 5 6 7 strongly disagree

8. I have trouble understanding directions.
strongly agree 1 2 3 4 5 6 7 strongly disagree

9. I am very good at reading maps.
strongly agree 1 2 3 4 5 6 7 strongly disagree

10. I do not remember routes very well when driving as a passenger in a car.
strongly agree 1 2 3 4 5 6 7 strongly disagree

11. I do not enjoy giving directions.
strongly agree 1 2 3 4 5 6 7 strongly disagree

12. It is not important to me to know where I am.
strongly agree 1 2 3 4 5 6 7 strongly disagree

13. I usually let someone else do the navigational planning for long trips. done
strongly agree 1 2 3 4 5 6 7 strongly disagree

14. I can usually remember a new route after I have traveled it only once.
strongly agree 1 2 3 4 5 6 7 strongly disagree

15. I do not have a very good ‘‘mental map’’ of my environment.
strongly agree 1 2 3 4 5 6 7 strongly disagree

Appendix B

## EIT Building Familiarity Rating

Please rate your familiarity with the EIT building from 1 to 5.

**Circle 1 if you are not familiar with the building, and 5 if you are very familiar, or some number in between if your agreement is intermediate.**

Not at all familiar 1 2 3 4 5 very familiar

Appendix C

## Route Drawing Questionnaire

**The route you were asked to learn was a multi-level path over four floors. You began the route on the top 4th floor and the route ended on the 1st floor. Please draw the route taken on each floor. On each path also indicate the location of all the landmarks you were required to remember with an X and label it with the landmark's name. Please also label the start and end of the path on that floor.**

4th floor path:

3rd floor path:

2nd floor path:

1st floor path:

Appendix D

**Example of Route Drawing Task Scoring Procedure:**

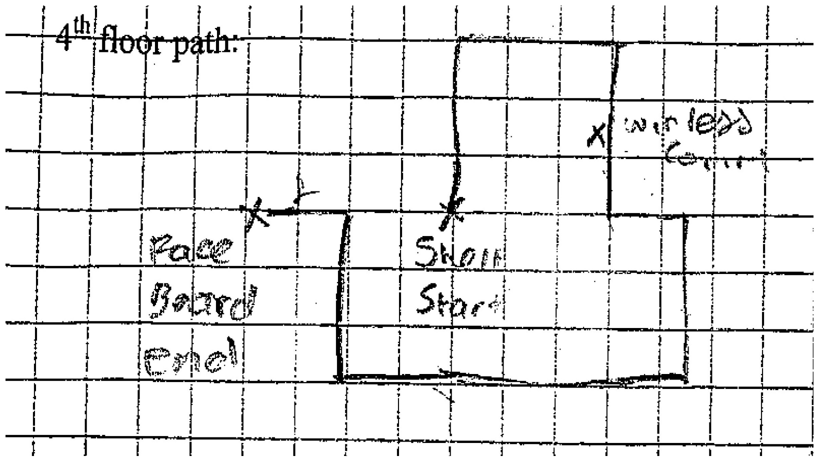


Figure 31: Drawing of $4^{th}$ floor path. All pathways are in the correct position and angle. Participant scored 8 out of 8.

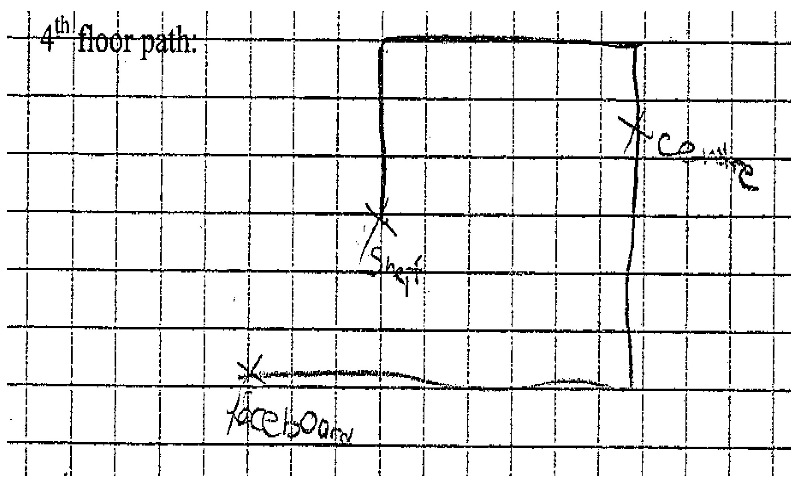


Figure 32: Drawing of $4^{th}$ floor path. Pathways are drawn are in the correct position, however some are missing. Participant scored 5 out of 8.

Appendix E

## **Path Pattern Identification Questionnaire**

Did you notice any similarities between the path taken on the 3rd and 4th floor?

Please circle YES or No

IF YES please explain:

Appendix F

**Directional Information Questionnaire**

**In this wayfinding task you were asked to remember the location of landmarks along a route. Please circle whether you had to turn left, right or go straight from each landmark listed below in order to travel from the start to the end of the route. (Please note: landmarks listed below are not presented in the same order they are along the path.)**

(1) Landmark: mammoth
LEFT RIGHT STRAIGHT

(2) Landmark: bison skeleton
LEFT RIGHT STRAIGHT

(3) Landmark: bench
LEFT RIGHT STRAIGHT

(4) Landmark: lounge

LEFT RIGHT STRAIGHT

(5) Landmark: face board

LEFT RIGHT STRAIGHT

(6) Landmark: train

LEFT RIGHT STRAIGHT

(7) Landmark: shelf

LEFT RIGHT STRAIGHT

(8) Landmark: snowflake door

LEFT RIGHT STRAIGHT

(9) Landmark: dinosaur

LEFT RIGHT STRAIGHT

(10) Landmark: Nanotechnology Institute

LEFT RIGHT STRAIGHT

(11) Landmark: Center for Wireless Communication

LEFT RIGHT STRAIGHT

(12) Landmark: balcony

LEFT RIGHT STRAIGHT

Appendix G

**Spatial Relationship Questionnaire**

**The "X"s below represent the approximate position of landmarks presented along the path. In each diagram, 2 landmarks are labeled. Please identify the 3rd landmarks location relative to the other 2 landmarks position by circling the X that best represents its position. (Please note: landmarks in each question may be on different floors)**

1) Mammoth?

**X**

X (Nanotechnology Institute)

**X** X (balcony) **X**

**X**

2) Train?

**X**

**X** X (Nanotechnology Institute) **X**

X (dinosaur)

**X**

3) Mammoth?

X bison **X**

**X**

**X** X balcony

**X**

4) Wooden Benches?

**X**

X bison

**X** X balcony **X**

**X**

**5)** Lounge? **X**

**X** dinosaur

**X** X balcony **X**

**X**

**6)** Face board**?**

**X**

X lounge

**X** X balcony **X**

**X**

7) Wooden Benches?

**X**

X bison

**X** X Snowflake door **X**

**X**

8) Face board?

**X**

X Center for communication

**X** X lounge **X**

**X**

Appendix H

**Simulator Sickness Questionnaire**

Instructions: Please provide a rating for each of the symptoms listed below

| **Symptom** | Rating | | | |
|---|---|---|---|---|
| **General Discomfort** | None | Slight | Moderate | Severe |
| **Fatigue** | None | Slight | Moderate | Severe |
| **Headache** | None | Slight | Moderate | Severe |
| **Eye Strain** | None | Slight | Moderate | Severe |
| **Difficulty Focusing** | None | Slight | Moderate | Severe |
| **Increased Salivation** | None | Slight | Moderate | Severe |
| **Sweating** | None | Slight | Moderate | Severe |
| **Nausea** | None | Slight | Moderate | Severe |
| **Difficulty Concentrating** | None | Slight | Moderate | Severe |
| **"Fullness of the Head"** | None | Slight | Moderate | Severe |
| **Blurred Vision** | None | Slight | Moderate | Severe |
| **Dizzy (eyes open)** | None | Slight | Moderate | Severe |
| **Dizzy (eyes closed)** | None | Slight | Moderate | Severe |
| **Vertigo** | None | Slight | Moderate | Severe |
| **Stomach Awareness** | None | Slight | Moderate | Severe |
| **Burping** | None | Slight | Moderate | Severe |
| **Other: Please explain** | | | | |

"Stomach Awareness" is usually used to indicate a feeling of discomfort, which is just short of nausea.

Appendix I

## Spatial Anxiety Scale

**In this questionnaire you will be asked to rate the level of anxiety you think you would feel in eight situations pertaining to indoor and outdoor wayfinding tasks. After each statement, circle a number to indicate your level of agreement with the statement.**

**Circle "1" if the situation would not make you anxious, and "7" if it would make you very anxious, or some number in between if your agreement is intermediate.**

1) Leaving a store that you have been to for the first time and deciding which way to turn to get to a destination.

Not at all 1 2 3 4 5 6 7 very much

2) Finding your way out of a complex arrangement of offices that you have visited for the first time.

Not at all 1 2 3 4 5 6 7 very much

3) Pointing in the direction of a place outside that someone wants to get to and has asked you for directions, when you are in a windowless room.

Not at all 1 2 3 4 5 6 7 very much

4) Locating your car in a very large parking lot or parking garage.

Not at all 1 2 3 4 5 6 7 very much

5) Trying a new route that you think will be a shortcut without the benefit of a map.

Not at all 1 2 3 4 5 6 7 very much

6) Finding your way back to a familiar area after realizing you have made a wrong turn and become lost while driving.

Not at all 1 2 3 4 5 6 7 very much

7) Finding your way around in an unfamiliar mall.

Not at all 1 2 3 4 5 6 7 very much

8) Finding your way to an appointment in an area of a city or town with which you are not familiar.

Not at all 1 2 3 4 5 6 7 very much

Appendix J

**Study 3 Landmarks**

| | |
|---|---|
| mailbox | bike stand |
| food stand | construction sign |
| bench | No u-turn sign |
| phone booth | pedestrian crossing sign |
| flower pot | swimming pool |
| basketball net | right-turn sign |
| rock | yield sign |
| parking sign | tomb stone |
| kangaroo sign | tent |
| arrow sign | traffic lights |
| child crossing sign | Canadian flag |
| garbage dump | mailbox |
| bus stand | water tank |
| food sign | umbrella |
| motor cycle | house |
| bush | flower pot |
| highway sign | bush |
| fire hydrant | map board |
| gas pump | coffee shop |
| garbage can | lodge |
| crane | lighthouse |