GENDER DIFFERENCES IN VIRTUAL ROUTE LEARNING

by

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ABSTRACT

Past studies have found evidence of gender differences in route-learning strategies, indicating that men rely on configurational strategies (e.g., cardinal directions) and women rely on topographic strategies (e.g., landmarks). Whether and how these gender differences in route-learning strategies extend to virtual environments is not fully known. In this dissertation, I investigated gender differences in learning virtual routes from two frames of reference—egocentric and allocentric. One hundred and twenty participants volunteered for the two experiments. After completing two tests of spatial abilities, the participants viewed four separate virtual routes and their eye movements were recorded. Afterwards, they provided written route directions. In the egocentric viewpoint experiment, I found no support for the hypotheses predicting that men and women would differ in configurational and topographic route-learning strategies (visual and written). There were significant gender differences in configurational strategies when I analyzed a subset of compass users, suggesting that there is a more complex relationship between gender and virtual route-learning strategies than previously assumed. In part, visual scanning of route elements was significantly correlated with written directions. The predicted gender differences in spatial abilities (object location memory and mental rotation) were significant, but spatial abilities only partially correlated with written directions and eye fixations. Unexpectedly, the results yielded a significant negative correlation
between women’s scores on the object location memory and written references to landmarks.

In the allocentric viewpoint experiment, gender differences in route-learning strategies were significant or trended towards significance. Furthermore, visual scanning of the virtual route was significantly correlated with providing written directions. As in the egocentric viewpoint experiment, gender differences in spatial abilities were significant, but these abilities rarely correlated with route-learning strategies.

Generally, the experimental results indicate that gender differences in virtual route-learning strategies are significant only under specific frames of reference. As well, allocating eye fixations on topographic and configurational elements of the environment correlates with making written references to those elements, regardless of viewpoint. Lastly, the use of a specific virtual route-learning strategy is not extensively associated with mental rotation and object location memory abilities, contradicting past assumptions about this relationship.

**Keywords:** Gender differences; route learning; virtual environments; spatial abilities; mental rotation; object location memory; eye movements; direction giving; frames of reference; egocentric; allocentric.
ACKNOWLEDGEMENTS

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## GLOSSARY

<table>
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<tr>
<td>Allocentric viewpoint</td>
<td>A viewing frame of reference in which the environment is visually defined by external objects such as landmarks (Ruggiero, Ruotolo, &amp; Iachini, 2009). This frame of reference is environment-centred (Shelton and Pippitt, 2007), potentially allowing the viewer to visualize and mentally represent its structure holistically as a 3D object (Lanca, 1998).</td>
</tr>
<tr>
<td>Attention</td>
<td>Attention refers to the allocation of mental focus on stimuli for further perceptual, sensory, and cognitive manipulation (Hoffman &amp; Subramaniam, 1998; McCormick, 1997; Posner, 1980).</td>
</tr>
<tr>
<td>Cardinal directions</td>
<td>An artificial worldwide coordinate system defined by four main cardinal points: North, South, East, and West (Dabbs, Chang, Strong, &amp; Milun, 1998).</td>
</tr>
<tr>
<td>Cognitive map</td>
<td>A mental representation of the environment (Tolman, 1948; Iaria et al., 2009).</td>
</tr>
<tr>
<td>Configurational route-learning strategy</td>
<td>A route-learning strategy based on the mental processing of worldwide coordinate information such as distant landmarks, metric distances, and cardinal points (Dabbs et al., 1998).</td>
</tr>
<tr>
<td>Degrees visual angle</td>
<td>The unit of measurement for visual angles (Coren, Ward, &amp; Enns, 1999).</td>
</tr>
<tr>
<td>Direction giving</td>
<td>The communication of route directions, which is used an experimental technique by measuring the frequency of words associated with a given wayfinding strategy (Allen, 2000).</td>
</tr>
<tr>
<td>Egocentric viewpoint</td>
<td>A viewing frame of reference in which the environment is defined from the traveller’s singular point of view or first-person perspective (Ruggiero et al., 2009; Vidal, Amorim, &amp; Berthoz, 2004).</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Eye tracker</td>
<td>An electronic instrument used to record a person’s ocular behaviour. Eye tracking metrics include fixation frequency, duration, dwell time, saccades, and pupil size.</td>
</tr>
<tr>
<td>Fixation</td>
<td>The area on which the eye remains relatively still for 200 ms or more (Rayner, 1998).</td>
</tr>
<tr>
<td>Frame of reference</td>
<td>The orientation and direction from which objects in the environment are perceived (Leone, 1998; Vidal et al., 2004).</td>
</tr>
<tr>
<td>Gazepoint</td>
<td>An area in which the eye remains relatively still below the fixation duration threshold (less than 200 ms in this dissertation).</td>
</tr>
<tr>
<td>Game experience</td>
<td>A variable operationalized as the number of hours per week that a person engages in video game playing.</td>
</tr>
<tr>
<td>Gender</td>
<td>Man or woman. The term used for the male and female members of the human species. Often associated with culture.</td>
</tr>
<tr>
<td>Handedness</td>
<td>A person’s dominant hand- left or right.</td>
</tr>
<tr>
<td>Landmark</td>
<td>A salient object with a particular shape and structure that serve as an aid during wayfinding (Jansen-Osmann and Wiedenbauer, 2004)</td>
</tr>
<tr>
<td>Learning</td>
<td>In its broadest sense, it refers to the “durable modification of behavior in response to information acquired from specific experiences” (Alcock, 2005).</td>
</tr>
<tr>
<td>LookZone</td>
<td>A region around an object of interest on a computer screen, graphically defined using the analysis software Gazetracker. The Lookzone is used to demarcate areas of interest for eye movement analysis (Lankford, 2000).</td>
</tr>
<tr>
<td>Magnetic head tracking</td>
<td>The determination of head position and orientation measured in six degrees of freedom at a distance of up to 36 inches from reference source (Applied Science Laboratories, 2001).</td>
</tr>
<tr>
<td>Mental object rotation</td>
<td>A spatial ability that allows a person to visualize and rotate a 3D mental representation of an object. This ability is hypothesized to be associated with the use of a configurational route-learning strategy (Voyer, Voyer, &amp;</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Navigation</td>
<td>The term is synonymous with wayfinding in that it refers to a process of learning one’s position in relation to an origin and a destination. Navigation is a nautical term, which is often used in the context of virtual environments. Wayfinding refers to the processing of spatial information through any means/medium, and traditionally refers to the physical environment (Hochmair and Frank, 2000).</td>
</tr>
<tr>
<td>Object location memory</td>
<td>A spatial ability that allows the accurate recall of the location of previously seen objects. This ability is believed to be associated with a landmark route-learning strategy (Eals and Silverman, 1994; Silverman and Eals, 1992).</td>
</tr>
<tr>
<td>Route learning</td>
<td>The cognitive integration of paths, landmarks, junctions, locations, cardinal information and so forth into a cohesive mental structure (Galea and Kimura, 1993). As defined in this dissertation, route learning does not necessarily require the active selection of paths segments when travelling along a route.</td>
</tr>
<tr>
<td>Saccade</td>
<td>A ballistic eye movement that is made between fixations. Its velocity can reach up to 500 degrees per second (Rayner, 1998).</td>
</tr>
<tr>
<td>Sex</td>
<td>The male or female member of a species.</td>
</tr>
<tr>
<td>Spatial abilities</td>
<td>Generally, spatial ability refers to the mental representation and manipulation of symbolic or non-linguistic information through space (Voyer et al., 1995).</td>
</tr>
<tr>
<td>Spatial accuracy</td>
<td>Spatial error between true eye position and computed measurement, which is less than 1 degree on ASL’s 504 eye tracker (Applied Science Laboratories, 2001).</td>
</tr>
<tr>
<td>Topographic route-learning strategy</td>
<td>A route-learning strategy that is based on reliance of salient objects in the environment for orientation. The use of landmarks and relative directions (left and right) are examples of topographic strategies (Dabbs et al., 1998).</td>
</tr>
<tr>
<td>Visual angle</td>
<td>A measure of the size of the retinal image (Coren et al., 1999).</td>
</tr>
</tbody>
</table>
| Visual attention                          | The allocation of sensory and perceptual focus across the
visual field (Henderson, 2003; Horrey, Wickens, & Consalus, 2006). In this dissertation, visual attention was operationally defined in terms of the amount of time that a participant spent looking at the area of interest.

<table>
<thead>
<tr>
<th><strong>Virtual environment</strong></th>
<th>“A synthetic, spatial (usually 3D) world” (Bowman et al., 2005) that can be viewed from multiple perspectives. A virtual environment can act as a metaphorical representation of the real world.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wayfinding</strong></td>
<td>The selection of route segments between a starting point and an endpoint. The concept is synonymous with navigation (Hochmair and Frank, 2000).</td>
</tr>
</tbody>
</table>

1: INTRODUCTION

1.1 Overview

Dynamic virtual environments are used across a variety of domains such as industrial design, psychiatric treatment, video games, online social worlds, training and simulation, scientific visualization, and geospatial applications. The realistic nature of three-dimensional (3D) digital environments provides an opportunity to improve on traditional two-dimensional (2D) methods of interaction and information design. Learning the structure of and navigating a virtual environment, however, can prove challenging for users, even when the environment is designed around real-world metaphors (Bowman et al., 2005). With the advent of more computationally powerful technologies (e.g., video game systems, geospatial applications, and 3D social spaces) the complexity and realism of virtual worlds is increasing. Ease of navigation will be an important goal of virtual environment design, as it is known that problems with navigation and orientation in virtual environments are rather common (Mills and Noyes, 1999, Wann & Mon-Williams, 1996). Therefore, it is crucial that we examine the factors (internal and external) that lead to effective and efficient learning of virtual spaces.

It is often assumed that because of their realistic qualities, 3D elements can ease the navigation process within virtual environments, but as Bowman et al. (2005) point out, this is not necessarily the case and a “more thorough
treatment of the subject is needed”. The navigation challenges encountered may in part stem from the additional spatial complexity that defines the geometric configuration of the virtual space (Sadeghian, Kantardzic, Lozitskiy, & Sheta, 2006). As in the real world, a virtual environment is often encountered piece-meal during navigation and this partial information must somehow be cognitively integrated to build up a mental structure of the path being travelled. The exact characteristics of the strategies that allow us to mentally integrate the environment are not yet known, and because of their association with navigation performance, it is important to examine them closely.

In real environments, we rely on a variety of cues to move from one location to another. These cues include salient objects (e.g., landmarks) that define the topography of the landscape and abstract elements (e.g., cardinal points) that delineate the Euclidean configuration of the space (Dabbs et al., 1998; Ecuyer-Dab & Robert, 2004). In the physical world, we are usually able to learn a route and orient ourselves without much difficulty. In a virtual environment, however, the task is more difficult because we do not have access to the same cues (e.g., vestibular signals, wide field of view, and binocular cues) found in the real world, or the navigation scheme may not permit the effective and efficient processing of information (Bowman et al., 2005). Moreover, virtual environments are not necessarily constrained by the laws of real-world physics such as gravity, and this lack of physical realism may lead to difficulties in the integration of the space (Bowman et al., 2005).
Successful navigation in a virtual environment is not simply a matter of using “intuitive” metaphors that may afford specific actions (e.g., a door handle affords grabbing), but is also associated with a host of processes such as movement planning, path integration, object recognition, points of view, structure of spatial knowledge, and so forth (Burigat & Chittaro, 2007; Hahm, Lee, Lim, Kim, Kim, & Lee, 2006; Montello, Richardson, Ishikawa, & Lovelace, 2006; Vidal et al., 2004). Thus, while navigation in a virtual environment is influenced by the external (structural) characteristics of the environment, it is also influenced by the internal (perceptual and cognitive) characteristics of the user. What is intuitive for one user in a given virtual environment may be disorientating for another. Therefore, to develop appropriate navigation schemes, it is necessary to understand the mental strategies and abilities that users rely on to process the spatial structure of the virtual space.

The theoretical constructs devised to explain real-world navigation differ in the specifics but “have in common an emphasis on progression from a less integrated to a more coordinate spatial framework that develops with experience” (Devlin & Bernstein, 1995). Many questions remain about what elements of the environment are necessary for successful integration of the spatial framework; how such elements are processed by our sensory and perceptual systems; how they are cognitively integrated; and what strategies are useful in their communication. A number of experiments have shown that not everyone learns a route in the same manner. In particular, research has found that men and women rely on different strategies when giving directions (e.g., Dabbs et al.,
1998; Ward, Newcombe, & Overton, 1986), which is assumed to be an indication of how the environment was initially acquired and subsequently structured in the mind. Further, given that route learning requires the processing of spatial information, a host of cognitive abilities (e.g., object location memory and mental rotation) have been associated with the mediation of route acquisition, integration, and externalization (Dabbs et al., 1998; Choi & Silverman, 2003; Rahman, Anderson, & Govier, 2005; Tlauka, Brolese, Pomeroy, & Hobbs, 2005; Hegarty et al., 2006). Yet the exact relationship between spatial abilities and the processes associated with the acquisition and communication of a route remains unknown, particularly as it pertains to virtual spaces.

In this dissertation, I report two experiments that sought to understand route learning by examining gender differences within virtual environments. I investigate the relationship between men and women’s attentional behaviour, spatial abilities, and direction-giving strategies. In addition, I examine the theoretical, experimental, and practical contributions of this research to our understanding of human navigation in virtual spaces.

1.2 Objectives and considerations

The immediate theoretical objectives of this project are to identify and examine the strategies and abilities employed by participants to learn a virtual route. This knowledge, I believe, can increase our understanding of human spatial cognition associated with navigation behaviour and its possible historical development. The practical objectives of the project are to investigate how knowledge of human spatial strategies and abilities can be utilized in the design
of virtual environments. Differences between virtual environments are unlikely to alter the fundamental nature of the cognitive and attentional processes that humans use to navigate them (though the manner in which those processes are expressed may indeed be influenced). Thus, examining our abilities to integrate spatial information can lead to further insights into how virtual environments can be utilized to increase our understanding of human navigation behaviour.

The experimental framework described in this dissertation is confirmatory in nature. Based on past theories and experimental evidence, I devised a set of hypotheses and tested them using methods and techniques gleaned from environmental and cognitive psychology. Given that virtual environments are a relatively recent development, however, this project contains several exploratory components that have not received much scrutiny in the literature. For example, the relationship between eye movements and complex cognitive processes has received little attention, particularly where virtual environments are concerned. So it was necessary to utilize techniques that have been rarely implemented in route learning studies or belong to different areas of research altogether. Therefore, to examine the process of virtual path integration, this project relies on a mixture of confirmatory and exploratory experimental methodologies.

As the title of the dissertation indicates, I focused on the investigation of gender differences in virtual route learning. Research into gender differences inevitably raises questions about the role of nature and nurture in our psychological development. On the one hand, it may be assumed that instinct is an ingrained biological imperative that cannot be changed by the environment.
On the other hand, it may be assumed that learning is a flexible ability that can be easily modified by experience. As Alcock (2005) points out, these dichotomous views do not stand on solid empirical ground. Instincts are not purely genetic and can also be modified by experience; learning is not solely the end result of experience but can also be influenced by biological factors (Alcock, 2005). So, while many of the ideas described in this dissertation have their basis in evolutionary biology, it makes no claims about the degree to which nature or nurture determine human navigation strategies and abilities.

1.3 Contributions

As 3D virtual environments proliferate and become more graphically complex, the study of men and women’s strategic ability to acquire, integrate, and communicate spatial information becomes increasingly important. These strategies and abilities have in the past been associated with performance (e.g., Cornell, Soronsen, & Mio, 2003; Kato & Takeuchi, 2003). Yet, many theoretical and methodological aspects of this type of investigation have only recently received attention. It is not fully known the extent to which they impact navigation performance in virtual environments. To examine these issues, I conducted two experiments that sought to understand human route-learning abilities and strategies within a virtual environment. While the experiments reported in this dissertation did not include active manipulation of the environment by participants, the knowledge gained acts as precursor to the development of effective and efficient methods of interaction by making the following theoretical, methodological, and practical contributions:
• Theoretical contributions

○ Virtual and real-world route learning: Although the main focus of the study is the examination of behaviour pertaining to the learning that takes place within a virtual environment, it is reasonable to expect that the findings are also relevant to our understanding of route learning in real-world settings (see Lloyd, Persaud, & Powell, 2009). Our understanding of how humans acquire, integrate, and communicate a route in the real world has been partly limited by the lack of research in realistic settings. Conducting an experiment in a virtual environment, which increases the realism of the experimental setting, gives us access to elements missing from more traditional lab settings like maps. It is thus expected that the experiments reported in this dissertation are pertinent not only to our understanding of virtual but also real-world route learning.

○ Eye movements: To develop a mental model of a real or a virtual environment, it is necessary to visually integrate its spatial elements; yet, the extent to which we can glean this complex process through the analysis of eye movement behaviour is unknown. Neither is it known the extent to which the eye tracking record can help us identify any differences between groups. This project contributes to our
understanding of how we allocate visuo-attentional resources to construct a mental model of the environment when learning a route and identifies any potential differences between men and women. It also contributes to our knowledge of the relationship between eye movements and processes associated with route learning (i.e., spatial abilities and direction giving).

- **Spatial abilities**: Examination of gender differences in spatial abilities has been a topic of research for over five decades (Voyer et al., 1995). Yet our understanding of the relationship between spatial abilities and spatial behaviours like route learning is limited. Even less is known about the role that spatial abilities play in the acquisition and integration of virtual information. In this dissertation, I report one of the few investigations into the association between spatial abilities and route learning, and it thus contributes to our understanding of the cognitive mechanisms underpinning route learning.

- **Frames of reference**: Participants in the two experiments conducted viewed the virtual environment from different frames of reference- egocentric and allocentric. Thus, the results demonstrate how eye movements, direction giving strategies, and spatial abilities are deployed under varying
viewpoints. This is significant because many route-learning studies have been conducted in settings that present information from a single point of view, and the extent to which this restriction affects performance has not been extensively addressed.

- **Ultimate mechanisms of behaviour**: As Alcock (2005) points out, even if all proximate causes (e.g., cognitive, genetic, and hormonal) of a given behaviour were understood, many questions would remain about its ultimate (evolutionary) historical development. The focus of this dissertation is on the immediate proximate mechanisms that influence route learning, but it also contributes to our understanding of the possible historical pathways that have led to their current expression in human spatial cognition.

- **Methodological contributions**
  - **Direction giving**: This experimental paradigm has been applied in several investigations of route learning using cartographic maps. It has rarely been applied in the investigation of virtual path integration. This project contributes to our understanding of how this technique allows us to understand virtual route learning.
  - **Eye tracking**: As human-computer interaction (HCI) research methodology, eye-tracking techniques have
garnered much attention in recent years. Yet, even though the technology has become more affordable, effective, and efficient in its implementation, many challenges still remain. This project describes a procedure that to my knowledge has not been implemented in previous research on virtual environments. Although many challenges still remain, this dissertation furthers our understanding of how eye-tracking techniques can be utilized to understand path integration within dynamic virtual environments.

- **Practical contributions**
  - **Virtual environments**: The design of virtual environments can be challenging because of the complexity introduced by dynamic 3D elements that define their spatial characteristics. While it is impossible to address every single element that influences route learning, this dissertation contributes to our understanding of three key elements that are relevant to their design. These elements are the salient topographic objects of the environment; the configurational information gleaned from a cardinal coordinate system; and the frame of reference (viewpoint) from which the environment is observed. In this project, I seek to demonstrate the extent to which the processing of these elements is associated with the spatial strategies and abilities employed by participants.
This knowledge can then be applied to the design of virtual environments in a way that supports those strategies and abilities.

1.4 Thesis guide

In Chapter 1, I provide an overview of the main topics addressed in this dissertation. In particular, I discuss the importance of understanding navigation within virtual environments. I explore these issues in terms of the underlying sensory, perceptual and cognitive elements associated with virtual navigation.

In Chapter 2, I describe the theoretical and experimental ideas that have guided route-learning research up to this point. These ideas include the ultimate (evolutionary) and proximate (sensory, perceptual, and cognitive) causes of route-learning behaviour. I describe the traditional methods of investigation, which include map reading, direction giving, eye movements, and tests of spatial abilities. Lastly, I state the research questions, predictions, exploratory topics, and research design adopted in this project.

In Chapter 3, I expand on the experimental framework and outline the specific research hypotheses I set out to investigate. I summarize issues and considerations related to the investigation of virtual environments, route learning, direction giving, and eye movements. I further expand on the relationship between eye movements, attention, and higher cognitive states. I describe the role of spatial abilities in route learning and the possible influence of frames of reference in route learning behaviour.
In Chapter 4, I describe the exact experimental procedure applied to the investigation of route learning, including the tasks, tests, and variables. Specifically, I focus on the methodology I used to analyze direction giving, eye movements, spatial abilities, demographics, and frames of reference (viewpoints). I report on the characteristics of the sample population. I outline the materials and the sequence of experimental tasks and events, including the changes made to the study as a result of pilot testing.

In Chapter 5, I report the experimental results obtained from the egocentric viewpoint experiment, in which participants learned a route seen from a first-person perspective. In Chapter 6, I report the results obtained in the allocentric viewpoint experiments, in which participants viewed the route seen from a top-down perspective.

In Chapter 7 and 8, I discuss the results from the egocentric and allocentric viewpoint experiments respectively.

In Chapter 9, I describe the theoretical, technical, and experimental limitations of the two studies conducted.

In Chapter 10, I provide concluding comments on the implication of the results in light of the research questions posed in Chapter 2. In addition, I discuss possible areas of research that would be interesting and useful to pursue in future studies.
2: THEORETICAL BACKGROUND

2.1 Overview

The effective and efficient processing of virtual routes is dependent not only on the structural characteristics of the virtual environment itself but also on the internal mechanisms that allow us to acquire, integrate, and communicate route information. The interaction between external and internal mechanisms leads to the development of spatial mental structures, which we rely on when travelling between a point of origin and a destination (Hochmair and Frank, 2002). Therefore, to improve the design of virtual environments, it is important to understand the nature of these mechanisms and how they interact with each other to help us orient ourselves along a virtual route.

Modern virtual environments vary in complexity and differ in a number of characteristics. In this dissertation, I focus on two main characteristics that define the spatial structure of virtual environments: topographic and configurational. These two spatial elements have been investigated in past research (e.g., Galea & Kimura, 1993; Dabbs et al., 1998; Ward et al., 1986), but for the most part, previous investigations were conducted within non-virtual environments. Throughout this dissertation, I often cite route-learning research conducted in non-virtual environments, which raises questions of ecological validity and transference. Yet, there is little reason to believe that the findings from non-virtual research are irrelevant to virtual route learning. After all, from an
evolutionary standpoint (Darwin, 1859), any organism’s navigation abilities have been in development for millenia (Alcock, 2005; Ecuyer-Dab & Robert, 2004), it is unlikely that those abilities would be substantially modified, or new ones developed, in the span of decades, which is the time span that virtual environments have existed. Moreover, recent research has shown that route-learning performance in virtual environments transfers to real environments (Lloyd et al., 2009), suggesting that similar mental processes mediate learning both types of environments.

There is no question that just like a map differs from the real-world environment it depicts, a virtual environment also differs in many respects from a real-world environment. Yet, in several ways, the spatial characteristics of virtual environments are similar to the characteristics of the physical world. Like real environments, virtual environments exist within a geometrical space, defined (though not necessarily explicitly so) by their Euclidean configuration. This geometrical configuration spans the volume of the virtual space in which the environment is contained, and as in real-world environments, it is not always visually available in its entirety. In the real world, the configurational or Euclidean structure of the environment is usually denoted by formalized schemes such as cardinal directions and metric distances or by informal ones such as the location of stars or the trajectory of the sun as it crosses the sky (Dabbs et al., 1998; Jansen-Osmann, Schmid, & Heil, 2007; Jansen-Osmann & Wiedenbauer, 2004; Miller & Santoni, 1986; Silverman & Choi, 2006). Similarly, a variety of formal and informal schemes have been developed to convey the configurational
structure of virtual space. The aim of these systems, whether real or virtual, is to provide spatial information that will allow a traveller to integrate the worldwide Euclidean configuration of the space and orient herself/himself along a route.

The topographic layout of virtual and non-virtual environments is denoted by a wide array of natural and artificial features, which are characterized by their visual saliency and relative locations along the route (Dabbs et al., 1998). These salient topographic features are termed landmarks, which may be natural or artificial (Dabbs et al., 1998; Choi & Silverman, 1997; Galea & Kimura 1993; Ward et al., 1986). There is no standard method of determining what truly constitutes a landmark. Any environmental feature may be used as a landmark during navigation; its characteristics determined by whether they act as an organizing concept (e.g., a reference point) or a navigation aid (Jansen-Osmann & Wiedenbauer, 2004).

When travelling along a path, we rely on a variety of route-learning strategies, which emphasize the perceptual acquisition, storing, and processing of different types of information. If reliance is placed on the salient features of the environment such as landmarks and relative directions, the strategy is called topographic; if reliance is placed on the Euclidean or world coordinate information of the environment, the strategy is defined as configurational (Choi & Silverman, 1997; Dabbs et al., 1998; Galea & Kimura 1993; Ward et al., 1986). The exact mechanisms and operations involved in the deployment of topographic and configurational route-learning strategies in the real world have not been extensively investigated and therefore are not fully known. Much less is known
about how these strategies are utilized in dynamic virtual environments. In this dissertation, I focus on questions related to route learning within virtual environments with the aim of understanding how men and women utilize distinct strategies and abilities to learn a path.

As is often the case in the psychological literature, it is useful to measure sample populations who exhibit large differences in behaviour, so as to more precisely pinpoint the parameters of the behaviour under scrutiny. Stemming in part from observations that men and women differ on certain spatial abilities like mental rotation, some route-learning researchers have focused on gender differences (e.g., Choi & Silverman, 1997; Dabbs et al., 1998; Galea & Kimura 1993; Ward et al., 1986). Much of the evidence that has been accumulated over the past couple of decades indicates that indeed gender differences in route learning do exist. The gender-based approach is important not only because it not only allows us to understand differences between men and women, but also because this knowledge can help us understand and improve general route-learning processes. Thus, while I focused on gender research, it should be kept in mind that this investigation is applicable in the wider context of human route-learning strategies and abilities, regardless of gender.

2.2 Route learning and virtual environments

As a research field within environmental psychology, *wayfinding* research aims to investigate the psychological mechanisms and processes associated with our ability to learn and navigate a route. The terms wayfinding and navigation are similar in meaning since they both involve selecting routes along a
network of segments between a point of origin and a destination (Hochmair & Frank, 2000). The concept of route learning, as used in this dissertation, is considered one aspect of wayfinding or navigation that does not necessarily involve actively selecting a path. To learn a route, we attend to and integrate various streams of information such as distances and cardinal trajectories; natural and artificial landmarks; and the spatial relationships between objects along the route (Dabbs et al., 1998). Learning in its broadest sense refers to the “durable modification of behavior in response to information acquired from specific experiences” (Alcock, 2005). So, while wayfinding/navigation encompasses a host of processes (e.g., path selection, dead reckoning, and psychomotor operations), in this dissertation I place emphasis on the learning that results from the visual integration and cognitive elaboration of virtual route information.

Configuration and topographic properties can take several forms and a traveller may rely on both to orient herself/himself along a route. The geometrical structure or configuration of an environment can be described “in terms of the relative position of points, lines, and angles” (Jansen-Osmann et al., 2007). Natural distal cues like the sun and the stars provide information about a route’s overall configuration. Artificial elements like metric distances and cardinal directions are formalized configurational properties of the environment. As mentioned, the environment can also be described in terms of the salient natural and artificial objects (landmarks) that shape its surface (Dabbs et al., 1998; Jansen-Osmann et al., 2007; Silverman & Choi, 2006). A navigator who in the
course of travel relies on the Euclidean geometry of the space is said to be using a *configurational* strategy; a navigator who relies on the salient feature of the environment is said to be using a *topographic* strategy.

Unlike two-dimensional (2D) virtual environments, 3D virtual environments resemble real-world settings spatially and may likely elicit similar route-learning processes. Traditional computer environments like web sites rely to a great extent on navigation elements and schemes confined to a 2D plane. Navigation in these 2D environments is usually accomplished by means of text hyperlinks, menus, and static icons. Navigation within a 3D virtual environment requires pseudo-realistic movement along networks of paths within the x, y, and z planes of the environment. Movement in virtual environments is pseudo-realistic in the sense that it does not require actual physical motion, yet a traveller may experience some of the factors experienced in real-world movement (e.g., optic flow, motion parallax, location displacement, and visual image transformations). It can be reasoned that, within certain limits, the same mental strategies and abilities operating when a traveller moves along a real path are operating when he/she moves along a virtual one.

Bowman et al. (2005) define virtual environments (VEs) as “a synthetic, spatial (usually 3D) world seen from a first-person point of view.” In this definition, the authors indicate that a VE is seen from a first-person perspective. I use the term VE more broadly to also include computer-generated environments that can be seen from multiple viewpoints such as first person (*egocentric*) and top down (*allocentric*). In their definition, Bowman et al. (2005)
also propose that a virtual environment’s view is “under the real-time control of the user.” For theoretical and experimental reasons, in this research, I take a more liberal approach, and though I acknowledge that real-time control is a characteristic of virtual environments, I do not provide control of viewpoint in the experiments.

Spatial information within a virtual environment can be acquired in several ways. As in cartographic maps, configurational information in a 3D virtual environment can be extracted through a variety of means, including metric distances and cardinal coordinates. The latter is reliant upon a graphical compass indicator, which is often oriented north up. There are some key differences, however, between compasses in a virtual environment and those on a map. On a map, all relevant information is visually available and the compass can remain static without the loss of directional meaning. In a virtual environment, the information is seen at a limited scale and from a specific azimuth, and so changes in direction lead to changes in orientation. This displacement can occur in multiple spatial dimensions (x, y, or z), making it necessary to update one’s position in relation to the cardinal frame with each shift of direction. When changes in direction are relatively few, updating one’s position in relation to a cardinal system can be done without the need to visually scan navigation aids such as the compass, but this strategy becomes more cognitively demanding when more changes in direction take place. Thus, to maintain a consistent representation of the environment’s coordinate frame in a
dynamic virtual environment, it may be necessary to attend to the compass more often than in a static map.

Although virtual landmarks lack some of the physical characteristics of real-world landmarks (e.g., life-sized scale), they usually contain more realistic properties than landmarks depicted in maps. Virtual landmarks can be explored from multiple points of view, possess a high degree of graphical realism, and behave in a spatially realistic manner (e.g., objects change size and position as one moves towards or away from them). These and other characteristics of virtual landmarks can be used to extract spatial information about a path, but it is not known precisely how this task is accomplished during navigation.

While virtual environments do provide a more realistic environment to investigate route-learning behaviours (Hochmair & Frank, 2000), conducting this research can be difficult because of the need to minimize extraneous variables, while still maintaining the general validity of the experience. Given the pseudo-realistic nature of virtual environments, a large set of factors may affect a user’s route-learning behaviour. Traditionally, researchers have investigated human-computer interaction by isolating the key elements of the virtual experience to reduce the amount of “noise” in the experimental setting. This approach has its limits because as virtual environments become more complex and as the tools of investigation become more precise, examining an interactive experience by breaking it down into constituent sub-components becomes exceedingly difficult. One runs the risk of simplifying the tasks and the environment to the point where the experience is no longer ecologically valid. Therefore, it is necessary to
balance the need for experimental control of the environment and the need for ecologically valid observations. For this reason, I took a liberal approach to the term virtual environment, foregoing some aspects of design (e.g., user control, colour, and textures) that would have increased realism at the cost of experimental precision. On the other hand, the environments tested in this project, remained relatively complex to elicit natural route-learning strategies and abilities.

2.2.1 Frames of reference in virtual environments

Route learning occurs in relation to cognitive representations of the environment viewed from a particular frame of reference, which under normal circumstances is aligned to a gravity-defined axis (Leone, 1998; Vidal et al., 2004). In daily life, we usually navigate the environment from a body-centred or egocentric frame of reference, viewing the environment from a first-person or eye–level perspective (Allen, 1997; Ruggiero et al., 2009). Allocentric frames of reference are object-like and world-centred representations of the environment, similar to the bird’s-eye-view depicted in maps (Allen, 1997; Aretz & Wickens, 1992; Ruggiero et al., 2009; Vidal et al., 2004). As we move through space, it is necessary to update the spatial representations of the environment, including the frames of reference, to successfully integrate the followed path and other elements of the environment (Vidal et al., 2004; Ruggiero et al., 2009). While reference frames refer to internal representations of the environment, they can be artificially manipulated in virtual environments through the use of viewpoints (e.g., first-person and top-down). We do not yet know the extent to which a given
frame of reference affects the strategies that we rely on to learn a route. This is an important area of research because in virtual environments information can easily be presented in different frames of reference and influence how we learn a route.

Understanding how frames of reference affect our route-learning strategies could lead to more effective design of virtual environments. While many of the most currently popular virtual environments (e.g., World of Warcraft) present information from an egocentric viewpoint, environments like Google Earth and Second Life are also able to present information from a top-down (allocentric) viewpoint. Are there differences in how we process spatial information from a given point of view? Previous research has found that when frames of reference are misaligned, causing nearby objects to appear to us in unusual orientations, our ability to recognize such objects is diminished (Leone, 1998). Evidence has also shown that when processing map information, participants mentally align different frames of reference using their spatial abilities (Aretz & Wickens, 1992). This is tentative evidence that the orientation and direction from which the environment is viewed influences how a traveller processes spatial information along a route.

Although past research shows that frames of reference affect our ability to cognitively map spatial structures (Tkacz, 1998; Vidal et al., 2004), it is not known exactly how frames of reference are related to the processing of configurational and topographic information. Some researchers posit that when navigating across large expanse of territories, we need to hold a ‘bird's-eye-view’
of our position relative to the global configuration of the environment (Dabbs et al., 1998). Furthermore, as hypothesized by Silverman and Eals (1992) and Ecuyer-Dab and Robert (2004), men’s ability to maintain this survey-level or allocentric reference frame is what allows them to attend to and maintain world-referenced information like cardinal directions. The suggestion is that one’s ability to map information onto a given frame of reference affects how that information is processed and this ability may differ between men and women. In a study by Lanca (1998), it was shown that men outperformed women in tasks related to the mental representation of 3D terrain (egocentric) from 2D contour maps (allocentric), providing some evidence that indeed men are likely to visualize and manipulate spatial information in a more holistic or allocentric manner than women. Unfortunately, this area of research has not been widely investigated. Therefore it is not possible to say to what extent (if any) frames of reference influence route-learning strategies. Nonetheless, given the prevalence of virtual environments with different frame of references, this area requires further research. Therefore, to further examine this topic, I conducted two experiments from two difference frames of reference or viewpoints. In the egocentric viewpoint experiment participants viewed a fictional virtual route from a first-person perspective; in the allocentric viewpoint experiment, participants viewed the same route from a top-down perspective. The results helped to further elucidate the role that frames of reference play in virtual route learning.
2.3 Gender and the evolutionary basis of route-learning strategies

Wayfinding is an area of research in environmental psychology that investigates the perception, acquisition, representation, and utilization of spatial knowledge when travelling along a route (Schmitz, 1997). As Hochmair and Frank (2000) indicate, the terms wayfinding and navigation are semantically similar and oftentimes used interchangeably in the literature. In keeping with this practice, I also use wayfinding and navigation as synonyms throughout this dissertation. I use wayfinding when referring to movement through the natural environment and navigation when referring to movement through a virtual world.

Previous research has shown that humans rely on a variety of strategies to travel along routes (Choi and Silverman, 2003; Dabbs et al., 1998; Saucier, Bowman, & Elias, 2003; Schmitz, 1999; Silverman, Mackewn, Fisher, Moro, & Olshansky, 2000). Generally, we rely on two categories of environmental information: The salient features along the route and the geometrical configuration of the space (Choi & Silverman, 2003; Galea & Kimura, 1993; Ward et al., 1986). To travel between a point of origin and a destination without becoming disoriented, we perform cognitive operations on the acquired information (Hochmair & Frank, 2000). This information is obtained from a variety of sources (e.g., kinaesthetic feedback, psychomotor coordination, and auditory information), but under typical circumstances we emphasize visual elements. Similarly, the focus of this research is learning that results from the visual scanning of virtual route information.
The nature of an organism's daily activities and the characteristics of the environment in which those activities are performed are assumed to influence the physical and cognitive mechanisms underlying the organism's behaviours (Alcock, 2005). The causes of those behaviours may be examined at *ultimate* and *proximate* levels of analysis. The ultimate causes of behaviour refer to the historical pathway that has led to current expression of the behaviour in light of evolutionary influences. The proximate causes of behaviour refer to the genetic and environmental interactions, as well as the underlying mechanisms that govern the behaviour in its present form. As Alcock (2005) points out, the proximate and ultimate levels of analysis are complimentary rather than antagonistic.

Research to date indicates that although we are able to use multiple route-learning strategies without much difficulty when prompted (Ward et al., 1986), men and women place *spontaneous* emphasis on different elements of the environment (Choi & Silverman, 2003; Dabbs et al., 1998; Galea & Kimura, 1993; Rahman Andersson, & Govier, 2005). Researchers have found that women rely on topographic features (i.e., landmarks and relative directions) and men rely on configurational properties of the environment (i.e., distances and cardinal directions) (Dabbs, et al., 1998). Why do these differences exist in the first place? Several theories have been proposed to account for the *ultimate* mechanisms that drive the evolution of gender differences in spatial abilities and route-learning strategies (Ecuyer-Dab & Robert, 2004; Silverman & Eals, 1992). These models emphasize the history of gender-based division of labour, child
rearing practices, and mate-selection pressures. The foraging model advocated by Eals and Silverman (1994) posits that prehistoric division of labour led to sexually dimorphic spatial behaviours such as route-learning strategies; the ability to remember the location of objects; and the ability to mentally manipulate visualized objects (i.e. mental rotation). Proponents of the foraging model posit that in the ancient past, women engaged mainly in gathering activities across a small activity range. Foraging activities associated with gathering encompass a wide variety of behaviours, and they are mainly accomplished through visual scanning of the vegetation matrix in which foodstuffs are embedded. Gatherers capable of learning and remembering the location of food sources, as well as “the contents of object arrays and the spatial relationships of the objects to one another”- would have been successful in their foraging activities (Silverman & Eals, 1992). If men and women did in fact differed in gathering activities, then it is theorized that over the course of evolution, gender differences in object location memory also increased in favour of women.

Evolutionary models of gender differences in labour division also include the idea that in the past, men engaged primarily in game hunting, and this entailed travelling across large spans of territory (Silverman & Eals, 1994). The spatial abilities required to successfully track and trap prey would have promoted behaviours that rely on the representation and manipulation of the environments' geometric characteristics. For instance, a hunter travelling an unfamiliar territory would need to rely on survey-level information (e.g., bird's-eye-view of the environment) to keep proper orientation, while ignoring most proximate
landmarks along the way (Dabbs et al., 1998; Silverman et al., 2000). As well, the need to successfully find his or her way in an unfamiliar terrain while engaging constantly moving targets would have led to a reliance on cognitive operations that mediate three-dimensional visualization and mental transformations of objects (Silverman & Eals, 1994; Silverman et al., 2000). Thus, over the course of evolution, the navigation strategies and spatial abilities associated with game hunting and extensive ranging would have favoured men.

The foraging model places division of labour as one of the driving forces behind gender differences in route learning. It is not, however, the only explanation. Another model takes into account behavioural mechanisms related to sexual selection. Gaulin and FitzGerald (1986) propose that the need to find and secure mates encouraged men to navigate larger ranges than those traversed by women. Navigation across large swaths of territory required the use of spatial skills and behaviours that differed from those needed to navigate smaller, and therefore more familiar, environments. Ecuyer-Dab and Robert (2004) have proposed a model for navigation-related differences men and women based on the synthesis of various ideas. They indicate that foraging, child rearing, and sexual selection have led to differences in navigation behaviour and spatial skills. Men's larger activity range is attributed to sexual selection processes, while the size of women's activity ranges is associated with activities related to a “strong concern for survival” of self and offspring (Ecuyer-Dab & Robert, 2004).
The three models suggest that the size of one's activity range and the types of activities carried out influenced the differential evolutionary development of men and women's spatial behaviours and skills. Extensive ranging would have promoted navigation strategies based on configurational or global elements of the environment such as cardinal directions and metric distances (Dabbs et al., 1998; Schmitz, 1999). Relying on landmarks when travelling across large and varied territories would likely tax the memory system, making this strategy unreliable during navigation (Ecuyer-Dab & Robert, 2004). The spatial abilities associated with travelling far distances may involve the mental manipulation of visualized figures (Ecuyer-Dab & Robert, 2004). This would be the case if the internalized representation of the environment were treated like an object that can be manipulated and viewed from multiple angles. If so, then psychometric tests of spatial skills related to mental rotation should demonstrate a male advantage and be associated with configurational route-learning strategies.

Route learning within small activity ranges, on the other hand, has been associated with a reliance on topographic knowledge of the environment, including nearby landmarks and relational directions such as left and right (Dabbs et al., 1998; Galea & Kimura, 1993). Encoding a relatively small amount of information over narrow ranges would not tax memory processes and would therefore be an effective strategy during navigation (Ecuyer-Dab & Robert, 2004). Thus, short-range navigation would be closely associated with one's ability to remember specific objects and their relative locations (Ecuyer-Dab & Robert, 2004; Schmitz, 1999). Tests measuring object location abilities should
show an advantage for women and be related to a topographic route-learning strategy.

2.4 Gender differences in route learning- current research

Although gender differences in route learning have not been extensively investigated, the findings up to date indicate men and women do rely on different strategies. Results from various experiments have shown that women rely on topographic elements (i.e., landmarks and relative directions) and men rely on configurational properties of the environment (i.e., metric distances and cardinal directions) to learn a route (Choi & Silverman, 2003; Dabbs et al., 1998; Galea & Kimura, 1993; Lawton, 2001; Jansen-Osmann et al., 2007; Ward et al., 1986). While some research has not found support for the hypothesized differences between men and women (e.g., Devlin, 2003), it is generally agreed that gender differences in route learning do exist. But many outstanding questions still remain regarding the exact mechanisms that underlie route-learning processes.

In discussing gender differences in route learning, it is important to clarify the difference between abilities and strategies. I refer to spatial abilities as those mental processes (e.g., mental rotation and object location memory) that are measured with tests whose scores represent a measure of ability. When speaking of route-learning strategies, however, I do not refer to ability but to a "stylistic" preference. Ward et al. (1986) examined participants' direction giving responses and found that men were more likely than women to provide directions containing configurational cues (i.e., cardinal directions and distance information). However, the findings also demonstrated that when prompted, men
and women were equally adept at providing cardinal directions. This indicated that differences in the way men and women give directions likely stem from differences in preferred strategy rather than underlying ability (Ward et al., 1986).

Gender differences in route learning have been examined in a variety of experimental settings, including real-world environments (Lawton, 1994; Malinowski & Gillespie, 2001; Saucier et al., 2003; Silverman et al., 2000), maps (Choi and Silverman, 2003; Dabbs et al., 1998; Rahman et al., 2005; Ward et al., 1986), photographs (Holding and Holding, 1989), and virtual environments (Devlin & Bernstein, 1995; Jansen-Osmann et al., 2007; Moffat, Hampson, & Hatzipantelis, 1998; Tlauka et al., 2005). Wayfinding has been measured with variables such as the number of steps taken along a route (Silverman et al., 2000); map drawings, (Harrell, Bowlby, & Hall-Hoffarth, 2000); response time (Holding & Holding, 1989); task completion speed rates (Moffat et al., 1998); error rates (Galea & Kimura, 1993); and written directions (Dabbs et al., 1998). Some of these findings indicate that the gender differences appear as participants travel along the route, while others show that the difference expresses itself afterwards. No consensus exists about the exact stage of learning in which gender differences in route-learning strategies and abilities manifest themselves.

MacFadden, Elias, & Saucier (2003) investigated whether gender differences in the use of landmarks and cardinal directions resulted from differences in the visual scanning of maps or from differences in direction giving. The visual scanning of maps takes place at early stages of learning and
processing, while giving directions takes places at later stages. MacFadden et al. (2003) recorded the eye movements of men and women conducting map-reading tasks. They assumed that the longer a participant fixated on a map feature (e.g., landmark and cardinal directions), the more attention (and hence cognitive processing) was devoted to that feature. Using this eye tracking methodology, it was possible to determine if the gender differences reported in the literature were a consequence of the way men and women communicated route information or if there was an underlying difference in the way that information was visually acquired initially.

MacFadden et al., (2003) found differences in the way men and women gave directions, but no differences in the way they scanned maps. As in previous findings, women reported more landmarks than men, and men reported more cardinal directions than women. The eye tracking record, however, did not show any differences in how men women explored landmarks and the compass. As the researchers note, these findings are an indication that when learning routes from a map, men and women explore space similarly but differ in how they give directions.

The issue of whether men and women differ in their visual acquisition of route information or if they differ only in the direction-giving strategies is important to help us determine how a cognitive map (i.e., the internal representation of the environment) is developed (MacFadden et al., 2003). A gender difference in the visual scanning of route elements on a map would indicate that differences in the internal representation of the environment is a
process that occurs at early stages of route learning and may be an indication of fundamental differences in the way we encode the environment. If the difference is only observed in the direction-giving record, then it suggests that the development of the cognitive map is a process that occurs at later stages of learning, once route information has been visually processed. Indeed, the differences may be the result of mechanisms associated with the communication of environmental information (e.g., memory and verbal abilities). As mentioned, the results from MacFadden et al.'s (2003) study indicated that men and women only differed in the way they gave direction and thus differences between men and women appear at later stages of route learning and processing.

The extent to which results from MacFadden et al.'s (2003) study generalize to virtual environments is unknown. First, the eye tracking apparatus used in their study was able to track eye movements but not head movements. The participants' head-movements were restricted with a chin rest, which constrained their ability to scan the map in a more naturalistic manner. Second, while the aim of the study was to investigate navigation behaviour, it may be the case that the use of a paper map did not elicit typical route scanning behaviour, as may be capture in the real world (Malinowski & Gillespie, 2001) suggest. For instance, the map's compass legend is static because the entire environment is seen at once from an allocentric perspective; so the cardinal indicators need to only point in one direction. Conventionally, the North indicator points up, towards the top of the page. A map-reader may not need to visually scan the compass to determine cardinal directions. Therefore, the eye tracking record may not show
gender differences in the visual scanning of the compass because fixations towards it are not elicited by the map design. Third, paper maps present all cartographic information at once. In natural and virtual world, we often encounter route information piece-meal and in three dimensions (Galea & Kimura, 1993). The visual patterns (e.g., optic flow, object displacement, motion parallax, and occlusion) usually encountered when moving through real and virtual worlds are absent from static paper maps, and therefore, the way information is usually presented on a map may not elicit characteristic ocular responses associated with route-learning strategies. In this study, I overcome some of these limitations through the use of a pseudo-realistic virtual environment and an eye-tracking system capable of recording eye movements without the need to restrain head movements.

2.5 Relationship between maps and virtual environments

Controlling extraneous variables in the natural world is a difficult, if not impossible, task. Wildlife, vegetation changes, light levels, and weather patterns are but a few of the factors that are beyond precise experimental control and manipulation. The difficulty in controlling such extraneous variables is one of the reasons why researchers investigating route learning have focused on laboratory-based settings, particularly cartographic maps (Malinowski & Gillespie, 2001). Elements in cartographic maps are easily manipulated and they are able to represent abstracted versions of an environment’s spatial structure in a controlled and consistent manner (Malinowski & Gillespie, 2001). Indeed, because of the spatial similarities between maps and the real world, it is often
assumed that the mental processes in operation during real-world navigation are similar to the mental processes operating during map-based exploration and learning (Malinowski & Gillespie, 2001; Hegarty et al., 2006; Rhaman et al., 2005; Silverman et al., 2000). In addition, it is thought that the cognitive representations of routes acquired from real-world experience have map-like qualities and are analogous to the mental representations acquired from maps (Uttal & Wellman, 1989). Although the extent of this hypothesized relationship is not known, maps have been convenient tools to investigate route-learning behaviour and account for much what we know about human route learning abilities. So, even though the aim of this dissertation is to understand virtual route learning, map-based research plays a predominant role in the theoretical underpinnings of the experimental design.

While much of the literature on route-learning is based on the use of cartographic maps, current computational technologies allows us to investigate route-learning behaviours and strategies in more naturalistic virtual environments. Questions still remain about the extent to which research based on cartographic maps transfer to virtual environment. Theoretically, there are several reasons why this is a reasonable proposition. In discussing the nature of cartographic maps, Liben (2001) outlines three main principles: purpose, duality, and spatialization. Closer examination of these principles reveals how they may also be applied to the study of virtual environments.

A map, according to Liben (2001), exists not only as representational entity but also a purposeful one. That is, a cartographic map is not only meant to
be a miniaturized version of a large-scale reality, but it also has a specific purpose, which affects the type of information that is included in its design. The same is true of virtual environments. As an example, take two of the most popular online virtual worlds: Second Life and Google Earth. Both environments allow user to create and interact with graphical elements that resemble objects in a physical environments. In this sense, both worlds are a metaphorical representation of physical environments. Yet, in spite of these superficial similarities, Second Life and Google Earth have different purposes:

1. Second Life purpose is to:
   - Discover a vast digital continent, teeming with people, entertainment, experiences and opportunity.
   - Buy, sell and trade with other Residents.
   - Engage in financial transactions in a marketplace.
   (Linden Research, Inc., 2011)

2. Google Earth’s purpose is to:
   - View, create, and share interactive files containing highly visual location-specific information.
   - Explore places of interest
   - Visualize social, scientific, cultural, and economic processes.
   - Search for schools, parks, restaurants, etc.
   - Get driving directions
   - View local business ads
   (Google, 2011)

These description from each company’s respective website, show that Second Life places emphasis on the entertainment value of the environment and its ability to connect users in a social network. The graphical and interactive
features of this environment are created to support these aims. For instance, the environments created in Second Life tend to be colourful and often exaggerate aspects of the real world. The level of realism is left to the discretion of the world builders. Google Earth, on the other hand, aims to deliver a more realistic experience in the sense that it uses real world geospatial information and features (e.g., landmark features, route distances, cardinal directionality, etc). These are two examples of how like maps, virtual environments are not only representations of something, but also have a purpose, which in part dictates the elements included in their design.

In referring to cartographic maps, Liben (2001) states that they are objects with dual identity. A map may have a particular size, shape, and aesthetic qualities that are unique to it. In other words, the map is something in and of itself (Liben, 2001). Yet, a map is also an artefact that stands for something else such as a city or a territory (Liben, 2001). This duality principle can be applied to virtual environments, which can be considered entities possessing unique characteristics (e.g., interactive elements, graphical styles, fonts, and navigation structure). Yet virtual environments can also be considered metaphorical entities that exist as representations of something else (e.g., a country, a city, or a fictional world). Some of the features that make up a virtual environment may be incidental, related to its existence as a unique object. Examples include features like the level of graphical detail, the colour and texture of objects, interface characteristics, and the responsiveness of interactive elements. These are incidental features with not intrinsic relationship to their referent objects and may
have been chosen perhaps because of some aesthetic or usability need. For example, the fact that a virtual landmark may have a text label does not mean that the real-world landmark it represents also contains a similar label. On the other hand, there are certain features of virtual environments that carry meaning closely related to the referent. A road on Google Earth, for instance, may run from East to West as it does in real life. Thus, the orientation of the roads bears a direct relationship to the real road it represents. Often, incidental and representational features are interrelated in a way that separating one from the other is not possible without losing essential qualities of the virtual environment. Continuing with the road example, it may be the case that the road is coloured red to denote a real-world property (e.g., major highway), but the colour itself is an arbitrary feature. As Liben (2001) stated, decisions about what features to include in a map may be based on the following factors:

- Shared physical qualities of the referent and the representation.
- Psychological associations between referents and representations
- Some arbitrary or aesthetic choice.

(Liben, 2001)

The duality principle is relevant to the investigation of virtual route-learning because it is important to determine which aspects of the environment have a real-world representation that in a sense increases the environments’ ecological validity, and which aspects are purely incidental. Not all features of the environment are under the experimenter’s control yet it is important to identify
them in order to determine their role in influencing participant behaviour. I discuss the feature of the virtual environment used in this study in section 3.3.

The *spatialization* principle of cartographic maps states that maps are designed to convey spatial information (Liben 2001). Map elements are positioned in relation to themselves, each other, and the background geographic space. Similarly, a virtual environment is inherently a system designed to conveyed information along spatial dimensions. More so than maps, a virtual environment utilizes space in a complex manner, able to dynamically depict spatial coordinates, scales, distance, object locations, viewpoints, and three-dimensional structures. Spatialization is one of the most important principles in virtual environments, as it could help or hinder route-learning processes. In this project, one of the most important spatial qualities of the environment was the frame of reference, which determined the orientation of viewing. In the first experiment the environment was viewed from a first-person perspective and in the second experiment the environment was viewed from a top-down perspective. These two viewpoints altered the structure of the environment seen by the participants and provided an insight into how this element of the spatialization principle influenced route-learning behaviour.

Liben’s (2001) cartographic map principles (purpose, duality, and spatialization) also apply to virtual environments and provide a rationale for employing similar theoretical and experimental approaches. Yet, it is also understood that given the pseudo-realistic nature of virtual environments, it is possible that the experimental results obtained in one type of environment may
not transfer to the other. To determine whether research from map experiments transfer to virtual environments was not the primary intent of this dissertation, yet given the similarities in methodologies with past cartographic research, it is expected that the results of the present experiment provide insights into this relationship.

2.6 Measuring route-learning strategies through direction giving

The direction-giving paradigm is among one of the most common procedures that researchers have used to measure gender differences in route-learning strategies, particularly in the map-reading literature. The general method requires that participants verbalize, draw, and/or write directions after performing a navigation task (Allen, 2000; Choi and Silverman, 2003; Dabbs et al., 1998; Lovelace, Hegarty, & Montello, 1999; Ward et al., 1986). The measures of interest include the frequency of references to landmarks, cardinal directions, and relational transpositions (e.g., left and right). The rationale for using the direction-giving paradigm is that communication of route knowledge gives us insight into the “cognitive map” or representation of the environment within a person’s mind (Allen, 2000). By applying this technique, for instance, researchers have learned that men and women differ on their reliance of environmental features such as landmarks and cardinal directions (Choi & Silverman, 2003; Dabbs et al., 1998; Galea & Kimura, 1993; MacFadden et al., 2003; Rahman et al., 2005).

Researchers believe that the frequency of specific route elements in the direction-giving record is an indication of the most salient environmental
knowledge in a person’s minds (e.g., Allen, 2000; Dabbs et al., 1998, Lovelace et al., 1999). However, it should be taken into account that direction-giving measures not only include information about the internal representation of the route, but also about the processes (e.g., language and memory) used to communicate that information (Allen, 2000; Liben, 2001). So, even though direction references are believed to be a glimpse of the cognitive map, many factors have yet to be understood, and the idea requires further experimental examination.

In spite of our limited understanding of direction-giving strategies, results from various experiments have shown that the method is effective in helping us investigate gender differences in route learning. I place particular emphasis on written directions as this method has shown consistent differences between men and women (e.g., Choi and Silverman, 2003; Dabbs et al., 1998; Ward et al., 1986). In practice, the method involves asking participants to write down directions after performing a navigation task. According to Lovelace et al. (1999), there are 3 major steps in the direction-giving process: 1) Activation of internal representation of the environment; 2) Selection of specific route; and 3) verbal communication of route and instructions. It should be noted, however, that direction giving is not an absolutely precise measure of route learning, nor is it a clear window into the internal representation of the environment. However, it is a procedure that has yielded consistent results and appears to be an adequate measure of route-learning strategies.
2.7 The role of eye movements in route learning

Eye tracking technology has garnered attention in HCI, but expense, operational complexity, and lack of adequate analytical methods have limited use of this technology (Schnipke & Todd, 2000). Eye movements are thought to be measures of attentional behaviour (McCormick, 1997; Mueller & Rabbitt, 1989; Posner, 1980; Rayner, 1998), and while the extent of this relationship is still a matter of some debate, it is generally accepted that movements of the eyes are coupled with shifts in attentional focus (Duchowski, 2007; Rudmann, McConkie, & Zheng, 2003). By examining ocular behaviour, it is possible to learn what elements of the route are of interest to a traveller at the moment that they are learning the route. If, as some researchers have proposed (Dabbs et al., 1998; Eals & Silverman, 1994; Ecuyer-Dab & Robert, 2004; Silverman & Choi, 2006), men and women differ in the way that they attend to route elements, then these differences could be evident in the eye-tracking record.

As discussed in 2.4, researchers have theorized that men and women may differ in their allocation of attention when navigating a route (Eals & Silverman, 1994). The findings that women’s ability to recall object locations from an array is superior to that of men's, for example, may be an indication that women possess a more ‘inclusive attentional style’ than men (Eals & Silverman, 1994). This style may include a preferential attention to landmarks and their spatial relationships (Ecuyer-Dab & Robert, 2004; Silverman, Choi, & Peters, 2007), which historically may have been useful in conducting foraging tasks and thus favoured women (Silverman & Eals, 1992). If gender difference do exist in
‘attentional style’, then it may be possible to detect these differences by examining eye movements during route learning.

As theorized, men may be more likely than women to allocate their attentional focus on configurational properties of the route (Choi & Silverman, 2003; Dabbs et al., 1998; Ward et al., 1986). A standardized representation of the route’s configuration is useful when travelling long distances, as it effectively and efficiently helps a traveller orient herself/himself in the absence of familiar landmarks by providing directional information in terms of an abstract frame of reference (Allen, 1997; Ward et al., 1986). A traveller who relies on learning the geometric configuration of the environment to travel long distances must find a way to acquire this information, which can be obtained in several ways, including cardinal directions gleaned from natural cues (e.g., stars) or artificial devices (e.g., a compass). Given men’s theorized reliance on configurational large-scale representations of the environment, it is thought that they are more likely than women to rely on a navigation strategy that takes into account cardinal directions. To date, several experiments (e.g., Choi & Silverman, 2003; Dabbs et al., 1998; Lawton, 2001; Ward et al., 1986;) have found support for this notion. It is feasible that analysis of the eye tracking record would show these differences in attentional style at the moment that the traveller is learning the route.

In this project, I focused on the two strategies that have received attention in the wayfinding literature—landmarks and cardinal directions. These two strategies have shown consistent gender differences and they can be experimentally controlled to investigate how humans acquire and integrate paths
within a virtual environment. I used fixation duration on elements of the
environment in order to determine which areas participants utilized during
navigation. Thus, in this project, fixation duration was a measure of attention that
provided insight into gender differences in route-learning strategies. Yet, it is
important to note that the relationship between attention and eye movement is
still a contentious topic.

2.7.1 Eye movements and attention

Although eye tracking techniques have been used for nearly a century in
the field of psychology (Jacob & Karn, 2003), eye movement research has
increasingly attracted the attention of HCI practitioners, who consider the
characteristics, sequence, and timing of these movements a real-time index of
users' cognitive activity (Rudmann et al., 2003). Henderson (2003) presented
three main reasons why eye movements are useful in the study of scene
perception.

1. Eye movement is an active process in which a viewer seeks out
and integrates visual information that is relevant to a given task.

2. Eye movements are an "overt behavioural manifestation of the
allocation of attention"- its mechanisms and operations.

3. Eye movements are "unobtrusive, sensitive, and real-time"
measures of "visual and cognitive processing."

(Henderson, 2003)
Given the graphical nature of most digital interfaces, eye movement research is well suited to HCI research. Chiefly, eye movements overcome some of the biases and limitations of traditional measures like memory recall, surveys, and interviews, which rely heavily on people’s conscious awareness and control of their own sensory, perceptual, and cognitive processes (Schiessl, Duda, Tholke, & Fischer, 2003). Under normal circumstances, maintaining conscious awareness of one’s eye movements over a scene (while simultaneously performing a navigation task) is rather difficult and would require extreme purposeful effort to control and direct. Thus, measures of eye movements are, to a certain extent, more objective measures of behaviour than surveys and questionnaires, which are sensitive to the biases introduced by the participant’s self-awareness of a testing situation (Schiessl et al., 2003) and the limits of maintaining conscious self-control over eye movements.

Inasmuch as eye movement research methods confer some advantages over traditional usability methods, they also pose new challenges to researchers. Aside from the technical and operational constraints of eye tracking systems such as variable and systematic errors (Hornof & Halverson, 2002; Schnipke & Todd, 2000), one issue of contention is the theoretical relationship between eye movements and attention. While the immediate and measurable goal of eye tracking research is to accurately determine the “visual line of gaze” (Jacob, 1991), its theoretical aim is to make inferences about the “nature, sequence and timing of cognitive operations” (Rudmann et al., 2003). Underlying eye-tracking research is the assumption that eye movements are indicators of attentional
processes (Hoffman, 1998; Huang & Paschler, 2007; Rayner, 1998; Recarte & Nunes, 2000). As we interact with the world around us, we attend to and integrate various sources of visual information. We shift our attention- or focus of awareness- to locations and features that are relevant to our goals (Horrey, Wickens, & Consalus, 2006). These attentional mechanisms may be endogenous and/or exogenous (Hoffman, 1998; Mccormick, 1997; Posner, 1980). Attention is endogenous or voluntary in the sense that we purposefully shift attentional focus to relevant features of the environment, based on our thoughts, goals, and intentions. Its exogenous or reflexive characteristics refer to the automatic shifting of attention to unexpected and salient features of the environment such as a flash of light. In that sense, attention is thought to be stimulus-driven (Mccormick, 1997; Muller & Rabbitt, 1989; Theeuwes, 1993,1995; Yantis, 1998). The challenge for eye tracking researchers investigating complex behaviours such as route learning is to make sense of voluntary and automatic attentional shifts and determine what eye movements can tell us about perceptual and cognitive operations.

When travelling along a path, we purposefully scan the environment and foveate its features to augment their details (Franconeri, Alvarez, & Enns, 2007; Hoffman, 1998; Horrey et al., 2006; Muller & Rabbitt, 1989). While some evidence suggests that attention can shift independent of eye movements (Muller & Rabbitt, 1989), it is generally understood that eye movements are intrinsically

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1 It is also known that we are capable of gathering information from the periphery of our vision, and while this is an important issue, I do not address it in this dissertation because the graphical and textual stimuli presented to participants required actual fixations to identify and process.
coupled with shifts in attention (Deubel & Schneider, 1996; Henderson, 2003; Huang & Paschler., 2007; Hodgson & Muller, 1995; Hoffman, 1998; Hoffman & Subramaniam, 1995). That is, a shift of the eyes is synchronous with a shift in attention. In this sense, eye movements are possible indicators of intent or purpose. Thus, it is often assumed that the eye tracking record can provide insight into the cognitive operations that we rely on when performing tasks like route learning.

The process of learning a route engages a complex set of cognitive and perceptual mechanisms, which must necessarily include attention and eye movements. Ward et al. (1986) state that the first stage of learning a route is attending to its features to encode their detail and spatial arrangement. Attentional shifts are required to search and encode the various features of a route. Whether this orientation of attention is performed consciously or not, vision usually plays a predominant role in the process by helping us scan and augment the details of attended features. One example of the close relationship between eye movements and attention is presented by Horrey et al. (2006), who found that when driving a car, the complexity and importance of secondary tasks (e.g., vocalizing a string of digits), influenced eye movements related to the primary task (i.e., driving). These results provide evidence that cognitive and perceptual operations influence eye movements and can be differentiated in the eye tracking record. In this dissertation, I assume that eye movements are likewise directly related to attentional processes associated with cognitive and perceptual operations during path integration. As discussed in the following
section, however, questions still remain about the extent to which we can discriminate complex cognitive operations through the eye movement record.

2.7.2 Eye movements and cognitive states

Eye tracking measurements tell us how a person allocates fixations (i.e., attention) on visual stimuli, but in and of themselves they tend to reveal little about higher cognitive operations. The evidence that ocular behaviour can provide insight into higher cognitive states is mixed (Rudmann et al., 2003). Research by Pelz and Canosa (2001) indicates that in spite of the difficulties in inferring cognitive processes from eye movements, it is possible to use the eye tracking record to detect complex cognitive operations. In one particular study, Pelz and Canosa (2001) recorded eye movements as participants engaged in hand washing, which is a physically simple but cognitively complex task. The researchers prompted the participants to enter a bathroom, wash their hands, and then exit the room. The results showed that during the hand-washing task some participants engaged in ‘look-ahead’ fixations (Pelz and Canosa, 2001). Not only did participants look at task relevant objects (e.g., hands and soap) while washing their hands, but they also looked at other objects (e.g., a towel) that were necessary for completing future tasks. This ability to plan for a future action and fixate on the objects necessary to complete it requires the coordination of high-level cognitive operations, which as the experiment showed can be gleaned from the eye tracking record. According to Pelz and Canosa (2001), these results suggest that eye movements provide a real-time index of complex perceptual strategies and cognitive operations. Still, the evidence that
eye movement can help us infer complex cognitive operations is mixed. Rudman et al. (2003), for example, asked participants to determine the direction of rotation of connected gears. While participant completed the experimental task, their eye movements were recorded. The results showed that during the task, participants fixated around the outer edges of the illustrated gears as if following the direction of the visualized rotation. These results indicated that participants' eye movements were an overt indicator of their cognitive operations (i.e., mental rotation of visualized images). Yet, in other cases this pattern of fixations was not observed, suggesting that fixations do not always reflect the contents of the mind.

While issues related to the relationship between eye movements and cognition still need further investigation, practitioners in the field of eye movement research generally assume there is functional relationship between eye movements, cognition, and perception (Duchowsky, 2003). A task such as learning a virtual route is cognitively demanding because it requires a host of mental processes such as object detection, identification, recognition, memorization, and recall. Further, the route-learning tasks in the present experiments also required the reading of landmark labels and compass indicator. All these perceptual and cognitive processes require the coupling of attention and eye movements. Therefore, in this dissertation, I maintain the theoretical position that eye movement methodologies are indicative of attentional strategies and cognitive operations related to route-learning tasks.
2.8 Spatial abilities

There are several classes of abilities that have been associated with our capacity to mentally represent and manipulate the spatial characteristics of the environment, but the nature of the relationship between spatial abilities and environmental processing has not been satisfactorily determined. In order to understand spatial abilities in general, a large body of research has sought to understand how such abilities differ between men and women. While not all classes of spatial abilities have reliably demonstrated these differences, some spatial abilities associated with tasks that require the mental visualization and manipulation of figures have indeed shown reliable gender differences (Voyer et al., 1995). This is an indication that some underlying factor may contribute to differences in spatial abilities among humans. While there is partial evidence that differences in some spatial abilities have somewhat diminished in recent years, gender differences in mental rotation have remained consistent (Voyer et al., 1995). Another class of spatial abilities that require the accurate recall of the location of objects has also shown gender differences (Ecuyer-Dab & Robert, 2004; Eals & Silverman, 1994; Silverman & Eals, 1992; Silverman & Choi, 2006). In essence, women are better than men at recalling the location of previously seen objects. This provides further evidence that, for whatever reasons, spatial abilities can differ among different populations. Yet, the relationship between these spatial abilities and route learning remains largely unknown.

Route learning requires the acquisition and integration of spatial features of the environment, and researchers theorize that to process these
environmental features specific spatial abilities are required (Dabbs et al., 1998; Ecuyer-Dab & Robert, 2004; Gaulin & FitzGerald, 1986; Hegarty et al., 2006; Moffat et al., 1998; Silverman & Eals, 1992; Ward et al., 1986). Moreover, given the observation that men and women differ in such abilities, it is reasoned that these differences also play role in navigation strategies. In particular, it is hypothesized that the route-learning strategy associated with the processing of salient topographic features (i.e., landmarks) are related to the ability to remember the location of objects and the use of relative directions (Dabbs et al., 1998; Eals & Silverman, 1994; Ecuyer-Dab & Robert, 2004; Silverman et al., 2007). Research has found that on average women score higher than men on this ability across a variety of test formats (Galea & Kimura, 1993; James and Kimura, 1997; McBurney, Gaulin, Devineni, & Adams, 1997; Tottenham, Saucier, Elias, & Gutwin, 2003; Silverman & Eals, 1994). Given that the topographic route-learning strategy is based on the recall of landmarks, including their relative positions along the route, it is expected that object location memory abilities are associated with this strategy (Choi and Silverman, 1996, 2003). Of particular interest, as far as this dissertation is concerned, is whether the hypothesized relationship between object location memory and the topographic strategy exists within virtual environments.

The configurational route-learning strategy emphasizes the processing of geometric configurations of the environment (e.g., cardinal directions) and may be closely related to spatial abilities that mediate the mental visualization and manipulation of 3D objects (Dabbs et al., 1998; Collins & Kimura, 1997; Ecuyer-
Dab & Robert, 2004; Hegarty et al., 2006; Lohman, 1986; Silverman et al., 2000; Silverman & Eals, 1992). Moffat et al. (1998) found a significant relationship between scores on mental rotation tests and navigation performance in a virtual maze, providing further evidence that this spatial ability is in fact associated with route learning. Other research has also found support for the hypothesized relationship between configurational strategies and spatial abilities (Hegarty et al., 2006; Rahman et al., 2005; Silverman et al., 2000).

The degree to which the relationship between spatial abilities and route-learning strategies exist in virtual environments is unknown. We also know little about the role that gender plays in this hypothesized relationship. Past research has shown that men and women differ on spatial abilities and route-learning strategies. Does this difference influence how spatial abilities operate during route learning? In this research, I explore this question by measuring gender differences in mental rotation and object location memory, as well as the correlation with two route-learning strategies (topographic and configurational).

### 2.9 Research questions and exploratory topics

In spite of the rapid commercial proliferation of virtual environments, research about navigation within these spaces is still limited. Thus, to gain a better understanding of how human process virtual environment information, it is necessary to build up on research conducted in non-virtual environments. Prior studies have shown that men and women differ in several aspects of route learning, but only a handful of studies have investigated the precise relationship between the perceptual and cognitive operations involved in the process.
Therefore, to better understand how virtual route information is processed and integrated, I seek to address the following questions and predictions:

1. **Do men and women differ in the strategies they use when giving directions after they have learned routes in a virtual environment?**
   I predicted that women would make more written references to landmarks than men, and men would make more written references to cardinal directions than women.

2. **Do men and women differ in their visual scanning strategies when learning a route in a virtual environment?**
   I predicted that women would allocate a greater percentage of fixation duration on landmark regions than men, and men would allocate a greater percentage of fixation duration on the compass than women.

3. **Is there a relationship in the way men and women visually explore a virtual route and the way in which they report directions?**
   I predicted that the percentage of participants’ fixation duration on landmarks would correlate with the number of references to landmarks, and that the percentage of participants’ fixation duration on the compass indicator would correlate with the number of references to cardinal directions.

As discussed, researchers theorize that learning a route requires the use of spatial abilities such as mental rotation and object location memory (Choi & Silverman, 2003; Dabbs et al., 1998; Ecuyer-Dab & Robert, 2004; Rahman et al.,
Moreover, since spatial abilities are known to differ between men and women, then such differences may be associated with route-learning strategies. Therefore, I also sought to examine the relationship between spatial abilities, visual scanning strategies, and direction giving. In particular, I aimed to answer the following questions:

4. *Is there a relationship between object location memory abilities and topographic route learning strategies?*

I predicted that women would score significantly higher than men in scores of object location memory test; scores on the object location memory test and the *number of written references to landmarks* would be positively correlated; and scores on the object location memory test and the *time fixating on landmarks (%)* would be positively correlated.

5. *Is there a relationship between mental rotation abilities and configurational route-learning strategies?*

I predicted that men would score significantly higher than women in scores of mental object rotation test; scores on the mental object rotation test and the *number of written references to cardinal directions* would be positively correlated; and scores on the mental object rotation test and the *time fixating on the compass (%)* would be positively correlated.

One of the features that characterize virtual environments is the ability to display information from multiple points of view or frames of reference. In terms
of gender differences, the role of viewpoint has not been extensively examined. To what extent does the frame of reference from which a virtual route is viewed alter route-learning strategies? To explore this question, I designed two experiments in which the environment is seen from an egocentric (eye-level) viewpoint and an allocentric (world-centred) viewpoint. While exploratory in nature, I hope that this examination provides insight into how frames of reference affect the processing, integration, and communication of virtual routes.
3: EXPERIMENTAL DESIGN- FRAMEWORK

3.1 Overview

Previous studies sought to understand gender differences in route learning using cartographic maps and the direction-giving paradigm (Ward et al., 1986), and this design was subsequently modified to include spatial abilities (Dabbs et al., 1998) and eye movements (MacFadden et al., 2003). Up to now, no studies have investigated the relationship between these factors in dynamic virtual environments. Nor have any of these studies taken into account the participant’s frame of reference in their design.

Virtual environments provide a level of realism that cannot be attained in paper maps. Virtual environments are also more flexible because they allow the researcher to manipulate multiple elements (e.g., point of view and scale) without altering other characteristics of the stimuli such as the relative position of objects and movement. I examined route-learning strategies by designing a virtual environment depicting a fictional town based on cartographic maps used in previous studies (e.g., Dabbs et al., 1998 and MacFadden et al., 2003). In two separate experiments, differing only in the point of view from which information was presented, participants completed route-learning tasks while their eye movements were recorded, gave directions, and completed spatial ability tests. In this chapter, I describe the research hypotheses, maps, virtual environment,
tasks, and the framework used to evaluate route-learning strategies and spatial
abilities.

3.2 Research hypotheses

Based on the theory of gender differences in route learning and previous
empirical research, I investigated the following hypotheses:

Hypothesis one (H1): Women will make more written references to
landmarks than men.

Hypothesis two (H2): Men will make more written references to cardinal
directions than women.

Hypothesis three (H3): Women will allocate a greater percentage of
fixation duration on landmark regions than men.

Hypothesis four (H4): Men will allocate a greater percentage of fixation
duration on the compass than women.

Hypothesis five (H5): The percentage of participants’ fixation duration on
landmarks will positively correlate with the number of references to landmarks.

Hypothesis six (H6): The percentage of participants’ fixation duration on
the compass indicator will positively correlate with the number of references to
cardinal directions. Analysis by gender is expected to yield similar results.

Hypothesis seven (H7): Women will score significantly higher than men
in scores of object location memory test.
Hypothesis eight (H8): Scores on the object location memory test and the number of written references to landmarks will be positively correlated.

Hypothesis nine (H9): Scores on the object location memory test and the time fixating on landmarks (%) will be positively correlated. Analysis by gender is expected to yield similar results.

Hypothesis ten (H10): Men will score significantly higher than women in scores of mental object rotation test.

Hypothesis eleven (H11): Scores on the mental object rotation test and the number of written references to cardinal directions will be positively correlated.

Hypothesis twelve (H12): Scores on the mental object rotation test and the time fixating on the compass (%) will be positively correlated.

Additionally, I conducted an exploratory analysis by gender on hypotheses H5, H6, H8, H9, H11, and H12. The results of this exploratory analysis by gender are expected to remain consistent with results obtained from the entire sample population.

3.3 Maps and virtual environments

The virtual environments used in the two experiments were digital versions of a fictional town originally designed as 2D sketch map (Figure 1) to investigate gender differences in route learning (e.g., Dabbs et al., 1998; MacFadden et al., 2003; and Ward et al., 1986).
Figure 1: Cartographic maps designed by Ward et al., 1986 (top) and Dabbs et al., 1998 (bottom) to test route-learning differences between men and women.
The maps depict a fictional town that contains various topographic (landmarks) and configurational (compass indicator) features. As seen in Figure 1, the content of these maps is generally similar across studies, but some details have been altered in each case to accommodate differences in experimental design.

In previous studies, participants were required to study routes from a map, and after doing so, they wrote directions on a piece of paper. The content of these directions was then analyzed to determine the map elements that participants used more frequently.

In the current experiments, participants had to learn a pre-recorded route in a virtual environment from a starting point to a destination. As shown in Figure 2, the starting points and the destinations were the same as those used by Dabbs et al. (1998), but I chose the specific paths to follow.
Figure 2: Starting route points and destinations in Dabbs et al.’s (1998) study. The dots represent the starting points and the destination for each route.

I used the modelling program Google SketchUp to create a 3D model of the map (Figure 3).
Figure 3: A portion of the experimental virtual environment seen from egocentric (a) and allocentric (b) viewpoints.

a. Egocentric viewpoint
b. Allocentric viewpoint

I sought to recreate the environment as closely as possible to the original sketch map. Like the original maps, the elements in the virtual environment were relatively simple shapes with little or no colour. I placed scarcely any vegetation along the routes. I measured the distances between elements found in the paper map and strove to keep these relative spatial relationships in the 3D model, though I had to make some compromises about positions to account for differences in the egocentric and allocentric viewpoints. For example, landmarks may appear to be located in the optimal (for eye tracking) position when seen from a top-down perspective, but they may not be optimally placed when seen from an eye-level viewpoint. Given that I needed a consistent environment
across both frames of reference, I made the appropriate adjustments to landmark positions to find a location that could be tracked in both viewpoints.

Although the town depicted in the original map was fictional, there were some landmarks that were familiar (e.g., McDonalds and Holiday Inn hotel). I also included some of these familiar landmarks, but in some cases, I changed them to accommodate for regional differences between the US and Canada. For instance, one of the landmarks in the original map was an America supermarket chain (Kroger). I changed the label for this landmark to the Canadian-based supermarket chain IGA. Also, to maintain consistency with the paper maps, I did not attempt to fully recreate the architecture of the familiar buildings to make them look like the real-world versions- their identity was solely indicated by the labels. The location of the compass icon on the virtual environment was also different than its location on the paper maps. This change was done for experimental (i.e., placing the compass along the participant’s line of sight may have caused inadvertent fixations) and technical (i.e., the design software provided only limited control over this feature) reasons.

The virtual environment was also modified to take into account the limitations of the eye-tracking system. For instance, the eye tracker had a degree of accuracy of less than one-degree visual angle. Therefore I laid out objects at distances greater than one degree (when viewed from the top) to avoid accuracy errors between true and measured eye position. However, maintaining this distance between objects was not always possible- particularly in the egocentric viewpoint- because of the dynamic movements of elements within the
environment as the camera travelled along a route. To illustrate, Figure 4 shows objects seen from an eye-level perspective; objects in the distance may be relatively close to each other on the visual field but farther apart when viewed up close. Thus, when the environment was viewed from an egocentric perspective, maintaining a distance between landmarks greater than one degree was not always possible. This particular issue did no exist when the environment was seen from an allocentric frame of reference because landmarks maintained their relative distance and location from each other.

Figure 4: Virtual objects seen from egocentric viewpoint. The same objects may appear close to each other when seen from a distance but farther apart when seen up close.
I imported the SketchUp model into Google Earth, which permits the display of satellite from multiple perspectives. Google Earth contained the necessary functions to display the 3D model, terrain, viewing characteristics (angle, azimuth, and scale), and motion. One important aspect of Google Earth’s functionality was the presence of a dynamic compass, which rotated whenever changes in orientation along the path occurred. The version of Google Earth that I used allowed me to position the compass in one of two places on the screen—the low centre region and upper right corner. When positioned in the centre, the size of the compass was rather large and occluded the road and landmarks. This was not an optimal location since non-compass related eye movements could have easily landed on this region. The second option for placing the compass was the upper right corner. The design of the compass was smaller, but its position did not occlude the environment as much, and the location was similar to the location found in the original maps. Thus, I opted to place the compass in this region.

I should note that unlike a map, which allows a reader to view the whole environment to be traversed, the virtual environment shows the environment piece-meal. Therefore, I had to make decisions about scale (i.e., how much information was viewable at one time), azimuth (viewing direction), elevation, and speed of camera motion. As there was no prior research in this area, I based some of the decisions on technical restrictions, experimental trials, and personal experience designing 3D spaces.
I set a path for the camera to follow along the centre of each virtual route and then recorded videos of movement from the starting point to the destination, as depicted in Figure 2. As the camera glided along the route, each landmark came into view, moved across the screen, and then disappeared. Therefore landmarks in the virtual environment were not visible at all times and dynamically changed location, size, and shape when the viewer encountered them. The compass was part of the interface layer above the route environment and was thus visible at all times throughout the video. Given the differences in length between the four routes, each video lasted different amounts of time. The four videos of the route as seen from the egocentric perspective lasted 1 m 10 s, 1 m 15 s, 1 m 12 s, and 1 m 25 s. The video of the routes seen from the allocentric perspective lasted 1 m 18 s, 1 m 22 s, 1 m 27 s, and 1 m 26 s.

3.4 Route-learning tasks

The process of learning a route requires the acquisition, integration, and externalization of environmental elements (e.g., landmarks) and characteristics (e.g., configuration). We use physical and mental mechanisms to accomplish this task. While physical actions (e.g., walking, pressing keys on a keyboard, or mouse control) may also provide orientation cues during navigation, in this dissertation, I focused on perceptual and cognitive processes operating during route learning. No overt physical actions were required during the experiment to navigate the route. Moreover, although route learning also involves actively choosing the segment of path to follow, I used a modified experimental protocol as the one employed by Galea and Kimura (1993), who asked participants to
learn a route that had been previously chosen by the experimenter. In that experiment, participants took the additional step of tracing the route themselves on the map. I omitted this latter step in the present experiments, as the video presentation format did not allow the participants to retrace the route. While excluding overt physical actions is a limitation in this dissertation, doing so allowed me to systematically isolate the mental mechanisms involved in the task of virtual route learning without introducing the potential confound of psychomotor skills and computer-usage experience.

Operationally, landmarks were defined as discrete visual representations of natural and artificial objects that have social and cultural significance (Osmann & Wiednebauer, 2004). As Osmann and Wiedenbauer (2004) state, landmarks have the following functions:

1. Signalling sites
2. Help for the location of other landmarks.
3. Confirmation of the route followed.

As seen on Figure 1, the landmarks on the map contain labels. In real and virtual environments this type of labels may not always be utilized. In addition, the navigator of real and virtual environments usually has a greater set of landmark features to choose from and thus labels may be redundant. In the present project, I opted to use labels to maintain consistency with previous research. Thus, the operational definition of a landmark included not only the graphical representation of the feature but also the associated label.
To delineate the environment’s configurational properties, the virtual environment in the present project contained a compass that rotated in place whenever changes in direction occurred (Figure 5). The design of the compass had a key limitation, particularly in the egocentric viewpoint experiment. From the egocentric viewpoint, the three-dimensional properties of the environment were visually salient. The compass, on the other hand, was represented as a two-dimensional icon with its plane perpendicular to that of the environment. This relationship between the compass and the environment was a limitation in the egocentric viewpoint experiment because changes in direction were difficult to discern, as more cognitive effort may be needed to bring the compass and environmental planes into alignment. In Figure 5, for example, the North indicator is pointing downwards towards the bottom of the screen and the ground. It must be remembered, however, that the environment runs horizontally, and true north lies “behind” the traveller while south lies ahead.

Figure 5: The compass (upper right) in the virtual environment rotated when changes in direction occurred. In the image, the north indicator is pointing downwards. The navigator has to take the extra step of aligning the compass with the horizontal layout of the environment.
In the allocentric viewpoint experiment, on the other hand, the environment was seen from a top down perspective and therefore the compass plane coordinates were parallel to the environments’ plane. There was no need for the participant to bring the compass and environment layout into alignment. In Figure 6, for instance, the compass clearly demarcates direction of travel: North lies towards the right; south to the left; west is up; and east towards the bottom.

**Figure 6:** The compass coordinate system aligned with the geometry of the environment on a one to one relationship. In the image, the north direction is clearly discernable (pointing to the right) and therefore no extra steps are needed to align it with the environment’s layout.

While participants did not choose which route to follow, they were required to actively scan the environment and choose the information that would allow them to remember the travelled route. I recorded four separate routes, choosing the path segments that provided a variety of directional changes along the major routes. Unlike Dabbs et al., (1998) and others, I chose the routes that participants had to learn beforehand, similar to the experimental design developed by Galea and Kimura (1993). Preventing participants from choosing their own routes had several advantages. First, it eliminated the introduction of confounds related to manual dexterity, psychomotor abilities, computer experience, and so forth. Secondly, the precise analysis of the eye tracking data
would have been too unwieldy if all 60 participants in both experiments would have been allowed to control their path. By recording a predetermined path, all participants viewed the same route, making the analysis of the eye tracking data more efficiently than it would have been possible otherwise.

3.4.1 Measuring direction giving

The direction-giving paradigm has been instrumental in the investigation of gender differences in route learning. Yet, a complete understanding of direction giving has not been achieved. Moreover, no standardized instrument or procedure has been developed to measure direction-giving strategies. Thus, questions remain about the extent that directions serve as indicator of route learning and internal representations of the environment.

I defined landmarks not only in terms of their graphical representation but also their corresponding labels. Thus, in the written-directions record, I examined the frequency of words that mentioned not only the description of an object but also its label. Prior to the experiment, I decided that references to a graphical element of the environment without a label- with the exception of traffic lights- would not count as a landmark. There were very few elements with no labels (e.g., ground textures) and analysis of the data showed there were no instances in which participants made references to information that did not have labels. I examined cardinal directions by noting the frequency of references to north, south, east, and west. This count included angular directions such as northeast and southwest, which- in spite of being a combination of cardinal references- were given a value of one. To sum up, the specific direction-giving
measures of interest were the number of written references to landmarks and number of written references to cardinal directions. The references to landmarks and cardinal directions for each route were totalled and averaged across the four routes. These scores represented the topographic or configurational strategy respectively. It should be noted that since I was interested in determining whether landmarks or cardinal directions were being used, I did not analyze the accuracy of the directions that participants provided.

3.4.2 Eye movements and route learning

Laboratory based navigation studies are restricted to small-scale representations of the environment (e.g., maps), but it is assumed that similar cognitive and perceptual mechanisms that operate during navigation of physical environments also play a role in laboratory navigation tasks. Galea and Kimura (1993) do indicate that performance on map-based wayfinding tasks might not fully resemble real wayfinding behavior, and therefore, to overcome some of the methodological constraints associated with laboratory studies, the route representations should be more “life-like” (Galea & Kimura, 1993). Realistic testing environments may incite more natural spatial behaviour when learning a route. As an example, Galea and Kimura (1993) mentioned that in the physical world, we usually encounter routes in sections, not all at once like in most maps. These differences in the spatial layout of the environment may facilitate one type of navigation strategy over another. In MacFadden’s (2003) study, participants may have preferred to use a particular visual scanning strategy because they had access to the entire route and all its features at once. The frame of
reference tends to be allocentric, as the entire configuration of the environment can be viewed at once.

MacFadden et al. (2003) did not find gender differences on visual scanning of maps but did find differences in direction giving, which indicates that gender differences in route-learning strategies may be related to a process that occurs after the route has been visually integrated. However, due to some of the limitations on conducting research with maps, those findings may not necessarily transfer across different types of environments. Therefore, in the present work, I sought to address some of these limitations through the use of a more realistic setting in a virtual environment.

The eye movement metric of interest in this project was the fixation duration. I operationally defined a fixation as the point on the screen where the participant's eye remained relatively still for 200 ms or more (Rayner, 1998). This definition has been determined on the basis of reading studies, and since the use of landmarks or the compass required reading in the present experiments, then the definition was adequate. Fixation duration was also the unit of measurement reported by MacFadden et al. (2003). In their study, however, MacFadden et al., 2003 (personal communication, February 2, 2010) did not set a threshold for fixation. There are advantages and disadvantages to defining a fixation on the basis of a threshold. Setting a fixation duration threshold, as I did in this dissertation, ensures that fixations capture a level of cognitive effort (e.g., memory, reading, and attention) while avoiding incidental fixations not associated with cognitive processes but some other sensory or
perceptual event. On the other hand, stringent levels make it more likely that fixations relevant to the route-learning task may not be captured, as would happen if fixation durations of 199 ms or less were made. Given that route learning in the virtual environment required a high level of cognitive effort and attention to gather route information, I found it more appropriate to set stringent levels on the definition of a fixation.

The implicit assumption behind the use of the fixation is that the longer a participant looks at a feature, the more attention he/she is allocating to it, and therefore, the more cognitive elaboration (e.g., learning and memory) is taking place. I used the fixation duration metric to calculate the percentage of time that participants spent viewing the regions of interest (landmarks and the compass indicator). I then averaged the percentage of viewing time over the four videos. These data did not include the “gaze points”, which refer to the areas where the eyes remained still for less than 200 ms. Fixations that landed outside the regions of interest were used to determine the percentage of time fixating on landmarks or the compass.

3.5 Measuring spatial abilities

To examine the relationship between spatial abilities and route-learning strategies, researchers have administered pencil-and-paper tests that measured two spatial abilities: object location memory and mental rotation. On average, tests of memory for the location of objects tend to favour women, and the test is thought to be associated with a topographic route-learning strategy (Silverman & Eals, 1992; Dabbs et al., 1998). The magnitudes of sex differences in tests of
mental rotation are some of the most consistent in the spatial cognition literature, and on average they tend to favour men (Voyer et al., 1995). It is believed that the cognitive processes associated with mental rotation are related to the use of a configurational route-learning strategy (Dabbs et al., 1998). While there are several other spatial abilities that may be related to route learning, I focused on object location memory and mental rotation abilities because each has been shown to differ across gender and has also been theoretically linked to the route-learning strategies of interest in this dissertation.

Silverman and Eals (1992) used a paper-and-pencil test to investigate gender differences in object location memory. During the test, participants examined several drawings of objects (e.g., a clock, a guitar, and a chair) on a piece of paper. Women showed superior ability to recall the location of objects after the original sheet was taken away and replaced by one in which the objects had been moved. Although the objects in that test were familiar, subsequent investigations showed that the differences remained even when uncommon object were utilized (Eals & Silverman, 1994). The object location memory test used in this project was obtained courtesy of Jean Choi. It contained 27 items and the scores consisted of the number of correct answers minus incorrect answers.

The mental rotation test was developed to examine a person’s ability to imagine and rotate previously seen drawings of abstract objects (Vandenberg & Kuse, 1978). Several versions of this test have been developed and the one used in this project is the standard test as revised by Peters (1995) in which
figures are rotated about the vertical axis. In this 24-item test, participants were presented with four stimulus figures and one target figure. Two of the four stimulus figures were rotated versions of the target figure and the other two could not be matched. Participants were asked to match the two correct stimulus figures to the target figure, and they only received a point when they got the two correct stimulus figures. If they only matched one figure, then they received no points for that item. The exact step-by-step procedure for administering this test was provided by Peters (1995).

I administered the two measures of spatial abilities to investigate their correlations with route-learning strategies predicted from evolutionary models. In particular, I analyzed object location memory tests to examine its bivariate relationship with eye movement and direction-giving topographic strategies. The mental rotation test was analyzed in relation to route-learning measures associated with the configurational strategies.

3.6 Interviews and demographics

I gathered demographics data related to age; whether or not the participant played video games; the number of hours per week a participant played video games; whether English was the participant’s first language and which language if other than English; handedness (left or right); if and how long (in years) a participant had held a driver’s license; number of hour per week the participant drove; and level of education achieved at the time of testing.
One of the reasons for using an eye tracking system to examine user behaviour is that users are largely unaware of low-level processes that take place in milliseconds. Nonetheless, at a general level, we are conscious of a given strategy that we use (or think we use), so I conducted informal interviews at the end of the experimental sessions. I did not make any specific predictions regarding their answers to the interview questions. This aspect of the study was exploratory in that I sought to let participants respond in a less restrictive manner than would be permitted in a formal questionnaire. After the participants had finished the route-learning tasks, I asked them to tell me "about the strategy that they used to learn the route". I took notes of their responses and prompted them to expand on their answers where appropriate. I did not intend to perform a quantitative analysis of these answers and I used them to provide context to the statistical analysis of the rest of the data.
4: EXPERIMENTAL METHODOLOGY

4.1 Overview

I designed two studies in which men and women had to view and learn four virtual routes that had been previously recorded. In the first experiment, participants learned a route from an egocentric (eye-level) perspective, and in the second experiment, they viewed the route from an allocentric (top-down) perspective. While participants learned the routes, I recorded their eye movements to determine which regions of interest (landmark or compass) they fixated on. I used fixations outside the main regions of interest to calculate proportional scores. After the participants completed the learning task, I asked them to write directions on a sheet of paper to determine which elements of the environment (landmarks or cardinal points) they referenced. The independent measure was gender and the dependent measures were fixations and references to elements of interest (landmarks or compass). I administered two spatial ability tests (object location memory and mental rotation) and a demographics questionnaire. I asked participants to answer semi-structured interview questions. After the experiment, I debriefed participants about the aims of the study and answered any of their questions about it. I asked them not to discuss the specifics of the experiment with their classmates because other students might participate in the study. At the end of the session, I provided participants with the honorarium and asked them to sign an honorarium confirmation form.
I conducted a pilot study (4.7) to evaluate and improve the design of the main experiments.

4.2 Participants

I recruited sixty participants for each of the two studies, for a total of 120 participants, equally divided between men and women. In addition, I recruited 7 participants for the pilot study. The participants were SFU students recruited thorough a variety of means including posters, online mailing lists, newsletters, in-class presentations, and face to face on the SIAT campus. I screened participants for normal or corrected vision. Students who wore glasses, hard contacts, or coloured contacts did not participate in the study. Each participant received a $20 honorarium.

4.3 Procedure

4.3.1 Welcome and introduction

When participants arrived at the lab, I gave them a brief tour to familiarize them with the lab setting. The aim of this tour was to minimize the levels of anxiety that participants may have had in entering a lab setting filled with electronic equipment. High levels of anxiety may affect performance in wayfinding tasks (Schmitz, 1997), so it is important to minimize any anxiety not associated with the task itself.

I read a welcome message to participants and proceeded to describe the general aims of the study along with the sequence of events throughout the
experimental session. I described the calibration procedure, reassured participants that there was no danger involved, and that they could withdraw from the experiment at any moment. I answered general questions about the study, but I informed participants that more specific questions would be answered after the experiment to avoid influencing their performance. I then provided participants with a consent form. This form was entitled *Gender Differences in Virtual Route Learning*. It is possible that some participants may have figured out the nature of the experiment by simply reading this title and modified their behaviour during the tasks. However, not explaining the gender factor in this study could be considered a form of deception. The investigation of gender differences, particularly where spatial abilities are concerned, can sometimes be controversial. Therefore, I felt that being forthcoming about the nature of the study at the outset was more important than any potential impact this knowledge may have on participant behaviour.

### 4.3.2 Spatial ability tests

The experimental session began with the administration of two spatial abilities tests: *object location memory* and *mental object rotation*. I alternated the order of presentation for each participant. The mental rotation test was Peters’ (1995) modified version of Vandenbergh and Kuse’s (1978) test of 3D mental rotation. I guided the participant through a sample problem as described in the instructions to ensure that they understood the correct way of completing the tasks. They then completed 3 sample problems on their own.
Peters (1995) recommends that participants be given 6 or 8 minutes total to complete the test, broken into two session of 3 or 4 minutes with a couple of minutes rest in between. In the egocentric experiment, I mistakenly gave all participants 10 minutes to complete the test with no break in between. In the allocentric experiment, I gave participants 8 minutes with a 2-minute break in between. I chose 8 minutes rather than 6 to maintain some level of consistency with the time allotted in the egocentric experiment.

When administering the object location memory test (Alexander, Packard, and Peterson, 2002; Silverman & Eals, 1994), I instructed participants to take a minute to examine a sheet of paper that contained black and white drawings of 27 figures including a guitar, a chair, a suitcase, a teddy bear, and so forth. If participants inquired whether they needed to memorize the figures, I simply reiterated that they needed to look at the figures and examine them. The sheet of paper was placed faced down on the table in front of the participants, and I instructed them to turn it over when I said that they could begin. When time expired, I asked participants to stop examining the figures and took the sheet away. I presented participants with a second sheet that had the same objects in different locations. I instructed them to take a minute to circle the objects that had been moved and to stop when the time was up.

As the reliability of the mental rotation and object location memory tests relies on participants’ lack of experience with them, I have opted not to show any images associated with them but a full description of the test can be found in Silverman & Eals, 1994.
4.3.3 Participant eye tracker calibration

Once I administered the spatial abilities tests, I proceed with participant eye tracker calibration. This procedure consisted of the following steps:

- Participants’ eyes were at a distance of approximately 30 inches from the tracked plane, which measured approximately 25 degrees visual angle vertically and horizontally. I instructed participants to sit back on the chair and to avoid making large body movements sideways or forward. Nevertheless, natural body movements did occur and so the eye-to-monitor distance varied slightly for each participant.
- Participants donned a headband that contained a Velcro patch located above the left eye.
- I placed a small sensor on the Velcro patch.
- Participants looked at a 9-dot image on the monitor and fixated on the centre dot. While they fixated on this dot, I focused the camera on the left eye and activated magnetic head tracking. This function permitted the camera to track the eye image even if participants moved their heads.
- I captured pupil and corneal reflections as instructed by the eye-tracker manufacturer to record proper gaze measurements.
- I performed calibration procedure that required participants to look at the nine dots without moving the head. I ensured that the system maintained proper pupil and cornea discrimination for all nine dots. If for some reason it was not possible to maintain proper image discrimination, I did not test these participants.

4.3.4 Practice trial

I conducted a practice session in a basic mock-up environment so that participants would familiarize themselves with the look and feel of the environment, as well as visible elements of Google Earth’s interface. The
practice environment consisted of basic square columns placed along an imaginary path. Each column contained a non-descriptive label such as alpha, beta, omega, and so forth. The camera followed the imaginary path from a first person perspective in the egocentric point of view experiment and a top-down viewpoint in the allocentric experiment (see Figure 7 for sample screenshots). I instructed participants to examine all general elements of the environment and the interface. I did not instruct them to examine landmarks, the compass, or any other specific element of the environment to avoid biasing their performance.

Figure 7: Practice environment. Environment designed for the practice trial seen from the egocentric (top) and allocentric (bottom) viewpoints.
4.3.5 Main experimental trials

The experimental tasks required participants to learn a route that I had previously recorded within the Google Earth environment. I used a modified version of Galea and Kimura (1993) instructions, as follows:

“I am going to show you a video of a fictional virtual town. I am going to take you on an imaginary Sunday afternoon drive and I want you to try to remember the drive as best you can. Do you have any questions?”

After reading the instructions, I answered participants’ questions about the tasks, ensuring that I would not inadvertently prompt them to rely on a specific route-learning strategy. The videos were presented in 4 different orders of presentation. I asked participants to pick a number out of black leather bag, corresponding to one of the possible presentation blocks.
After answering participants’ questions and ensuring that they understood the task, I played the video and recorded their eye movements. Once the video stopped, the eye tracker automatically stopped recording data. After each video, I provided participants with a clipboard, a pencil, and a sheet of paper with the following instructions:

Please give directions from the start point and the end point. Give only the information that another person would need to know in order to travel the route.

I informed participants that they were not required to draw maps but to write directions using prose. In total participants filled out four sheets corresponding to the four routes viewed. There was no limit on word count or on time to produce the directions.

At the start of the trials, the view of the route remained still and participants viewed the starting point for 5 seconds. The five seconds allowed participants to gather information to help them orient themselves. In addition, this five-second pause allowed participants’ eyes to adjust to changes in brightness caused by stimulus onset and thus prevent the loss of pupil and corneal discrimination by the eye tracking system. I included these five seconds in the final analysis. After five seconds, the camera (and hence the viewpoint) began to move along a predetermined route that included left and right turns. Every aspect of the video, aside from viewpoint, remained the same in the two experiments. The camera stopped at the destination and remained still for five seconds. I also included the eye fixations gathered during these five seconds in the final analysis.
After presenting all four videos, I conducted an informal interview and asked participants to tell me about the strategy that they used to learn the route.

### 4.4 Software and equipment

#### 4.4.1 Eye tracking system

I used Applied Science Laboratories 504 eye tracker to record eye movements. The accuracy of the eye-tracking system was less than one degree. Its sampling and output rate were 60 Hz. The eye tracking system consisted of several components: a stationary camera captured video images of the eye that were used to measure the participant’s point of gaze; a control unit processed the video feed; the control interface software was installed in a Windows XP computer; a separate Windows XP system was used to display the experimental stimuli and record eye movements; a 19-inch monitor at 1024 x 768 resolution displayed experimental stimuli; two video monitors displayed the environment as seen on the participant monitor and rendered eye information (i.e., pupil and corneal reflections) designed to facilitate system operation; and an Ascension Flock-of-Birds unit provided head-tracking capabilities that permitted participants to move their heads freely without the need for a chinrest.

#### 4.4.2 Analysis software

Gazetracker is a third-party application that works with ASL’s eye tracking unit to aid in the data gathering and analysis process. I set up the stimulus presentation using Gazetracker’s functions designed for this purpose. The software was capable of recording eye-tracking data streamed from the main
control unit and synchronizing these data with the streamed video image. Its LookZone creation function allowed the segmentation of regions of interest using almost any shape. The program processed eye movement data for each LookZone and for the regions outside the LookZones. The shapes defining each LookZone could be repositioned, resized, and transformed to more accurately track dynamic objects within the virtual environment. Using the Gazetracker interface, I defined all fixation characteristics and data export parameters. I exported all the processed data into Excel spreadsheets. The data were then transferred into PASW Statistics 18.0 for final analysis.

4.4.3 Miscellaneous

The task instructions, spatial ability tests, and questionnaires were all printed on paper. To minimize participant body movements when completing the direction-giving tasks, I provided them with a clipboard. To control ambient light, I used a variety of light sources because during some sessions different levels of lighting were necessary to properly track eye movements.

4.5 Statistical analysis

A total of 120 students equally divided between men and women agreed to participate. Two separate samples of 60 students participated in each experiment, and students who participated in one experiment were not allowed to participate in the other. The participants were students in the School of Interactive Arts and Technology with the majority of them enrolled in the undergraduate program.
The eye tracking data consisted of the total fixation duration that participants spent looking at landmarks, the compass, and background area, each summed across four separate trials. Given that the route and its surrounding environment were presented in video format, each landmark appeared for several seconds on the screen, and then it disappeared out of view as the drive-through continued. During this time, participants could fixate on these landmarks continuously or discretely. Because the total amount of fixation duration was used as the main eye-tracking metric of interest, the duration of repeated fixations on a single landmark were summed up. The compass was located on the upper right corner of the screen and remained in that location for the entire duration of the video. Fixation duration times on the compass were summed up for the duration of the video and across the four separate trials.

Fixations were operationalized as the points where a participant's gaze remained relatively still for 200 ms or more (Rayner, 1998). I used this metric to calculate the percentage of time fixating on all landmarks and the compass. The written directions consisted of the frequency of references to landmarks and cardinal directions, averaged across the four trials. I calculated scores on the mental object rotation test, object location memory tests, and demographic variables for age, video game experience, spoken language, handedness, driving experience, and education.

I examined the characteristics of the eye movement, written directions, and spatial abilities data through the use of histograms and boxplots to identify outliers and determine degree of skewness. Skewness and kurtosis values are
reported. I examined outliers to determine their severity and identify any technical, calculation, or input errors that may have resulted in extreme values. Although there were a number of outliers in the eye movement, written directions, and spatial ability scores, I did not find any technical, calculation, or input errors that may have warranted their removal from the final analysis.

To determine if the data met assumptions of normality, I applied the Shapiro-Wilk W test for normality of distribution. I tested homogeneity of variance by applying Levene’s test of equality of error variance. If the data met assumptions of normality, I examined group differences with the Student’s t-test for independent samples, reporting the appropriate value if the assumption of homogeneity of variance was violated. If the data were non-normal, I used the non-parametric equivalent of the Student’s t-test, Mann-Whitney U, to investigate group differences. Effect sizes were measured with the Pearson correlation coefficient and interpreted with Cohen’s (1988, 1992) suggestions for small ($r = .10$), medium ($r = .30$), and large ($r = .50$) effects.

I examined correlations between score distributions for the grouped samples and also for separate samples based on gender. When data met assumptions of normality, I applied Pearson’s correlation coefficient. When assumptions of normality were violated, I applied Spearman’s coefficient for ranked data. In cases where the data violated assumptions of normality and contained a large number of tied ranks, I applied Kendall’s $tau$ rank correlation coefficient.
I conducted a correlation analysis on variable pairs as stated in the hypotheses, but it is possible to conduct a further layer of analysis to partial out the effects of third variables. For instance, I could have investigated the relationship between the time fixating on the compass (%) and the number of written references to cardinal directions while controlling the effects of mental object rotation. A partial correlation analysis would give an account of the size of the unique portion of variance between the two variables of interest. I did not conduct a partial correlation analysis for several reasons. Besides time constraints, the data set was small, and in some cases it did not meet parametric assumptions that would readily lend themselves to this type of analysis.

4.6 Assumptions

4.6.1 Real and virtual environments as lab settings

The experimental stimulus in these experiments consisted of 3D virtual renderings of a fictional town based on a 2D map used in a variety of studies (e.g., Dabbs et al., 1998; MacFadden et al., 2003; Ward et al., 1986;). A dynamic 3D virtual environment is structurally different from a 2D map but bears similarities to the real world. While I assumed that a virtual environment’s resemblance to the real world would elicit more ‘natural’ route-learning behaviour than a paper map, it is entirely possible that the opposite is in fact true. There is no evidence, as far I know, that indicates that virtual environments are less or more ecologically valid than maps. Nevertheless, it is reasonable to assume that an environment that contains realistic features (e.g., motion, 3D objects, and
multiple perspectives) is more likely to elicit naturalistic responses than an environment that does not contain such features.

4.6.2 Virtual and real-world route learning

The artificiality of a virtual route-learning experiment is not confined to the stimuli itself but also to the experimental task. In the real world we use physical motion through space to integrate the path travelled. In a virtual environment, a traveller must use other means (usually a mouse and keyboard) to move from the start to the end of a route. In this project, I opted for tasks that only required participants to view a video of a previously recorded drive-through of the route. The extent to which passively learning a route, viewed on a 19" display, affects the visual and direction-giving strategies of a navigator is not known. The possibility remains that performing a route-learning task in one environment does not necessarily transfer to another. Some experimental evidence indicates that performance in route learning can transfer between virtual and real environments (Lloyd et al., 2009). For instance, participants who learned a route in a guided tour within virtual and real environments showed similar route-learning performance (Lloyd et al., 2003). Yet, other evidence has shown that making navigation decisions is important for route learning to transfer to the real world (Farrell, Arnold, Pettifer, Adams, Graham, & MacManamon, 2003). Although, it is not possible to say with certainty whether route-learning performance in virtual environments transfers to real-world environments, I assumed that given the similarities between them, the strategies employed should be comparable.
4.6.3 Defining landmarks

The exact properties of *landmarks* as theoretical constructs have not been fully delineated. There are a variety of ways in which landmarks can be defined, but in this project, I emphasized their visual properties (e.g., shape and structure) that serve as aids during route learning. Generally, a landmark is a salient feature that defines the topography of the environment, and which can be used as reference points for orientation when travelling along a route (Foo, Warren, Duchon, & Tarr, 2005; Stankiewicz & Kalia, 2007). Landmarks may include familiar objects such as buildings, parks, traffic lights, and lampposts. They may also include more abstract entities such as the edges of large objects, cracks on the pavement, luminance levels, object textures, colours, and even areas with emotional or cognitive significance. Yet, there are some objects that are more difficult to define as either topographic or configurational features of the environment. Streets are an example of these features. Paths, streets, and highways have a concrete visual form that would characterize them as topographic entities, but they also provide directional data in a grid-like manner across large expanse of space; and this is a property more closely associated with the Euclidean geometry of the environment than its topography. While I gathered data on streets, I did not include them as landmarks. This permitted me to maintain analytical continuity with MacFadden et al.’s (2003) investigation, in which streets were not included in the final analysis. Although, it should be noted that Deborah Saucier (personal communication, February 2, 2010) is of the opinion that streets should be considered landmarks.
4.7 Pilot study

Seven participants volunteered for the pilot study and they received $20 for their participation. The general experimental procedure was similar to the main study. The aim of the pilot study was to test the technical and experimental integrity of the study. Based on the results of the pilot test, I altered various aspects of the study as follows.

- Streamlined the participant calibration procedure to minimize technical errors and reduce calibration time.
- Moved and resized various elements of the virtual environment so that they were suitable for accurate eye tracking.
- Decreased the speed of the camera movement in the video to make it easier for participants to learn the route.
- Edited the introduction to the study to clarify various aspects of the protocol.
- Improved video quality to minimize “choppiness”.
- Improved the experimental procedure by providing more concise instructions at each phase of the experiment, particularly the spatial abilities tests.
- Reworded instructions for the practice trial, removing references to landmarks and compass to avoid prompting participants on their use.
• Changed the direction-giving format. Initially participants were to write directions on screen but this caused them to move their bodies, introducing errors in the recording of eye movements.

• Moved labels closer to the landmarks they represented.

• Moved street labels to the middle of the route instead of placing them on the side, where they provided conflicted information with landmark labels.

• I added traffic lights because participants mentioned that missing lights looked odd.

• I removed some of the unlabelled paths because they were not adding any useful information and cluttered the environment.

• Changed the street shading because some participants mentioned that it was attention grabbing and distracting.

• Added a pause of 5 seconds at the beginning and at the end of the video. Participants indicated that without this 5 second pause the route was disorienting.

• Adjusted the height at which the environment was seen to provide a clearer view of distant objects.

• Added a calibration check in the 2nd trial because I noticed errors were introduced throughout experiment due to participant movements and changes in their pupil responses over time.
• Streamlined the experiment to shorten duration to one hour (down from one and a half hour).

During the pilot test, I also examined the responses in the spatial ability tests to ensure that participants were following instructions accurately. I did not find any problems, and the participants were able to complete the tests without issues. I made a few minor adjustments to the manner in which participants were tested with the eye tracker to minimize errors, but these adjustments did not impact the experimental design at large.
5: EXPERIMENT 1 RESULTS- EGOCENTRIC VIEWPOINT

5.1 Overview

In this chapter, I present the results of the analysis on the collected data for eye movements, written directions, and spatial abilities. A summary of the data can be found on Table 1. I report the demographics data (5.2); the statistical relationships between gender and route learning strategies (5.3); and the relationship between gender, spatial abilities, and route learning (5.4).

Table 1: Summary of descriptive data and frequency distributions

<table>
<thead>
<tr>
<th></th>
<th>Number of written references to landmarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Women</td>
<td>Mean = 2.5</td>
</tr>
<tr>
<td></td>
<td>Min = 0.3</td>
</tr>
<tr>
<td></td>
<td>Max = 6.5</td>
</tr>
<tr>
<td></td>
<td>Mdn = 2.4</td>
</tr>
<tr>
<td></td>
<td>SD = 1.47</td>
</tr>
<tr>
<td>Men</td>
<td>Mean = 2.7</td>
</tr>
<tr>
<td></td>
<td>Min = 0.0</td>
</tr>
<tr>
<td></td>
<td>Max = 7.3</td>
</tr>
<tr>
<td></td>
<td>Mdn = 2.5</td>
</tr>
<tr>
<td></td>
<td>SD = 1.53</td>
</tr>
<tr>
<td>Number of written references to cardinal directions</td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Women</strong></td>
<td></td>
</tr>
<tr>
<td>Mean = 0.2</td>
<td></td>
</tr>
<tr>
<td>Min = 0.0</td>
<td></td>
</tr>
<tr>
<td>Max = 1.0</td>
<td></td>
</tr>
<tr>
<td>Mdn = 0.0</td>
<td></td>
</tr>
<tr>
<td>SD = 0.29</td>
<td></td>
</tr>
<tr>
<td><strong>Men</strong></td>
<td></td>
</tr>
<tr>
<td>Mean = 0.5</td>
<td></td>
</tr>
<tr>
<td>Min = 0.0</td>
<td></td>
</tr>
<tr>
<td>Max = 3.5</td>
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</tr>
<tr>
<td>Mdn = 0.0</td>
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<tr>
<td>SD = 0.86</td>
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</table>

<table>
<thead>
<tr>
<th>Time fixating on landmarks (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Women</strong></td>
</tr>
<tr>
<td>Mean = 16.7</td>
</tr>
<tr>
<td>Min = 5.2</td>
</tr>
<tr>
<td>Max = 22.7</td>
</tr>
<tr>
<td>Mdn = 16.7</td>
</tr>
<tr>
<td>SD = 3.49</td>
</tr>
<tr>
<td><strong>Men</strong></td>
</tr>
<tr>
<td>Mean = 17.2</td>
</tr>
<tr>
<td>Min = 12.9</td>
</tr>
<tr>
<td>Max = 21.3</td>
</tr>
<tr>
<td>Mdn = 17.6</td>
</tr>
<tr>
<td>SD = 2.09</td>
</tr>
</tbody>
</table>
### Percentage of time fixating on the compass (%)

<table>
<thead>
<tr>
<th></th>
<th>Women</th>
<th></th>
<th></th>
<th>Men</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Mean = 3.7</strong></td>
<td><strong>Min = 0.6</strong></td>
<td><strong>Max = 10.9</strong></td>
<td><strong>Mean = 4.4</strong></td>
<td><strong>Min = 0.2</strong></td>
<td><strong>Max = 13.0</strong></td>
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<tr>
<td></td>
<td><strong>Mdn = 3.1</strong></td>
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<td></td>
<td><strong>Mdn = 4.1</strong></td>
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<tr>
<td></td>
<td><strong>SD = 2.40</strong></td>
<td></td>
<td></td>
<td><strong>SD = 3.06</strong></td>
<td></td>
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</tr>
</tbody>
</table>

### Object location memory test

<table>
<thead>
<tr>
<th></th>
<th>Women</th>
<th></th>
<th></th>
<th>Men</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Mean = 9.3</strong></td>
<td><strong>Min = 5</strong></td>
<td><strong>Max = 14</strong></td>
<td><strong>Mean = 7.6</strong></td>
<td><strong>Min = 3</strong></td>
<td><strong>Max = 13</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Mdn = 9.5</strong></td>
<td></td>
<td></td>
<td><strong>Mdn = 8.0</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>SD = 2.23</strong></td>
<td></td>
<td></td>
<td><strong>SD = 2.99</strong></td>
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</tr>
</tbody>
</table>
The results of the analysis are presented below. As described in section 2.9, the “exploratory analysis” refers to analysis of topics that have not been empirically addressed in past research but are important in understanding gender differences in route learning.

- **Route-learning strategy**
  - **[H1]** There was no significant difference between men and women on the average number of written references to landmarks (5.3.1).
  - **[H2]** There was no significant difference between men and women in the number of written references to cardinal directions (5.3.2). There was a significant difference favouring men when an exploratory analysis was conducted on participants who made a number of written references to cardinal directions greater than 0 (5.3.3).
• Correlations between route-learning strategies

  o **[H5]** There was a significant positive correlation between *time fixating on landmarks (%)* and the *number of written references to landmarks* when the two sample populations were analyzed as a single group (5.3.9.1).

  o **[Exploratory Analysis]** There was a positive correlation between women’s *time fixating on landmarks (%)* and the *number of written references to landmarks* (5.3.9.2).

  o **[Exploratory Analysis]** There was no correlation between men’s *time fixating on landmarks (%)* and the *number of written references to landmarks* (5.3.9.3).

  o **[H6]** There was a significant positive correlation between the *time fixating on the compass (%)* and the *number of written references to cardinal directions* when the two sample populations were analyzed as a single group (5.3.11.1).

  o **[Exploratory Analysis]** There was a significant positive correlation between women’s *time fixating on the compass (%)* and the *number of written references to cardinal directions* (5.3.11.2).
- **Exploratory Analysis** There was a significant positive correlation between men’s *time fixating on the compass (%)* and *the number of written references to cardinal directions* (5.3.11.3).

- **Summary** The results of the correlation tests confirmed the hypothesis that there would be a significant positive correlation between the *time fixating on landmarks (%)* and *the number of written references to landmarks* when the two sample populations were analyzed as a single group. There was also a positive correlation between women’s *time fixating on landmarks (%)* and *the number of written references to landmarks*. However, I found no positive correlation between the two variables for men’s data. As predicted, I found evidence that the *time fixating on the compass (%)* was positively correlated with the *number of written references to cardinal directions* when the sample populations were analyzed as a single group. When I analyzed the sample populations separately, I found evidence of a positive correlation between women’s *time fixating on the compass (%)* and *the number of written references to cardinal directions*. Men’s *time fixating on the compass (%)* was also positively correlated to the *number of written references to cardinal directions*.

- **Spatial abilities**
- **Relationship between object location memory and topographic route-learning strategies**
  - [H7] Women scored significantly higher than men on tests of *object location memory* (5.4.1).
  - [H8] There was no significant correlation between scores on the *object location memory* test and the *number of written references to landmarks* when men and women were analyzed as a single group (5.4.2.1).
  - [Exploratory Analysis] There was a significant negative correlation between women’s scores on the *object location memory* test and the *number of written references to landmarks* (5.4.2.2).
  - [Exploratory Analysis] There was no significant correlation between men’s scores on the *object location memory* test and the *number of written references to landmarks* (5.4.2.3).
  - [H9] There was no significant correlation in scores of the *object location memory* test and *time fixating on landmarks (%)* when the two samples were analyzed as a single group (5.4.3.1).
[Exploratory Analysis] There was no significant correlation in scores of the object location memory test and time fixating on landmarks (%) when women (5.4.3.2) and men (5.4.3.3) were analyzed separately.

Summary As predicted women scored significantly higher than men in the object location memory test. However, I found no evidence to support the hypothesis that scores on the object location memory test were correlations with the references to landmarks or with the time fixating on landmarks. When I analyzed the data by gender, I found an unexpected negative correlation between the two variables in women’s data.

Relationship between mental rotation and configurational route-learning strategies

[H10] Men scored significantly higher than women on the mental object rotation test (5.4.5).

[H11] There was a significant positive correlation between scores on the mental object rotation test and the number of written references to cardinal directions when the two sample populations were analyzed as a single group (5.4.6.1).

[Exploratory Analysis] There was no significant correlation between scores on the mental object rotation test and the number of written references to cardinal directions when women (5.4.6.2) and men (5.4.6.3) were analyzed separately.

[H12] There was no significant correlation between scores on the mental object rotation test and the time fixating on the compass (%) when the two sample populations were analyzed as a group (5.4.7.1).

[Exploratory Analysis] There was no significant correlation between scores on the mental object rotation test and the time fixating on the compass (%) when women (5.4.7.2) and men (5.4.7.3) were analyzed separately.

Summary As predicted, men scored higher than women in the mental rotation test. Also supported was the prediction that scores on the mental rotation test would be positively correlated with references to cardinal directions. This was not the case when I analyzed men and women separately. I did not find support for the hypotheses that scores on the mental rotation test would be correlation with fixations on the compass, even when I analyzed men and women’s data separately.
5.2 Demographic data

A total of 60 volunteers (30 men, 30 women) participated in the allocentric point of view study. The majority of the participants were students enrolled in the undergraduate program at the School of Interactive Arts and Technology. Each participant received $20 for his/her participation. A complete summary table of the demographic data can be found in Appendix E. Of interest, forty percent of all participants were under the age of 20; approximately 53% were between the ages of 20 and 25; 5% between 26-30; and approximately 2% over the age of 30. 46.7% of women were under 20 years of age, 46.7% were between 20-25; 6.7% between 26-30; and none over the age of 30. 60% of men were between the ages of 20-25; 33% under the age of 20; 3.3% between 26-30; and 3.3% over the age of 30. 55% percent of all participants reported English as their second language. Approximately 63% of women and 47% of men indicated that English was their second language. The language spoken by the participants included Chinese (Cantonese and Mandarin), Korean, German, Romanian, Russian, Persian, Punjabi, Serbian, and Spanish. Chinese was the most common language reported by participants who’s English was not their first language.

5.3 Gender and route-learning strategies

In this section, I report the results of the analysis associated with the relationship between gender, written directions, and eye fixations. As indicated in section 3.2, I theorized that women would rely on a topographic strategy, and therefore they would make a greater number of written references to landmarks
and spend more time fixating on landmarks than men. Men would rely on a configurational strategy, and they would make a greater number of references to cardinal directions and spend a greater amount of time fixating on the compass than women. A summary of the predictions is illustrated Table 2.

Table 2: Predicted differences between women (W) and men (M) in virtual route learning.

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>W</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dependent Variables</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H1 Number of Written References to Landmarks (avg)</td>
<td>&gt;</td>
<td></td>
</tr>
<tr>
<td>H2 Number of Written References to Cardinal Directions (avg)</td>
<td>&lt;</td>
<td></td>
</tr>
<tr>
<td>H3 Time Fixating on Landmarks (%)</td>
<td>&gt;</td>
<td></td>
</tr>
<tr>
<td>H4 Time Fixating on Compass (%)</td>
<td>&lt;</td>
<td></td>
</tr>
</tbody>
</table>

To investigate the extent to which the visual scanning of the virtual route correlated with direction giving, I performed a correlation analysis on the data. In particular, I hypothesized that the proportion of time fixating on landmarks and the compass would correlate with the number of written references to landmarks and cardinal directions respectively. I also performed an exploratory analysis of these correlations by gender. A summary of the predictions is illustrated Table 3.
Table 3: Predicted correlations between eye fixations and direction giving. The + sign denotes a positive correlation

<table>
<thead>
<tr>
<th>Eye fixations</th>
<th>Written directions</th>
</tr>
</thead>
<tbody>
<tr>
<td>H5 Time Fixating on Landmarks (%)</td>
<td>+ Number of Written References to Landmarks (avg)</td>
</tr>
<tr>
<td>H6 Time Fixating on the Compass (%)</td>
<td>+ Number of Written References to Cardinal Directions (avg)</td>
</tr>
</tbody>
</table>

5.3.1 Hypothesis one- the number of written references to landmarks

I hypothesized that when giving written directions after a route-learning task, women would, on average, make more written references to landmarks than men.

5.3.1.1 Descriptive analysis

As seen on Figure 8, on average men ($M = 2.7$, $SD = 1.53$) made a greater *number of written references to landmarks* than women ($M= 2.5$, $SD = 1.47$). There was a noticeable overlap in the 95% confidence interval for each sample group, which suggested a non-significant difference between them.
Figure 8: Average number of written references to landmarks made by women and men with a 95% confidence interval.

The histograms (Figure 9) show that the distribution of scores were more or less symmetrical and thus appeared normal. Women’s score distribution was positively skewed (Skewness = 0.84, SE = 0.43), and men’s distribution of scores was also positively skewed (Skewness = 0.73, SE = 0.43). Women’s score distribution was leptokurtic (Kurtosis = 0.54, SE = 0.83) and so was men’s distribution (Kurtosis = 1.07, SE = 0.83).
Figure 9: Distribution of scores for the number of written references to landmarks.

The boxplot (Figure 10) shows that the distributions were skewed toward the low end of the scale, especially for men. Yet, this deviation did not appear particularly severe. There was one outlier in the women's group.

Figure 10: The number of written references to landmarks.

In spite of the skewed distributions, the Shapiro Wilk $W$ tests of normality was not significant for either men's ($W = .95, p = .19$) or women's ($W = .95, p =$
.15) score distribution. Results of the Levene’s test showed that the variances of scores for the number of written references to landmarks were homogenous ($F(1, 58) = 0.06, p = .80$).

Participant F58 was an outlier and she made 6.5 written references to landmarks, which was higher than her group’s mean ($M = 2.5, SD = 1.47$). The corresponding eye movement value (i.e., time fixating on landmarks [%]) was not outside the norm. One other extreme value in her profile was a lower than average score in the object location memory test. There was no evidence to suggest that this participant belonged to a different sample population and was therefore included in the final analysis.

The data for the number of written references to landmarks met the parametric assumptions, and therefore I used the Student’s t-test to investigate the statistical relationship between men and women.

**Figure 11:** Error graph for the average number of written landmarks with a 95% confidence interval
5.3.1.2 H1 results

As suggested by the overlap of confidence intervals (Figure 11) and indicated by the results of the test, the average difference between men ($M = 2.7$, $SD = 1.53$) and women ($M = 2.5$, $SD = 1.47$) in the number of written references to landmarks was not significant ($t (58) = -0.62, p = .27$). I found no support for the hypothesis that when giving written directions after a route-learning task, women would make more written references to landmarks than men.

5.3.2 Hypothesis two- the number of written references to cardinal directions

I hypothesized that when giving written directions after a route-learning task, men would make a greater number of written references to cardinal directions than women.

5.3.2.1 Descriptive analysis

Figure 12 shows that, on average, men ($M = 0.5$, $SD = 0.86$) made a greater number of written references to cardinal directions than women ($M = 0.2$, $SD = 0.29$). While it seems unusual to have a mean number of written references lower than 1, recall that this is a composite value averaged over 4 different routes. For example, if over the course of learning 4 routes, a participant made 2 references to cardinal directions, the average value across all four routes will be 0.5 ($2/4$). The underlying statistical relationship between the cardinal direction values remains the same with the added advantage of allowing
us to compare them with scores measured on a different scale (i.e., average time fixating on the compass [%] and average scores on the mental object rotation test).

Figure 12: Average number of written references to cardinal directions.

The histograms (Figure 13) show that the distribution for women was positively skewed (Skewness = 1.52, SE = 0.43) and men’s distribution was also positively skewed (Skewness = 2.15 SE = 0.43). Women’s distribution was leptokurtic (Kurtosis = 1.30, SE = 0.83) and men’s distribution was also leptokurtic (Kurtosis = 4.61, SE = 0.83).
Figure 13: Frequency distribution of values related to the number of written references to cardinal directions.

Figure 14 illustrates the lack of symmetry in the distributions and identified a high number of outliers, two of which were severe in the men’s group.

Figure 14: Number of written references to cardinal directions. Asterisks represent severe outliers.

Table 4 contains a summary list of participants who were identified as outliers in the number of written references to cardinal directions. For these
participants, I also report the extreme scores in demographic, spatial ability, written references, and eye fixation variables.

Table 4: Participants with extreme scores on the number of written cardinal directions and other variables

<table>
<thead>
<tr>
<th>Participant code</th>
<th>Variable</th>
<th>Value</th>
<th>Group statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F28</td>
<td>Number of written references to cardinal directions</td>
<td>0.7</td>
<td>$M = 0.2$ $Mdn = 0.0$ $SD = 0.29$</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time fixating on the compass (%)</td>
<td>6.1</td>
<td>$M = 3.7$ $Mdn = 3.1$ $SD = 2.40$</td>
</tr>
<tr>
<td></td>
<td>Number of years with a driver’s license</td>
<td>7.0</td>
<td>$M = 2.3$ $Mdn = 2.0$ $SD = 1.8$</td>
</tr>
<tr>
<td>F55</td>
<td>Number of written references to cardinal directions</td>
<td>0.7</td>
<td>$M = 0.2$ $Mdn = 0.0$ $SD = 0.29$</td>
</tr>
<tr>
<td></td>
<td>Mental object rotation test score</td>
<td>24.0</td>
<td>$M = 14.6$ $Mdn = 15$ $SD = 6.42$</td>
</tr>
<tr>
<td>F28</td>
<td>Number of written references to cardinal directions</td>
<td>1.0</td>
<td>$M = 0.2$ $Mdn = 0.0$ $SD = 0.29$</td>
</tr>
<tr>
<td></td>
<td>Mental object rotation test score</td>
<td>5.0</td>
<td>$M = 14.6$ $Mdn = 15$ $SD = 6.42$</td>
</tr>
<tr>
<td></td>
<td>Number of written landmarks</td>
<td>5.2</td>
<td>$M = 2.5$ $Mdn = 2.4$ $SD = 1.47$</td>
</tr>
<tr>
<td>Men</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M36</td>
<td>Number of written references to cardinal directions</td>
<td>1.7</td>
<td>$M = 0.5$ $Mdn = 0.0$ $SD = 0.86$</td>
</tr>
<tr>
<td></td>
<td>Time fixating on the compass (%)</td>
<td>7.8</td>
<td>$M = 4.4$ $Mdn = 4.1$ $SD = 3.06$</td>
</tr>
<tr>
<td></td>
<td>Number of years with a driver’s license</td>
<td>7.0</td>
<td>$M = 3.7$ $Mdn = 3.0$ $SD = 3.12$</td>
</tr>
<tr>
<td></td>
<td>Object location memory test score</td>
<td>12.0</td>
<td>$M = 7.6$ $Mdn = 8.0$ $SD = 2.99$</td>
</tr>
<tr>
<td>M35</td>
<td>Number of written references to cardinal directions</td>
<td>1.3</td>
<td>$M = 0.5$ $Mdn = 0.0$ $SD = 0.86$</td>
</tr>
<tr>
<td>M07*</td>
<td>Number of written references to cardinal directions</td>
<td>2.2</td>
<td>$M = 0.5$</td>
</tr>
<tr>
<td>Participant code</td>
<td>Variable</td>
<td>Value</td>
<td>Group statistics</td>
</tr>
<tr>
<td>------------------</td>
<td>----------</td>
<td>-------</td>
<td>------------------</td>
</tr>
</tbody>
</table>
|                  | cardinal directions |       | *Mdn* = 0.0  
*SD* = 0.86 |
|                  | Time fixating on the compass (%) | 13.0 | *M* = 4.4  
*Mdn* = 4.1  
*SD* = 3.06 |
|                  | Number of hours playing video games | Over 10 hours per week |  
• 57% played video games less than 5 hours per  
• 23% played between 5 and 10 hours  
• 17% played over 10 hours. |
| **M61** | Mental object rotation test score | 23.0 | *M* = 20.2  
*Mdn* = 20.0  
*SD* = 3.10 |
|                  | Number of written references to cardinal directions | 3.5 | *M* = 0.5  
*Mdn* = 0.0  
*SD* = 0.86 |
|                  | Mental object rotation test score | 23.0 | *M* = 20.2  
*Mdn* = 20.0  
*SD* = 3.10 |

* Outlier flagged as severe  
**Number of participants in brackets.

There appeared to be two distinct populations in each sample group. One group used cardinal directions as a strategy and the other did not. Given that not many participants used cardinal directions, the values of those who did use them appeared extreme. Although some of the outliers show abnormal values in other variables, I did not find experimental evidence to warrant their removal. Additionally, even though it appeared as if there were two different populations within each sample group, I chose to analyze the two sample groups without splitting them into separate groups. However, in section 5.3.3, I report the analysis performed only on those participants who made a number of references to cardinal directions greater than 0.
The results of the Shapiro-Wilk $W$ test of normality were significant for women ($W = .668, p = .000$) and men ($W = .641, p = .000$). Levene’s test of homogeneity of variances was also significant ($F (1, 58) = 11.48, p = .001$). Thus, the data violated parametric assumptions.

5.3.2.2 H2 results

Since the data violated parametric assumptions, I used Mann-Whitney $U$ to investigate the statistical relationship between women ($Mdn = 0.0, SD = 0.29$) and men ($Mdn = 0.0, SD = 0.86$) on the number of written references to cardinal directions. The results of this test were not significant ($Mann-Whitney U = 401.50, p = .2$). I found no evidence that when giving written directions after a route-learning task, men made a greater number of written references to cardinal directions than women.

5.3.3 Exploratory analysis of participants who made a number of written references to cardinal directions greater than 0

As reported, a large number of participants did not make any references to cardinal directions. This large number of participants contributed to deviations from normality, and the final results of the test may not have been representative of the true nature of the data. Therefore, I performed an exploratory analysis on those participants who made references to cardinal directions, excluding those who did not. Ten women and eleven men made references to cardinal directions. To randomly eliminate one of the male participants, I generated a random number from one to eleven using an online number generator from random.org (Haahr, 1998). In total, I analyzed 10 men and 10 women.
5.3.3.1 Descriptive analysis

On Figure 15, the mean graph shows that on average, men \((M = 1.2, SD = 0.96)\) made a greater number of written references to cardinal directions than women \((M = 0.52, SD = 0.25)\). Men’s confidence interval was larger than that of women, and there was an overlap between them. The overlap was small and did not necessarily indicate that the samples came from the same population.

![Figure 15: Average number of written references to cardinal directions.](image)

The histograms (Figure 16) show that the distribution for women’s scores was positively skewed \((Skewness = 0.61, SD = 0.69)\) and that of men was also positively skewed \((Skewness = 1.70, SD = 0.69)\). Women’s score distribution was platykurtic \((Kurtosis = -0.16, SE = 1.33)\) and men’s was leptokurtic \((Kurtosis = 2.92, SE = 1.33)\). The skewness and kurtosis values did not appear particularly non-normal.
Figure 16: Frequency distribution of values related to the number of written references to cardinal directions.

The boxplots (Figure 17) show that both distributions were skewed to the low end of the scale, and men’s distribution had a wider range of scores than women’s. There were no outliers identified, but it should be kept in mind that the data for each group represented the scores for only 10 participants.

Figure 17: Number of written references to cardinal directions.
The results of the Shapiro-Wilk \( W \) normality test were not significant for women \((W = .89, p = .15)\), but they were significant for men \((W = .87, p = .008)\). Levene’s test of homogeneity of variances was significant \((F (1, 18) = 7.42, p = .014)\). Thus, the data violated assumptions of normality and homogeneity of variances.

5.3.3.2 Exploratory analysis results

Given that the data violated parametric assumptions, I conducted a Mann-Whitney \( U \) test. The results indicated that men \((Mdn = 1.0, SD = 0.96)\) scored significantly higher than women \((Mdn = 0.5, SD = 0.25)\) on the number of written references to cardinal directions \((Mann-Whitney U = 21.50, p = .012)\). The effect size as measured with the Pearson correlation coefficient was \(r = -.50\), which is considered a large effect that explains 25% of the total variance (Cohen 1988, 1992). Thus, contrary to the findings in section 5.3.2, men did make a significantly greater number of written references to cardinal directions than women. In the present analysis, when only participants who made references to cardinal directions were taken into account, there was evidence to support the hypothesis that when giving written directions after a route-learning task, men made a greater number of written references to cardinal directions than women.

5.3.4 Summary

The hypothesis that men and women would differ in the average number of written references to landmarks was not supported. As well, I found no evidence that men and women differed significantly in the number of written
references to cardinal directions. However, when only the subset of 20
participants who used cardinal directions were analyzed, I found that men made
a significantly greater number of written references to cardinal directions.

5.3.5 Hypothesis three- time fixating on landmarks (%)

I hypothesized that when learning a route, women would allocate a greater
percentage of fixation time on landmark regions than men. In the sections that
follow, I first report the results of a descriptive analysis of the data. The aim was
to demonstrate how I arrived at decisions regarding the appropriate statistical
procedures. I then report the results of the inferential analysis and the
determination of whether the hypothesis was supported or refuted. I use this
reporting structure throughout the chapter.

5.3.5.1 Descriptive analysis

As Figure 18 illustrates, on average, men \((M = 17.2, \ SD = 2.09)\) spent a
greater amount of time fixating on landmarks (%) than women \((M = 16.7, \ SD = 3.49)\). The overlap of the confidence intervals, however, indicated that this
difference did not appear significant.
Figure 18: Average time fixating on landmarks (%) with a 95% confidence interval (CI).

The histograms in Figure 19 show the distribution of scores for the time fixating on landmarks (%). Women’s score distribution was negatively skewed (Skewness = -1.20, SE = 0.43), which suggested deviation from normality. Men’s distribution of scores appeared more or less symmetrical (Skewness = -0.07, SE = 0.43), suggesting a normal distribution. As shown by the shape of the peaks the distribution of women’s scores was leptokurtic (Kurtosis = 3.07, SE = 0.83) and that of men was slightly platykurtic (Kurtosis = -0.31, SE = 0.83).
Figure 19: Frequency distribution of values for the percentage of time that men and women fixated on landmarks.

The boxplots in Figure 20 demonstrate that women’s distribution of scores was skewed to the low end of the scale, and men’s score distribution was somewhat symmetrical. There were two outliers in the women’s score distribution.

Figure 20: The percentage of time that men and women fixated on landmarks. Outliers are depicted as circles along with the participant code.
The test of normality indicated that the distribution of scores was non-normal for women (Shapiro-Wilk $W = .92$, $p = .03$) and normal for men (Shapiro-Wilk $W = .99$, $p = .97$). Given that Levene’s test does not require the distributions to be normal, I used it to test the equality of variances between the samples. Results of the Levene’s test showed that the variances of scores for the time fixating on landmarks (%) were homogenous ($F (1, 58) = 2.73$, $p = .10$). Therefore, even though only women’s distribution of scores was non-normal, I assumed that parametric assumptions had been violated.

Participant F46 and F08 were outliers from the women’s group. I examined the two outliers closer, and a review of the data preparation procedure did not reveal any technical errors, data entry errors, or erroneous calculations. The percentage of time that participant F46 fixated on landmarks was 10.0%, which was lower than the 16.7% average for the women’s sample population. She also had the second highest value (87.5%) in time fixated outside the main areas of interest (%). These areas constituted streets, ground, sky, interface elements (e.g., elevation indicator, Google branding, and copyright information) and other background aspects of the environment such as mountain ranges. The women’s group average on time fixated outside the main areas of interest (%) was 79.6%. The unusual high amount of fixation time outside the main regions of interest accounted for the low time fixating on landmarks (%). Although a technical malfunction could not be ruled out, I had no reason to suspect that this was anything other than normal visual scanning behaviour. Participant F46 also disclosed that she spent about 21 hours driving per week. The group’s mean
was 4.2 hours. She had no other extreme demographic values or spatial ability scores that indicated she belonged to a different sample group. It is worth noting that her *number of written references to landmarks* ($M = 1.0$) was the third lowest in the sample group ($M = 2.5$, $SD = 1.47$), which indirectly suggested that her landmark scanning behaviour was normal.

Participant *F08* had the lowest value for the *time fixating on landmarks* (%). She also had the highest value (93.2) for the *time fixating outside the main areas of interest* (%). At least in part, this high value accounted for the participant's low *time fixating on landmarks* (%). There did not appear to be anything unusual about the *number of written references to landmarks* she reported. In the *mental object rotation* test, the participant had the fifth highest score (21) in her sample group ($M = 14.6$, $SD = 6.42$). She also had a higher than average score (12) than her group's mean ($M = 9.3$, $SD = 2.23$) in test of *object location memory*. She was one of the few participants in her group who opted to use cardinal directions during the tasks and her higher than average score in the *number of written references to cardinal directions* reflected this.

As I did not have experimental evidence that the two outliers belonged to a sample population other than the one under consideration, I chose to retain the scores.

Given the violation of the parametric assumptions for the samples, I applied the Mann-Whitney *U* test (suitable for non-parametric data) to determine if there was a statistically significant difference between gender and the *time fixating on landmarks* (%). As depicted in Figure 21, I reported the median
because for non-parametric analysis, the median is a more appropriate statistic than the mean (Field, 2005).

Figure 21: Median of the time fixating on landmarks (%) with a 95% confidence interval (CI).

5.3.5.2 H3 results

The results of the inferential test showed that men ($Mdn = 17.6, SD = 2.09$) did not significantly differ from women ($Mdn = 16.7, SD = 3.49$) in the time fixating on landmarks (%) ($U = 420.00, p = .33$). Thus, there was no evidence to support the hypothesis that when learning a route, women allocated a greater percentage of fixation time on landmark regions than men.

5.3.6 Hypothesis four- time fixating on the compass (%)

I hypothesized that when learning a route, men would allocate a greater amount of time fixating on the compass (%) than women.
5.3.6.1 Descriptive analysis

On average, men ($M = 4.4$, $SD = 3.06$) allocated a greater amount of time on the compass (%) than women ($M = 3.7$, $SD = 2.40$) (Figure 22). There was an overlap between the 95% confidence interval in each sample group.

Figure 22: Average percentage of time that men and women fixated on the compass (%) with a 95% confidence interval.

The histograms (Figure 23) show that the distribution of scores was positively skewed for women ($Skewness = 1.13$, $SE = 0.43$) and men ($Skewness = 0.73$, $SE = 0.43$). The distribution for women ($Kurtosis = 1.31$, $SE = 0.83$) and men ($Kurtosis = 0.51$, $SE = 0.83$) were leptokurtic. These results suggested that women’s score distribution deviated from normality more so than men’s.
Figure 23: Frequency distribution of values for the percentage of time that men and women fixated on the compass.

The boxplots (Figure 24) illustrated that the distributions for men and women were skewed towards the low end of the scale. There was one outlier in each group: F57 in the women's group and M07 in the men's group.

Figure 24: Boxplots for the percentage of time that men and women fixated on the compass.
Participant F57’s *time fixating on the compass* (10.9%) was higher than the group’s average (*M* = 3.7, *SD* = 2.40). I found no evidence that this value was the result of technical, data entry, or calculation error. In spite of the participant’s higher than average *time fixating on the compass (%)*, she did not make any *number of written references to cardinal directions* during the tasks. There was no evidence of extreme scores in her demographic profile, spatial ability scores, or other experimental variables.

Participant’s M07’s *time fixating on the compass* (13.0%) was higher than the group’s average (*M* = 4.4, *SD* = 3.06). The participant also had the second highest value (2.2) for the *number of written cardinal directions* in the men’s group (*M* = 0.5, *SD* = 0.86). In tests of *mental object rotation*, the participant scored 23 out of 24 possible points.

Although the two participants showed extreme scores in several measures, I found no direct evidence that their fixations on the compass belonged to a different sample population. I opted to include both scores in the final analysis.

The results of the Shapiro-Wilk *W* normality test were significant for women’s score distribution (*W* = .91, *p* = .02). The results of the normality test for men’s distribution were non-significant (*Shapiro-Wilk W* = .94, *p* = .12). Results of the Levene’s test showed that the variances of scores for the *time fixating on the compass (%)* were homogenous (*F* (1, 58) = 1.62, *p* = .21).
Figure 25 shows that as predicted men ($Mdn = 4.1, SD = 3.06$) spent a greater amount of time fixating on the compass (%) than women ($Mdn = 3.1, SD = 2.40$).

**Figure 25:** Median time that men and women fixated on the compass (%) with a 95% confidence interval.

5.3.6.2 **H4 results**

The difference between men and women on the time fixating on the compass (%) was not significant ($Mann-Whitney U = 398.00, p = .22$). There was no evidence to support the hypothesis that when learning a route, men would allocate a greater proportion of time fixating on the compass (%) than women.

5.3.7 **Exploratory analysis of participants who made a number of written references to cardinal directions greater than 0**

Given that the majority of participants did not make references to cardinal directions, I conducted an analysis of those participants who did make references
to cardinal points. As seen on Figure 26 on average men ($M = 6.5$, $SD = 1.59$) spent a greater percentage of time fixating on the compass than women ($M = 4.8$, $SD = 1.89$).

Figure 26: The **time fixating on the compass (%)** by participants who made a number of written references to cardinal directions greater than 0.

Women (**Shapiro-Wilk** $W = .97$, $p = .92$) and men’s (**Shapiro-Wilk** $W = .94$, $p = .52$) data distributions met parametric assumptions of normality. The data also met assumptions of homogeneity of variances ($F (1, 18) = .13$, $p = .72$). The results of the $t$-test were significant at $p < .05$ ($t (18) = -2.26$, $p = .018$). The effect size as measured with the Pearson correlation coefficient was $r = 0.47$, which is considered a moderate to large effect (Cohen 1988, 1992). These significant results were consistent with the tests performed on data related to cardinal directions (7.3.1). It should be kept in mind, however, that these data
corresponded to only 20 participants (10 men and 10 women), which greatly reduced the strength of the results.

5.3.8 Summary

The results of the inferential test showed that there was no difference between men and women on the average time fixating on landmarks (%). There was no evidence to support the hypothesis that on average men spent a greater amount of time fixating on the compass (%) than women. Analysis of participants who made references to cardinal directions, however, did yield significant differences, showing that men spent more time fixating on the compass than women.

5.3.9 Hypothesis five - correlation between the time fixating on landmarks (%) and the number of written references to landmarks

I hypothesized that the time fixating on landmarks (%) would be positively correlated with the number of written references to landmarks.

5.3.9.1 Analysis by group

I first conducted a correlation analysis for the entire sample population as a single group regardless of gender.
Figure 27: Correlation between the grouped time fixating on landmarks (%) and the number of written references to landmarks.

The scatterplot (Figure 27) shows a general trend depicting a positive correlation between the grouped time fixating on landmarks (%) and the number of written landmarks. The results of the normality test revealed that the distribution of scores for the grouped number of written references to landmarks deviated significantly from normality (Shapiro-Wilk $W = .95$, $p = .02$). The grouped time fixating on landmarks (%) also deviated significantly from normality (Shapiro-Wilk $W = .93$, $p = .003$). Given the non-normal characteristics of the data and the moderate size of the sample, I applied Spearman's coefficient for ranked data to investigate the correlation between the two variables. The results of the test showed that the correlation between the time fixating on landmarks (%) and the number of written references to landmarks was significant in the positive direction at a $p < .05$ level (Spearman's rho = .26, $p = .02$). That is, an
increase in the *time fixating on landmarks* (%) resulted in an increase in the *number of written references to landmarks*.

### 5.3.9.2 Exploratory analysis by gender - women

I examined the correlation between *time fixating on landmarks* (%) and the *number of written references to landmarks* using gender as a grouping variable.

**Figure 28:** Correlation between women’s *time fixating on landmarks* (%) and the *number of written references to landmarks*.

![Scatterplot showing correlation](image)

The scatterplot (Figure 28) shows a somewhat positive correlation between the two variables. As reported, the distribution of scores for women’s *number of written references to landmarks* was normal (5.3.1.1). However, the distribution of scores for *time fixating on landmarks* (%) was non-normal (5.3.5.1). Therefore, I used the Spearman’s coefficient for ranked data to examine the correlations. The results indicated that women’s *time fixating on*
landmarks (%) was positively correlated with the number of written references to landmarks at a $p < .05$ significance level (Spearman’s $\rho = .31$, $p = .048$).

5.3.9.3 Exploratory analysis by gender- men

The scatterplot (Figure 29) shows no salient correlation between men’s time fixating on landmarks (%) and the number of written references to landmarks.

Figure 29: Correlation between men’s time fixating on landmarks (%) and the number of written references to landmarks.

The distributions of data for men’s time fixating on landmarks (%) (5.3.5.1) and the number of written references to landmarks (5.3.1.1) were previously reported as normal. Thus, I used Pearson’s correlation coefficient to test the bivariate relationship between them. With a coefficient of $r = .15$, the correlation test was not significant ($p = .21$). Therefore, as the scatterplot suggested, the
time fixating on landmarks (%) was not correlated to the number of written references to landmarks for men’s data.

5.3.10 Summary

The results of the correlation tests showed that there was a significant positive correlation between the time fixating on landmarks (%) and the number of written references to landmarks when the two sample populations were analyzed as a single group. There was also a positive correlation between women’s time fixating on landmarks (%) and the number of written references to landmarks. I found no positive correlation between the two variables for men’s data.

5.3.11 Hypothesis six- correlation between the time fixating on the compass (%) and the number of written references to cardinal directions

I hypothesized that the time fixating on the compass (%) would be positively correlated with number of written references to cardinal directions. I first sought to establish if a correlation existed with men and women as a single group and then I performed an exploratory analysis on men and women separately. In this analysis, I included all 60 participants.

5.3.11.1 Analysis by group

The scatterplot (Figure 30) shows that, as a group, men and women’s scores on the time fixating on the compass (%) seemed to correlate with the number of written references to cardinal directions.
A large number of participants did not make any *written references to cardinal directions* as shown by the scores lying along the horizontal axis in Figure 30. As mentioned, I had no reason to exclude extreme scores and thus retained them for further analysis. The normality test for the grouped *number of written references to cardinal directions* was significant (*Shapiro-Wilk W* = .57, *p* = .000). This same test was also significant for the grouped *time fixating on the compass (%)* (*Shapiro-Wilk W* = .94, *p* = .004). Because of this deviation from normality and the large number of tied ranks in the data, I used Kendall’s *tau* rank correlation coefficient to investigate the bivariate relationship between the *time fixating on the compass (%)* and the *number of written references to cardinal directions*. The results of the correlation test were significant at a *p* < .001 level (*Kendall’s tau* = .45, *p* = .000). Therefore, I found evidence that the
time fixating on the compass (%) was positively correlated with the number of written references to cardinal directions when men and women were analyzed as a single group.

5.3.11.2 Exploratory analysis by gender - women

As seen in Figure 31, there were not enough non-zero values along the horizontal axis to permit the detection of a meaningful correlation between the time fixating on the compass (%) and the number of written references to cardinal directions.

The previous normality test had shown that women’s distribution of scores for the time fixating on the compass (%)(5.3.6.1) and the number of written references to cardinal directions (5.3.2.1) were non-normal. Therefore, I used
Kendall’s *tau* rank correlation coefficient to investigate the bivariate relationship between the two variables. The results showed that the variables were significantly correlated at a *p* = .01 level (*Kendall’s tau* = .32, *p* = .01). The *time fixating on the compass (%)* was positively correlated with the *number of written references to cardinal directions*.

### 5.3.11.3 Exploratory analysis by gender - men

The scatterplot (Figure 32) for the correlation between men’s *time fixating on the compass (%)* (5.3.6.1) and the *number of written references to cardinal directions* (5.3.2.1) also illustrates that only 11 out of the 30 men used cardinal directions when giving written directions.

**Figure 32:** Scatterplot depicting the correlation between men’s time fixating on the compass (%) and the number of written references to cardinal directions.
A previous analysis did not yield significant results for the normality tests performed on men’s *time fixating on the compass (%)* (5.3.6.1). The analysis did yield significant results for the *number of written references to cardinal directions* (5.3.2.1). Thus, given the deviation from normality on the latter variable, I used Kendall’s *tau* rank correlation coefficient. I found a significant correlation between the two variables at *p* < .001 level (*Kendall’s tau* = .56, *p* = .000). The *time fixating on the compass (%)* was positively correlated with the *number of written references to cardinal directions*.

### 5.3.12 Summary

There was evidence that the *time fixating on the compass (%)* was positively correlated with the *number of written references to cardinal directions* when the sample of 30 men and 30 women were analyzed as a single group. When I analyzed the sample populations separately, I found evidence of a positive correlation between women’s *time fixating on the compass (%)* and the *number of written references to cardinal directions*. Men’s *time fixating on the compass (%)* was also positively correlated to the *number of written references to cardinal directions*.

### 5.3.13 Overall summary: gender and route-learning strategies

As illustrated in Table 5, I found no evidence to support the hypotheses that men and women would differ in the number of references to either landmarks or cardinal directions. Nor did I find a significant gender difference in the time fixating on landmarks or the compass. When I analyzed a subset of
participants who made actual references to cardinal directions, I did find the expected differences, favouring men, in the scanning of the compass and written references to cardinal directions.

Table 5: Statistical results of the analysis investigating gender differences in virtual route-learning strategies.

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>W</th>
<th>M</th>
<th>Egocentric</th>
<th>Allocentric</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td></td>
<td></td>
<td>&gt;</td>
<td>NS</td>
</tr>
<tr>
<td>H2</td>
<td></td>
<td></td>
<td>&lt;</td>
<td>NS</td>
</tr>
<tr>
<td>H3</td>
<td></td>
<td></td>
<td>&gt;</td>
<td>NS</td>
</tr>
<tr>
<td>H4</td>
<td></td>
<td></td>
<td>&lt;</td>
<td>NS</td>
</tr>
</tbody>
</table>

As shown in Table 6, the results of the correlation analysis supported the hypotheses that scanning the route would be associated with written directions. Fixating on landmarks was correlated with making written references to landmarks and fixating on the compass was associated with providing written references to cardinal directions.

Table 6: Results of correlation analysis between eye fixations and written directions.

<table>
<thead>
<tr>
<th>Eye fixations</th>
<th>Written directions</th>
<th>Egocentric</th>
<th>Allocentric</th>
</tr>
</thead>
<tbody>
<tr>
<td>H5</td>
<td>Time Fixating on Landmarks (%)</td>
<td>+</td>
<td>Number of Written References to Landmarks (avg)</td>
</tr>
<tr>
<td>H6</td>
<td>Time Fixating on the Compass (%)</td>
<td>+</td>
<td>Number of Written References to Cardinal Directions (avg)</td>
</tr>
</tbody>
</table>

* p < .05     *** p < .001
As shown in Table 7, when I analyzed the data by gender, the results were also significant for correlations, excluding men’s landmark data. That is, there was no relationship between men’s fixations on landmarks and providing references to landmarks.

Table 7: Exploratory correlations by gender between eye fixations and written directions.

<table>
<thead>
<tr>
<th>Eye fixations</th>
<th>Written directions</th>
<th>Egocentric</th>
<th>Allocentric</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Women- Exploratory</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Fixating on Landmarks (%)</td>
<td>Number of Written References to Landmarks (avg)</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Time Fixating on the Compass (%)</td>
<td>Number of Written References to Cardinal Directions (avg)</td>
<td>P = .01</td>
<td></td>
</tr>
<tr>
<td><strong>Men- Exploratory</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Fixating on Landmarks (%)</td>
<td>Number of Written References to Landmarks (avg)</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Time Fixating on the Compass (%)</td>
<td>Number of Written References to Cardinal Directions (avg)</td>
<td>***</td>
<td></td>
</tr>
</tbody>
</table>

* p < .05  *** p < .001

5.4 Gender, spatial abilities, and route learning

In this section, I report the results of the analysis examining the relationship between spatial abilities and route learning. Keeping in line with past research, I predicted that women and men would differ in object location memory and mental object rotations as illustrated in Table 8.
Table 8: Predicted gender differences in spatial abilities.

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Dependent Variables</th>
<th>W</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>H7</strong></td>
<td>Object location memory</td>
<td></td>
<td>&gt;</td>
</tr>
<tr>
<td><strong>H10</strong></td>
<td>Mental Object Rotation</td>
<td>&lt;</td>
<td></td>
</tr>
</tbody>
</table>

As stated in the hypotheses (3.2) and illustrated in Table 9, I expected that mental rotation would be positively associated with configurational route-learning strategies (compass fixations and references to cardinal directions) and object location memory would be positively associated with topographic strategies (landmark fixations and references).

Table 9: Predicted correlations between measures of spatial abilities and route-learning strategy.

<table>
<thead>
<tr>
<th>Spatial ability</th>
<th>Route learning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>H8</strong> Object location memory</td>
<td>Number of Written References to Landmarks (avg)</td>
</tr>
<tr>
<td><strong>H9</strong> Object location memory</td>
<td>Time Fixating on Landmarks (%)</td>
</tr>
<tr>
<td><strong>H11</strong> Mental rotation</td>
<td>Number of Written References to Cardinal Directions (avg)</td>
</tr>
<tr>
<td><strong>H12</strong> Mental rotation</td>
<td>Time Fixating on the Compass (%)</td>
</tr>
</tbody>
</table>
To explore whether these correlations were also influenced by gender, I conducted a correlation analysis of men and women’s data separately.

5.4.1 Hypothesis seven - object location memory

I hypothesized the women would, on average, score higher than men on tests of object location memory. The scores were based on the number of correct answers minus the number of incorrect answers in a paper test of object location memory.

5.4.1.1 Descriptive analysis

The graph (Figure 33) shows that indeed, on average, women ($M = 9.3$, $SD = 2.23$) scored higher than men ($M = 7.6$, $SD = 2.99$) on the object location memory test. The overlap of 95% confidence intervals between the two groups was not large but suggested that the two populations may be significantly different.
As shown in the histogram (Figure 34), the characteristics of the distribution of scores appeared normal for men and women (Figure 34). Women’s score distribution was positively skewed (Skewness = 0.05, SE = 0.43) and men’s scores were negatively skewed (Skewness = -0.07, SE = 0.43). The score distributions were platykurtic for women (Kurtosis = -0.64, SE = 0.83) and men (Kurtosis = -1.03, SE = 0.83). The skewness and kurtosis deviations were small and did not appear out of the ordinary.
Figure 34:  Frequency distribution of scores on the object location memory test.

![Frequency distribution of scores on the object location memory test.](image)

The boxplots (Figure 35) corroborate that the distribution of scores was more or less symmetrical for men and women. There were no outliers in the data.

Figure 35:  Boxplots on the scores on the object location memory test.

![Boxplots on the scores on the object location memory test.](image)

The results of the Shapiro-Wilk $W$ tests of normality on *object location memory* were not significant for women ($W = .974$, $p = .66$) and men ($W = .950$, $p$
= .17). Levene’s test for homogeneity of variances was not significant \((F(1, 58) = 3.49, p = .07)\). As shown in the error graph (Figure 36), women’s \((M = 9.3, SD = 2.23)\) average score in the object location memory test was higher than men’s \((M = 7.6, SD = 2.99)\).

Figure 36: Average scores on object location memory with a 95% confidence interval.

5.4.1.2 H7 results

In spite of the overlap in confidence intervals (Figure 36), the results of the Student’s \(t\)-test were significant at a \(p < .01\) level \(t(58) = 2.50, p = .007\). The effect size as measured with the Pearson correlation coefficient was \(r = .31\), which is a moderate effect size accounting for 9% of the total variance (Cohen 1988, 1992). On average, women scored significantly higher on the object location memory test than men providing support for hypothesis 7.
5.4.2 Hypothesis eight - correlation between scores on the object location memory test and the number of written references to landmarks

I hypothesized that the scores on the *object location memory* test would positively correlate with the *number of written references to landmarks*.

5.4.2.1 Analysis by group

The scatterplot (Figure 37) shows that, as a group, the scores for the *object location memory* test and the *number of written references to landmarks* did not appear to share a linear relationship.

![Figure 37: Scatterplot of the correlation between the grouped scores on the object location memory test and the number of written references to landmarks.](image)

The previously reported test of normality on the grouped distribution of scores for the *object location memory* test was not significant (5.4.3.1) and the data were normal. However, the normality test on the grouped scores for the *number of written references to landmarks* (5.3.9.1) was significant, and because
of this deviation from normality, I used Spearman’s coefficient for ranked data to examine the correlations between the two variables. The results of the correlation test were not significant (Spearman’s rho = -.02, p = .43). Thus, there was no evidence that the grouped scores on the object location memory test were significantly correlated to the number of written references to landmarks.

5.4.2.2 Exploratory analysis by gender - women

As shown in Figure 38, the general trend for women’s scores on the object location memory test and the number of written references to landmarks hint at a negative correlation between the two variables. There were several extreme values, but as discussed, none of the outliers were discarded.

Figure 38: Scatterplot of the correlation between women’s scores on the object location memory test and the number of written references to landmarks.
The reported tests of normality for women’s scores on the *object location memory* test (5.4.1) and the *number of written references to landmarks* were not significant (5.3.1.1). Because the data met assumptions of normality, I used Pearson’s correlation to test the bivariate relationship between the variables. The test was significant at a $p < .05$ level ($r = -.35, p = .03$). There was evidence that, contrary to expectation, women’s scores for the *object location memory* test were negatively related to the *number of written references to landmarks*. That is, the higher the score on the *object location memory* test the smaller the *number of written references to landmarks*.

### 5.4.2.3 Exploratory analysis by gender- men

Figure 39 shows the correlation between men’s scores on the *object location memory* test and the *number of written references to landmarks*. There was no obvious correlation between the variables.

**Figure 39:** Scatterplot for men’s scores on the object location memory test and the number of written references to landmarks.
As reported, the distribution of men’s scores on the *object location memory* test (5.4.1) and the *number of written references to landmarks* (5.3.1.1) did not deviate from normality. Therefore, I used Pearson’s correlation coefficient to examine the bivariate relationship between the variables. With a coefficient of $r = .265$, the test was not significant ($p = .08$). Thus, there was no evidence that men’s scores on the *object location memory* test were correlated with the *number of written references to landmarks*.

### 5.4.3 Hypothesis nine- correlation between scores on the object location memory test and the time fixating on landmarks (%)

I hypothesized that scores on *object location memory* test would be positively correlated to the *time fixating on landmarks* (%).
5.4.3.1 Analysis by group

The scatterplot shown in Figure 40 suggested that no significant correlation existed between scores on object location memory test and the time fixating on landmarks (%).

Figure 40: Correlation between total score on the object location memory test and the time fixating on landmarks (%).

The results of the Shapiro-Wilk $W$ test of normality indicated that the distribution of scores for the grouped data on object location memory was normal ($W = .97, p = .11$). The distribution of scores for the time fixating on landmarks (%) was non-normal ($Shapiro-Wilk W = .93, p = .003$). Because of this deviation from normality and the moderate size of the sample, I examined the correlation between the two variables using Spearman’s coefficient for ranked data. The results of the correlation test were not significant ($Spearman's rho = -.025, p = \ldots$)
There was no significant correlation between object location memory and the time fixating on landmarks (%).

5.4.3.2 Exploratory analysis by gender - women

The correlation between women's scores on object location memory and the time fixating on landmarks (%) is shown in Figure 41. The scatterplot did not reveal a meaningful correlation between the two variables, although there was a slight suggestion of a curvilinear relationship.

Figure 41: Correlation between women's scores on the object location memory test and the time fixating on landmarks (%).

As reported previously, the distribution of scores for women's object location memory test (5.4.1) was not significant. The distribution of scores for women's time fixating on landmarks (%) was non-normal (5.3.5.1). Because of this violation of parametric assumptions, I used the Kendall's tau to examine the
correlation between the two variables. The results of the correlation test were not significant \((Kendall's \ tau = -0.06, p = .32)\). There was no evidence that women’s scores on the object location memory test were positively correlated to the time fixating on landmarks (%).

5.4.3.3 Exploratory analysis by gender- men

Men’s distribution of scores for object location memory and the time fixating on landmarks (%) are shown in Figure 42. There was no detectable linear relationship between the variables.

As reported, men’s distribution of score for object location memory (5.4.1) was normal. The distribution of scores for the time fixating on landmarks (%) (5.3.5.1) was normal as well. Therefore, I used Pearson’s correlation coefficient
to investigate the bivariate relationship between the two variables. With a
coefficient of $r = .09$, the results of the correlation test were not significant ($p = .32$). Thus, there was no evidence that men’s scores on object location memory were correlated with the time fixating on landmarks (%).

5.4.4 Summary

As predicted, women scored significantly higher than men on the object location memory test. I found no evidence that scores on the object location memory test were significantly correlated to the number of written references to landmarks when men and women were analyzed as a single group. However, contrary to what would be expected, there was evidence that women’s scores for the object location memory test were negatively related to the number of written references to landmarks. I found no correlation between men’s scores on the object location memory test and the number of written references to landmarks. In addition, I found no significant correlation between scores on the object location memory test and the time fixating on landmarks (%) when women and men were analyzed as a single group and separately.

5.4.5 Hypothesis ten- mental object rotation

I hypothesized that on average men would score higher than women on the mental object rotation test.

5.4.5.1 Descriptive analysis

The bar graph (Figure 43) shows that men ($M = 20.2$, $SD = 3.11$) scored higher than women ($M = 14.6$, $SD = 6.42$) on the mental object rotation test. The
scores were based on the number of correct answers in a test that required participants to mentally rotate three-dimensional drawings. The confidence intervals did not overlap, which strongly suggested that the means were drawn from different populations.

**Figure 43:** Mean scores on the mental object rotation test with a 95% confidence interval. The scores represent the number of correct answers on the mental object rotation test.

An examination of the distribution of scores (Figure 44) revealed that women’s score distribution had a wider a range than that of men, whose scores were more compacted about the mean. Women’s distribution of scores was positively skewed \((\text{Skewness} = 0.05, \ SE = 0.43)\) and men’s distribution was negatively skewed \((\text{Skewness} = -0.07, \ SE = 0.43)\). In addition, women’s distribution was platykurtic \((\text{Kurtosis} = -0.64, \ SE = 0.83)\) and men’s distribution was also platykurtic \((\text{Kurtosis} = -1.04, \ SE = 0.83)\).
Figure 44: Frequency distribution of men and women’s scores on the mental object rotation test.

The boxplots (Figure 45) show that women’s scores were skewed to the higher end of the scale, and had a wider range of values than men’s data distribution.

Although none of the score were identified as outliers, I examined women’s data and found that one participant scored a 1 in the test. I found no
evidence of input or calculation error. The participant had practiced beforehand and understood the task, so there was no evidence that she lacked understanding on how to complete the test. Besides this extreme score in the mental object rotation test, the participant made a higher than average number of references to landmarks. I retained this score for further analysis.

The results of the Shapiro-Wilk $W$ test of normality were not significant for women’s scores ($W = .96, p = .31$), but they were significant for men’s scores ($W = .92, p = .02$). Levene’s test for homogeneity of variances was significant ($F (1, 58) = 17.53, p = .000$). Given the non-normal distribution of men’s scores, I used a non-parametric test (Mann-Whitney $U$) to examine the inferential relationship between the two groups. Since the median is a more appropriate statistic than the mean for non-parametric tests, I reported this statistic. The graph (Figure 46) shows that men ($Mdn = 20, SD = 3.11$) scored higher than women ($Mdn = 15.0, SD = 6.42$) on the mental object rotation test. There was a small overlap in the confidence interval.
5.4.5.2 H10 results

The Mann-Whitney $U$ test was significant at a $p < .001$ level ($U = 219$, $p = .000$). The effect size as measured with the Pearson correlation coefficient was $r = -.443$, which is a medium to large effect that explains between 9-25% of the total variance (Cohen 1988, 1992). Thus, men scored significantly higher than women on the *mental object rotation* test.

5.4.6 Hypothesis eleven- correlation between scores on the mental object rotation test and average number of written references to cardinal directions

I hypothesized that scores on the *mental object rotation* test would be positively correlated with the *number of written references to cardinal directions*.

5.4.6.1 Analysis by group

The scatterplot (Figure 47) of the correlation between the two grouped variables revealed a potential positive correlation. While there were some
noticeable extreme scores on the graph, I had previously decided to keep the scores for further analysis because I did not find an experimental rationale for the contrary.

Figure 47: Scatterplot for grouped scores on the mental object rotation test and the number of written references to cardinal directions.

As reported, the distribution of grouped scores for the *mental object rotation* test (5.4.7.1) and the *number of written references to cardinal directions* (5.3.11.1) deviated from normality. Due to this violation of parametric assumptions, I used Spearman’s coefficient for ranked data to investigate the correlation between the two variables. The results of the correlation test were significant at a $p = .05$ level ($Spearman’s \rho = .17, p = .05$). Thus, there was evidence of a positive correlation between the grouped scores for the *mental object rotation* test and the *number of written references to cardinal directions*. 
5.4.6.2 Exploratory analysis by gender - women

As gleaned from the scatterplot (Figure 48), women’s scores on the mental object rotation test did not appear to share a linear relationship with the number of written references to cardinal directions. There was a large number of scores with a value of 0 for the number of written references to cardinal directions.

Figure 48: Scatterplot for women’s scores on the mental object rotation test and the number of written references to cardinal directions.

As reported, women’s distribution for scores on the mental object rotation test (5.4.5) was normal, but the distribution was non-normal for the number of written references to cardinal directions (5.3.2.1). Using Kendall's tau rank correlation coefficient, I tested the correlation between the two variables. The results of the test were not significant (Kendall's tau = .11, p = .24). There was
no evidence that women’s scores on the *mental object rotation* test were correlated with the *number of written references to cardinal directions*.

### 5.4.6.3 Exploratory analysis by gender - men

The scatterplot (Figure 49) shows that the general trend of scores on the *mental object rotation* test and the *number of written references to cardinal directions*. There were only a few scores above 0 for average *number of written references to cardinal directions*. Given this low number of scores, it was not possible to ascertain with certainty any meaningful correlation between the two variables. It did appear as if the higher the score on the *mental object rotation* test the higher *number of written references to cardinal directions*.

**Figure 49:** Scatterplot for men’s scores on the mental object rotation test and the number of written references to cardinal directions.
As reported, the distributions of men’s scores on the mental object rotation test (5.4.5) and their number of written references to cardinal directions (5.3.2.1) deviated from normality. Therefore, I used Kendall’s tau rank correlation coefficient to examine the correlation between the variables. The results of the test were not significant (Kendall’s tau = .22, p = .07). There was no evidence that men’s scores on the mental object rotation test were significantly correlated with the number of written references to cardinal directions.

5.4.7 Hypothesis twelve- correlation between scores on the mental object rotation test and the time fixating on the compass (%)

I hypothesized that the scores on the mental object rotation test would be positively correlated with the time fixating on the compass (%).

5.4.7.1 Analysis by group

The scatterplot in (Figure 50) shows the grouped scores for the mental object rotation test and the time fixating on the compass (%). The scores did not seem to share a clear linear relationship.
Figure 50: Scatterplot for grouped scores on the mental object rotation test and the time fixating on the compass (%).

The results of the Shapiro-Wilk $W$ test of normality on the grouped distribution of scores for the mental object rotation test were significant ($W = .90, p = .000$). As reported, the normality test for the grouped time fixating on the compass (%) (5.3.11.1) was also significant. Because the data did not meet parametric assumptions, I used Spearman’s coefficient for ranked data to examine the bivariate relationship between the variables. With a coefficient $rho = .09$, the test was not significant ($p = .25$). Thus, the grouped scores for the mental object rotation test were not correlated with the time fixating on the compass (%).

5.4.7.2 Exploratory analysis by gender- women

The correlation between women’s scores on the mental object rotation test and the time fixating on the compass (%) is shown on Figure 51. No salient
linear relationship between the two variables could be gleaned from the scatterplot.

**Figure 51:** Scatterplot for women’s scores on the mental object rotation test and the time fixating on the compass (%).

As reported, women’s distribution of scores for the *mental object rotation* test (5.4.5) was normal. On the other hand, their data distribution for the *time fixating on the compass* (%) (5.3.6.1) was non-normal. Given this deviation from normality, I used Kendall's *τ* rank correlation coefficient to investigate the bivariate relationship between the two variables. The results of the test were not significant (*Kendall’s τ* = .15, *p* = .13). Therefore, there was no evidence that the scores on the *mental object rotation* test correlated with the *time fixating on the compass* (%).
5.4.7.3 Exploratory analysis by gender - men

The scatterplot in Figure 52 depicts the correlation between men’s score on the mental object rotation test and the time fixating on the compass (%). I found no obvious correlation in the data.

Figure 52: Scatterplot for men’s scores on the mental object rotation test and the time fixating on the compass (%).

As reported, men’s distribution of score for the mental object rotation test (5.4.5) deviated from normality. The data distribution for the time fixating on the compass (%) (5.3.6.1) was normal. Given that the mental object rotation test deviated from normality, I used Kendall's tau rank correlation coefficient to examine the correlation between the two variables. The results of the test were not significant (Kendall's tau = -.032, p = .41). There was no evidence that the scores of the mental object rotation test correlated with the time fixating on the compass (%).
5.4.8 Summary

I found support for the hypothesis that on average men scored significantly higher than women on the *mental object rotation* test. I found evidence that when analyzed as a single group, men and women showed a positive correlation between scores of the *mental object rotation* test and the *number of written references to cardinal directions*. There was no evidence, however, that these two variables were correlated when men and women were analyzed separately.

The hypothesis that, as a group, men and women’s scores for the *mental object rotation* test were correlated with the *time fixating on the compass (%)* was not supported. Neither did I find support for this contention when I analyzed men and women separately.

5.4.9 Overall summary: gender, spatial abilities, and route learning

As illustrated in Table 10, men and women significantly differed on tests of spatial abilities.

Table 10: Results of statistical analysis on gender differences in spatial abilities.

<table>
<thead>
<tr>
<th>Dependent Variables</th>
<th>W</th>
<th>M</th>
<th>Egocentric</th>
<th>Allocentric</th>
</tr>
</thead>
<tbody>
<tr>
<td>H7 Object location memory</td>
<td>&gt;</td>
<td></td>
<td>**</td>
<td></td>
</tr>
<tr>
<td>H10 Mental Object Rotation</td>
<td>&lt;</td>
<td></td>
<td>***</td>
<td></td>
</tr>
</tbody>
</table>

* p < .05  ** p < .01  *** p < .001
Women scored higher than men on the *object location memory* test, and men higher than women on the *mental object rotation* test. Contrary to prediction, however, I did not find strong support for positive correlations between these two spatial abilities and route learning strategies (Table 11). Only the positive correlation between mental rotation abilities and references to cardinal directions reached significance.

**Table 11: Results of correlation analysis between spatial abilities and virtual route-learning strategies.**

<table>
<thead>
<tr>
<th>Spatial ability</th>
<th>Route learning</th>
<th>Egocentric</th>
<th>Allocentric</th>
</tr>
</thead>
<tbody>
<tr>
<td>H8 Object location memory</td>
<td>+ Number of Written References to Landmarks (avg)</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>H9 Object location memory</td>
<td>+ Time Fixating on Landmarks (%)</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>H11 Mental rotation</td>
<td>+ Number of Written References to Cardinal Directions (avg)</td>
<td>p = .05</td>
<td></td>
</tr>
<tr>
<td>H12 Mental rotation</td>
<td>+ Time Fixating on the Compass (%)</td>
<td>NS</td>
<td></td>
</tr>
</tbody>
</table>

* p < .05

As shown in Table 12, when I analyzed the correlations by gender, I found only a *negative* relationship between *object location memory* and *the number of written references to landmarks*. The rest of the correlations were not significant.
### Table 12: Exploratory correlations by gender between spatial abilities and route-learning strategies.

<table>
<thead>
<tr>
<th>Spatial ability</th>
<th>Route learning</th>
<th>Egocentric</th>
<th>Allocentric</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Women - Exploratory</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Object location memory</td>
<td>Number of Written References to Landmarks (avg)</td>
<td>*(-)</td>
<td></td>
</tr>
<tr>
<td>Object location memory</td>
<td>Time Fixating on Landmarks (%)</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Mental rotation</td>
<td>Number of Written References to Cardinal Directions (avg)</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Mental rotation</td>
<td>Time Fixating on the Compass (%)</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td><strong>Men - Exploratory</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Object location memory</td>
<td>Number of Written References to Landmarks (avg)</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Object location memory</td>
<td>Time Fixating on Landmarks (%)</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Mental rotation</td>
<td>Number of Written References to Cardinal Directions (avg)</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Mental rotation</td>
<td>Time Fixating on the Compass (%)</td>
<td>NS</td>
<td></td>
</tr>
</tbody>
</table>

* p < .05
6: EXPERIMENT 2 RESULTS - ALLOCENTRIC VIEWPOINT

6.1 Overview

In this chapter, I report the results of the analysis on eye movements, written directions, and spatial abilities (summarized in Table 13) for the allocentric point of view experiment. I report the demographics data (6.2) the statistical relationship between gender and route learning strategies (6.3), and the relationship between gender, spatial abilities, and route learning (6.4).

Table 13: Summary of descriptive data and frequency distributions

<table>
<thead>
<tr>
<th></th>
<th>Number of written references to landmarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Women</strong></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>2.9</td>
</tr>
<tr>
<td>Min</td>
<td>0.2</td>
</tr>
<tr>
<td>Max</td>
<td>8.25</td>
</tr>
<tr>
<td>Mdn</td>
<td>2.5</td>
</tr>
<tr>
<td>SD</td>
<td>2.03</td>
</tr>
<tr>
<td><strong>Men</strong></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>2.0</td>
</tr>
<tr>
<td>Min</td>
<td>0.0</td>
</tr>
<tr>
<td>Max</td>
<td>4.5</td>
</tr>
<tr>
<td>Mdn</td>
<td>1.7</td>
</tr>
<tr>
<td>SD</td>
<td>1.17</td>
</tr>
</tbody>
</table>
### Number of written references to cardinal directions

<table>
<thead>
<tr>
<th>Gender</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
<th>Mdn</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Women</td>
<td>0.2</td>
<td>0.0</td>
<td>2.0</td>
<td>0.0</td>
<td>0.48</td>
</tr>
<tr>
<td>Men</td>
<td>0.6</td>
<td>0.0</td>
<td>2.5</td>
<td>0.5</td>
<td>0.71</td>
</tr>
</tbody>
</table>

### Time fixating on landmarks (%)

<table>
<thead>
<tr>
<th>Gender</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
<th>Mdn</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Women</td>
<td>36.1</td>
<td>15.7</td>
<td>48.4</td>
<td>36.3</td>
<td>6.54</td>
</tr>
<tr>
<td>Men</td>
<td>32.0</td>
<td>20.5</td>
<td>42.5</td>
<td>32.8</td>
<td>4.87</td>
</tr>
<tr>
<td></td>
<td>Time fixating on the compass (%)</td>
<td>Object location memory test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------</td>
<td>----------------------------------</td>
<td>----------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Women</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Mean</em></td>
<td>2.7</td>
<td>9.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Min</em></td>
<td>0.0</td>
<td>6.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Max</em></td>
<td>10.3</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Mdn</em></td>
<td>1.7</td>
<td>10.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>SD</em></td>
<td>2.67</td>
<td>1.98</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Men</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Mean</em></td>
<td>4.7</td>
<td>8.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Min</em></td>
<td>0.0</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Max</em></td>
<td>23.5</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Mdn</em></td>
<td>3.8</td>
<td>9.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>SD</em></td>
<td>4.80</td>
<td>2.78</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Graph of Time fixating on the compass (%)](image1)

![Graph of Object location memory test](image2)
The statistical analysis yielded the following results:

- **Route-learning strategy**
  - [H1] At a $p = .055$ significance level, the difference between men and women on the average number of written references to landmarks was not significant but trended towards it (6.3.1).
  - [H2] There was a significant difference between men and women in the number of written references to cardinal directions (6.3.2).
  - [H3] There was a significant difference between men and women on the average time fixating on landmarks (%) (6.3.4).
  - [H4] There was a significant difference between men and women in the time fixating on the compass (%) (6.3.5).
  - **Summary** Although I did not find support for the hypothesis that women would make a greater number of references to landmarks than men, the results approached significance. I found support for the hypothesis that men would make a greater number of references to cardinal directions than
women. For the scanning the data, I found support for the hypothesis that women would spend a greater amount of time looking at landmarks than men. I also found support for the hypothesis that men would spend a greater amount of time looking at the compass than women.

- **Correlations between route-learning strategies**
  - [H5] There was a significant positive correlation between the *time fixating on landmarks (%)* and the *number of written references to landmarks* when the two sample populations were analyzed as a single group (6.3.7.1).
  - [Exploratory Analysis] There was a significant positive correlation between women’s *time fixating on landmarks (%)* and the *number of written references to landmarks* (6.3.7.2).
  - [Exploratory Analysis] There was a significant positive correlation between men’s *time fixating on landmarks (%)* and the *number of written references to landmarks* (6.3.7.3).
  - [H6] There was a significant positive correlation between the *time fixating on the compass (%)* and the *number of written references to cardinal directions* when the two sample populations were analyzed as a single group (6.3.8.1)
  - [Exploratory Analysis] There was a significant positive correlation between women’s *time fixating on the compass (%)* and the *number of written references to cardinal directions* (6.3.8.2).
  - [Exploratory Analysis] There was a significant positive correlation between men’s *time fixating on the compass (%)* and the *number of written references to cardinal directions* (6.3.8.3).
  - **Summary** As predicted, looking at landmarks was correlated with making references to landmarks. The correlation remained significant even when the data were analyzed by gender. I also found support for the hypotheses that looking at the compass would be correlated with making references to cardinal directions. The correlation remained significant even when the data were analyzed by gender.

- **Spatial abilities**
- **Object location memory and topographic route-learning strategies**
  - [H7] Women scored significantly higher than men on tests of *object location memory* (6.4.1).
  - [H8] There was no significant correlation between scores on the *object location memory* test and the *number of written
references to landmarks when men and women were analyzed as a single group (6.4.2.1).

- [Exploratory Analysis] There was no significant correlation between women’s scores on the object location memory test and the number of written references to landmarks (6.4.2.2).
- [Exploratory Analysis] There was no significant correlation between men’s scores on the object location memory test and the number of written references to landmarks (6.4.2.3).
- [H9] There was no significant correlation between scores on the object location memory test and the time fixating on landmarks (%) when the two samples were analyzed as a single group (6.4.3.1).
- [Exploratory Analysis] There was no significant correlation in scores on the object location memory test and the time fixating on landmarks (%) when women (6.4.3.2) and men (6.4.3.3) were analyzed separately.
- Summary As predicted, women scored higher than men on the object location memory test. However, I found no support for the hypothesis that object location memory would be correlated with references to landmarks, even when the data were analyzed by gender. There was no support for a correlation between scores on object location memory and fixating on landmarks either, even when men and women’s data were analyzed separately.

- Mental rotation and topographic route-learning strategies

- [H10] Men scored significantly higher than women on the mental object rotation test (6.4.5).
- [H11] There was no significant positive correlation between scores on the mental object rotation test and the number of written references to cardinal directions when the two sample populations were analyzed as a single group (6.4.6.1).
- [Exploratory Analysis] There was no significant correlation between scores on the mental object rotation test and the number of written references to cardinal directions when women (6.4.6.2) and men (6.4.6.3) were analyzed separately. However, with a value of $p = .056$, women’s test results trended towards significance.
- [H12] There was a significant positive correlation between scores on the mental object rotation test and the time fixating on compass (%) when the two sample populations were analyzed as a group (6.4.7.1).
- [Exploratory Analysis] There was no significant correlation between scores on the mental object rotation test and the
time fixating on compass (%) when women (6.4.7.2) and men (6.4.7.3) were analyzed separately.

- **Summary** As predicted, men scored higher than women on the mental rotation test. I also found support for the hypothesis that mental rotation is correlated with references to cardinal directions. The correlation was not significant for men, but it approached significance in women’s data. I found support for the hypothesis that scores on the mental rotation test would be correlated with fixations on the compass, but this correlation was not significant when men and women were analyzed separately.

### 6.2 Demographic data

A total of 60 volunteers (30 men, 30 women) participated in the allocentric point of view study. The majority of the participants were students enrolled in the undergraduate program at the School of Interactive Arts and Technology. Each participant received $20 for his/her participation. A complete summary table of the demographic data can be found in Appendix F. It is worth noting that approximately 18% of all participants were under the age of 20, 60% between the ages of 20 and 25, about 13% between 26 and 30, and 8% over the age of 30. Approximately 13% of women were under the age of 20, 60% were between the ages of 20 and 25, about 17% between 26 and 30, and 10% over the age of 30. About 23% of men were under the age of 20, 60% were between the ages of 20 and 25, 10% between the ages of 26 and 30, and about 7% over the age of 30. 57% percent of participants reported English as their second language. 70% of women and approximately 43% of men indicated that English was their second language. The language spoken by participants whose first language was not English included Chinese (Cantonese and Mandarin), Czech, Korean, Hindi, Japanese, Persian, Polish, Punjabi, Spanish, Turkish, Ukrainian, Urdu, and
Vietnamese. Chinese (11 participants) and Persian (5 participants) were the most common language reported by participants whose first language was other than English.

6.3 Gender and route learning strategies

In this section, I report the results of the analysis associated with the relationship between gender, written directions, and eye fixations. As stated in section 3.2, I hypothesized that women would make a greater number of written references to landmarks and spend more time fixating on landmarks than men. Men would make a greater number of references to cardinal directions and spend a greater amount of time fixating on the compass than women. Additionally, I performed a correlation analysis on the data. I hypothesized that the proportion of time fixating on landmarks and the compass would correlate with the number of written references to landmarks and cardinal directions respectively. I also performed a correlational analysis of the data by gender.

6.3.1 Hypothesis one- the number of written references to landmarks

I hypothesized that when giving written directions after a route-learning task, women would on average make more written references to landmarks than men.

6.3.1.1 Descriptive analysis

As shown in Figure 53, on average, women ($M = 2.9$, $SD = 2.03$) made a greater number of written references to landmarks than men ($M = 2.0$, $SD = 1.17$). The overlap between the 95% confidence intervals of the two sample
populations was small, suggesting that the differences between them were indeed significantly different.

Figure 53: Average number of written references to landmarks made by women and men with a 95% confidence interval.

The histograms (Figure 54) show the distribution of scores for the number of written references to landmarks. Women’s score distribution was positively skewed ($Skewness = 0.85, SE = 0.43$), and men’s distribution of scores was also positively skewed ($Skewness = 0.43, SE = 0.43$). Women’s score distribution was leptokurtic ($Kurtosis = 0.18, SE = 0.83$) and men’s distribution was platykurtic ($Kurtosis = -0.70, SE = 0.83$).
Figure 54: Distribution of scores for the number of written references to landmarks.

Figure 55 shows that the distributions were skewed toward the low end of the scale, and the spread of scores was larger for women than men. There was one outlier in the women's group.

Figure 55: Boxplots for the number of written references to landmarks.

Participant F22 made 8.2 written references to landmarks, which was the highest score in the women's group ($M = 2.9$, $SD = 2.03$). She also had the
highest time fixating on landmarks (%). Her score of 14 in the mental object rotation test was higher than average in the women’s group ($M = 9.50$, $SD = 3.78$) There was no experimental evidence to indicate that this participant belonged to a different sample population and I retained her score in the final analysis.

The Shapiro-Wilk $W$ test of normality was significant for women ($W = .93$, $p = .04$) and non-significant for men ($W = .94$, $p = .09$). Results of the Levene’s test indicated that the variances of scores for the number of written references to landmarks were heterogeneous ($F(1, 58) = 8.1$, $p = .006$). Given that the data for the number of written references to landmarks did not meet the parametric assumptions, I used the Mann-Whitney $U$ test to investigate the statistical relationship between the variables. I reported the median rather than mean (Figure 56) because it is a more appropriate statistic for non-parametric tests.

Figure 56: Median number of written references to landmarks with a 95% confidence interval
6.3.1.2 H1 results

The results of the Mann-Whitney $U$ test indicated that the median difference between women ($Mdn = 2.5, SD = 2.03$) and men ($Mdn = 1.7, SD = 1.17$) on the number of written references to landmarks was just above the threshold of significance but trended towards it ($U = 342.5, p = .055$). The effect size as measured with the Pearson correlation coefficient was $r = -.21$, which is considered a small to moderate effect explaining between 1-9% of the total variance (Cohen 1988, 1992).

I did not find support for the hypothesis that when giving written directions after a route-learning task women would make more written references to landmarks than men. However, at a significance level of $p = .055$, it is worthwhile to report these results as approaching significance.

6.3.2 Hypothesis two- the number of written references to cardinal directions

I hypothesized that when giving written directions after a route-learning task, men would make a greater number of written references to cardinal directions than women.

6.3.2.1 Descriptive analysis

Figure 57 shows that on average men ($M = 0.6, SD = 0.71$) made a greater number of written references to cardinal directions than women ($M = 0.2, SD = 0.48$). There was a slight overlap of confidence intervals as demonstrated by the error bars. Similar to the results obtained in the egocentric point of view experiment, the composite scores for this variable were less than one because
the written references to cardinal directions made by each participant were low. These scores were averaged across four different routes and the averages were used to calculate the test statistic (mean), which in some instances had values lower than one.

**Figure 57**: Average number of written references to cardinal directions.

![Graph showing gender comparison](image)

The histograms (Figure 58) show that the distribution for women was positively skewed \((Skewness = 2.60, \ SE = 0.43)\) and men’s distribution was also positively skewed \((Skewness = 1.09, \ SE = 0.43)\). Women’s distribution was leptokurtic \((Kurtosis = 6.64, \ SE = 0.83)\) and men’s distribution was also leptokurtic \((Kurtosis = 0.48, \ SE = 0.83)\).
Figure 58: Frequency distribution of values for the number of written cardinal directions.

Figure 59 illustrates that the distributions skewed towards the lower end of the scale. The women’s group had a high number of severe outliers. Although men’s distribution also had participants with extreme values, they did not constitute outliers.

Figure 59: Number of references to written cardinal directions. Asterisks represent severe outliers.
Table 14 contains a summary list of participants who were identified as outliers for data related to the number of *written references to cardinal directions*. For these participants, I also reported the extreme scores in demographic, spatial ability, written references, and eye fixation variables.

Table 14: Participants with extreme scores on the number of written cardinal directions and other variables

<table>
<thead>
<tr>
<th>Participant code</th>
<th>Variable</th>
<th>Value</th>
<th>Group statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Women</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F31*</td>
<td>Number of written references to cardinal directions</td>
<td>0.3</td>
<td>( M = 0.2 )  \  ( Mdn = 0.0 )  \  ( SD = 0.48 )</td>
</tr>
<tr>
<td></td>
<td>Time fixating outside main areas of interest (%)</td>
<td>22.9</td>
<td>( M = 33.3 )  \  ( Mdn = 29.8 )  \  ( SD = 12.4 )</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>Over 30</td>
<td>Frequencies in years**:  \  Under 20 (4)  \  Between 20-25 (18)  \  Between 26-30 (5)  \  Over 30 (3)</td>
</tr>
<tr>
<td></td>
<td>Number of hours playing video games per week</td>
<td>5-10</td>
<td>Frequencies in hours**:  \  Does not play (13)  \  Less than 5 (11)  \  Between 5-10 (6)</td>
</tr>
<tr>
<td>F73*</td>
<td>Number of written cardinal directions</td>
<td>0.3</td>
<td>( M = 0.2 )  \  ( Mdn = 0.0 )  \  ( SD = 0.48 )</td>
</tr>
<tr>
<td></td>
<td>Object location memory test score</td>
<td>8</td>
<td>( M = 9.8 )  \  ( Mdn = 10 )  \  ( SD = 1.98 )</td>
</tr>
<tr>
<td></td>
<td>Mental object rotation test score</td>
<td>4</td>
<td>( M = 9.5 )  \  ( Mdn = 9.0 )  \  ( SD = 3.78 )</td>
</tr>
<tr>
<td>F75*</td>
<td>Number of written cardinal directions</td>
<td>0.5</td>
<td>( M = 0.2 )  \  ( Mdn = 0.0 )  \  ( SD = 0.48 )</td>
</tr>
<tr>
<td></td>
<td>Object location memory test score</td>
<td>8</td>
<td>( M = 9.8 )  \  ( Mdn = 10 )  \  ( SD = 1.98 )</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>Under 20</td>
<td>Frequencies in years**:  \  Under 20 (4)  \  Between 20-25 (18)  \  Between 26-30 (5)  \  Over 30 (3)</td>
</tr>
<tr>
<td>F39*</td>
<td>Number of written cardinal directions</td>
<td>1.0</td>
<td>( M = 0.2 )  \  ( Mdn = 0.0 )  \  ( SD = 0.48 )</td>
</tr>
<tr>
<td></td>
<td>Time fixating on compass (%)</td>
<td>10.3</td>
<td>( M = 2.7 )  \  ( Mdn = 1.7 )  \  ( SD = 2.67 )</td>
</tr>
<tr>
<td></td>
<td>Time fixating on landmarks (%)</td>
<td>28.7</td>
<td>( M = 36.1 )  \  ( Mdn = 36.3 )</td>
</tr>
</tbody>
</table>

---

**Note**: Frequencies in years**: Under 20 (4)  \\  Between 20-25 (18)  \\  Between 26-30 (5)  \\  Over 30 (3)  \\  Does not play (13)  \\  Less than 5 (11)  \\  Between 5-10 (6)
<table>
<thead>
<tr>
<th>Participant code</th>
<th>Variable</th>
<th>Value</th>
<th>Group statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mental object rotation test score</td>
<td>14</td>
<td>$M = 9.5$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$Mdn = 9.0$</td>
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<td></td>
<td></td>
<td></td>
<td>$SD = 3.78$</td>
</tr>
<tr>
<td>F42*</td>
<td>Number of written cardinal directions</td>
<td>1.0</td>
<td>$M = 0.2$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$Mdn = 0.0$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$SD = 0.48$</td>
</tr>
<tr>
<td></td>
<td>Time fixating on compass (%)</td>
<td>5.8</td>
<td>$M = 2.7$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$Mdn = 1.7$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$SD = 2.67$</td>
</tr>
<tr>
<td></td>
<td>Object location memory test score</td>
<td>13</td>
<td>$M = 9.8$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$Mdn = 10$</td>
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<td></td>
<td></td>
<td></td>
<td>$SD = 1.98$</td>
</tr>
<tr>
<td>F40*</td>
<td>Number of written cardinal directions</td>
<td>1.2</td>
<td>$M = 0.2$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$Mdn = 0.0$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$SD = 0.48$</td>
</tr>
<tr>
<td></td>
<td>Time fixating on the compass (%)</td>
<td>6.8</td>
<td>$M = 2.7$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$Mdn = 1.7$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$SD = 2.67$</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>26-30</td>
<td>Frequencies in years**: Under 20 (4) Between 20-25 (18) Between 26-30 (5) Over 30 (3)</td>
</tr>
<tr>
<td>F78*</td>
<td>Number of written cardinal directions</td>
<td>2.0</td>
<td>$M = 0.2$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$Mdn = 0.0$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$SD = 0.48$</td>
</tr>
<tr>
<td></td>
<td>Time fixating on compass (%)</td>
<td>9.9</td>
<td>$M = 2.7$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$Mdn = 1.7$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$SD = 2.67$</td>
</tr>
<tr>
<td></td>
<td>Number of written references to landmarks</td>
<td>0.5</td>
<td>$M = 2.9$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$Mdn = 2.5$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$SD = 2.03$</td>
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<tr>
<td></td>
<td>Object location memory test score</td>
<td>12</td>
<td>$M = 9.8$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$Mdn = 10$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$SD = 1.98$</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>Over 30</td>
<td>Frequencies in years**: Under 20 (4) Between 20-25 (18) Between 26-30 (5) Over 30 (3)</td>
</tr>
</tbody>
</table>

* Outlier flagged as severe
**Number of participants in brackets.

As in the egocentric point of view experiment, there appeared to be two distinct populations in each sample group. One group used cardinal directions and the other did not. The outliers were identified as extreme because the majority of participants did not spontaneously use cardinal directions. There was no experimental rationale to discard the outliers, so in the present analysis l
chose to include all the outliers in the statistical tests. In the egocentric point of view experiment, I chose to conduct an exploratory analysis of those participants who made a number of references to cardinal directions greater than 0. The almost equal number of women (10) and men (11) who made references to cardinal directions allowed me to make a simple randomized adjustment to equalize the sample size. Yet, in the present experiment, 7 women and 17 men made references to cardinal directions. The numerical disparity between the two sample groups was quite large, so I chose to forego exploratory analysis of only those participants who made a number of references to cardinal directions greater than 0. Instead, I analyzed the entire sample population whether or not they made references to cardinal directions.

The results of the Shapiro-Wilk $W$ test of normality for the number of written references to cardinal directions were significant for women ($W = .514, p = .000$) and men ($W = .826, p = .000$). Levene’s test of homogeneity of variances was also significant ($F(1, 58) = 7.21, p = .009$). Given that the data violated parametric assumptions, I used Mann-Whitney $U$ to investigate the statistical relationship between women ($Mdn = 0.0, SD = 4.80$) and men ($Mdn = 0.5, SD = 0.71$) on the number of written references to cardinal directions.

6.3.2.2 H2 results

The results of this test were significant at a $p < .01$ level ($Mann-Whitney U = 289.50, p = .003$). I found evidence that when giving written directions after a route-learning task, men made a greater number of written references to cardinal directions than women. The effect size as measured with the Pearson correlation
coefficient was \( r = -0.35 \), which is considered a moderate effect that explains over 9% of the total variance (Cohen 1988, 1992).

### 6.3.3 Summary

The tests indicated that the difference between men and women in the *number of written references to landmarks* approached significance. I also found evidence that on average men and women differed significantly in the *number of written references to cardinal directions*.

### 6.3.4 Hypothesis three- time fixating on landmarks (%)

I hypothesized that when learning a route, women would allocate a greater proportion of fixation time (%) on landmark regions than men.

#### 6.3.4.1 Descriptive analysis

Figure 60 shows that on average women \( (M = 36.1, SD = 6.54) \) spent a greater proportion of *time fixating on landmarks (%)* than men \( (M = 32.0, SD = 4.87) \). The overlap of the confidence intervals was small and suggested that the two means were drawn from different sample populations.
Figure 60: Average time fixating on landmarks (%) with a 95% confidence interval (CI).

![Bar chart showing average time fixating on landmarks by gender with 95% CI error bars.]

Figure 61 shows the distribution of scores for the *time fixating on landmarks* (%). Women’s score distribution was negatively skewed (*Skewness* = -0.74, *SE* = 0.43), which suggested a small deviation from normality. Men’s distribution of scores was also negatively skewed (*Skewness* = -0.08, *SE* = 0.43). Women’s distribution was leptokurtic (*Kurtosis* = 2.05, *SE* = 0.83) and men’s distribution was platykurtic (*Kurtosis* = -0.14, *SE* = 0.83). None of these values indicated a significant deviation from normality however.
The boxplots (Figure 62) shows that women’s distribution of scores was skewed to the low end of the scale, and men’s score distribution was somewhat symmetrical. There was one outlier in the women’s data.
Participant F60 in the women’s group had the lowest value for the *time fixating on landmarks (%)*. She had the highest value (81.8%) in the women’s group (\( M = 33.3, \ SD = 12.4 \)) for the *time fixating outside the main areas of interest (%)*. These ‘outside areas’ referred to streets, ground, sky, interface elements (e.g., elevation indicator, Google branding, and copyright information) and large-scale environmental features such as mountain ranges and the sky. The high percentage of fixation time allocated to these outside areas partly explain why the participant spent a low *time fixating on landmarks (%)*. While her score in the number of *written references to landmarks* (1.5) was below average (\( M = 2.9, \ SD = 2.03 \)), it was not extreme enough to constitute an outlier. Her score (12) on the *object location memory* test was higher than her group’s average (\( M = 9.8, \ SD = 1.98 \)). In the *mental object rotation* test, the participant had the second highest score (15) in her sample group (\( M = 9.5, \ SD = 3.78 \)). Finally, the participant did not allocate any fixations on the compass and did not use cardinal directions. While outside the norm, I had no reason to believe that her *time fixating on landmarks (%)* was anything but normal scanning behaviour and thus chose to retain the score for further analysis.

The results of the normality test indicated that the distributions of scores were normal for women (*Shapiro-Wilk W* = .96, \( p = .28 \)) and for men (*Shapiro-Wilk W* = .98, \( p = .87 \)). Results of the Levene’s test showed that the variances of scores for the *time fixating on landmarks (%)* were homogenous (\( F(1, 58) = 0.80, \ p = .38 \)). The data for both sample populations met assumptions of normality.
Given that the data met assumptions of normality, I applied the Student’s $t$-test to determine the statistical relationship between men and women on the time fixating on landmarks ($\%$). Figure 63 shows that on average women ($M = 36.1$, $SD = 6.54$) spent a greater proportion of time fixating on landmarks ($\%$) than men ($M = 32.0$, $SD = 4.87$).

Figure 63: Error graph for the average time fixating on landmarks ($\%$) with a 95% confidence interval (CI).

6.3.4.2 H3 results

The results of the $t$-test were significant at a $p < .01$ level ($t(58) = 2.76$, $p = .004$). Therefore, the hypothesis that when learning a route, women would allocate a greater proportion of time fixating on landmarks ($\%$) than men was supported. The effect size as measured with the Pearson correlation coefficient was $r = .34$, which is considered a moderate effect that explains over 9% of the total variance (Cohen 1988, 1992).
6.3.5 Hypothesis four- time fixating on the compass (%)

I hypothesized that when learning a route, men would allocate a greater proportion of time fixating on the compass (%) than women.

6.3.5.1 Descriptive analysis

On average, men ($M = 4.7$, $SD = 4.80$) allocated a greater fixation time on the compass (%) than women ($M = 2.7$, $SD = 2.67$) (Figure 64). There was a small overlap between the 95% confidence interval in each sample group.

Figure 64: Average time that men and women fixated on the compass (%) with a 95% confidence interval.

The histograms (Figure 65) show that the distribution of scores was positively skewed for women ($Skewness = 1.58$, $SE = 0.43$) and men ($Skewness = 2.30$, $SE = 0.43$). The score distributions for women ($Kurtosis = 2.34$, $SE = 0.83$) and for men ($Kurtosis = 7.23$, $SE = 0.83$) were leptokurtic. These values suggested that the distributions deviated from normality.
Figure 65: Frequency distribution of values for the time that men and women fixated on landmarks (%).

The boxplots (Figure 66) show that the distributions for men and women were skewed towards the low end of the scale. The women's distribution had two outliers and men's distribution had one severe outlier.

Figure 66: Boxplots for the time that men and women fixated on the compass (%).

Participant F78’s time fixating on the compass (9.9%) was higher than the group’s average ($M = 2.7$, $SD = 2.67$). The participant’s score (2.0) on the
number of written references to cardinal directions was the highest in the women’s group ($M = 0.2, SD = 0.48$). Her score (15) on the mental object rotation test was higher than the group’s average ($M = 9.5, SD = 3.78$). The number of written references to landmarks that she made (0.5) was lower than the group’s average ($M = 2.9, SD = 2.03$).

Participant F39’s time fixating on the compass (10.3%) was higher that the group’s average ($M = 2.7, SD = 2.67$). She made a higher (1.0) than average ($M = 0.2, SD = 0.48$) number of written references to cardinal directions. Her score (14) on the mental object rotation test was higher than the group’s average ($M = 9.5, SD = 3.78$). She allocated a lower (28.7) than average ($M = 36.1, SD = 6.54$) time fixating on landmarks (%).

Participant M88 had the highest (23.5) time fixating on the compass (%) in the men’s group ($M = 4.7, SD = 4.80$). His number of written references to cardinal directions (1.2) was higher than average ($M = 0.6, SD = 0.71$). He was one of the oldest participants (over 30 years of age). His score (2) in the object location memory test was the lowest in the men’s group ($M = 8.7, SD = 2.78$). The number of years that he had held a driver’s license (16) prior to the study was higher than average ($M = 4.4, SD = 4.05$).

I found no evidence that the outliers in the time fixating on the compass (%) were the result of technical, data entry, or calculation error. I retained all values for further analysis.

The results of the Shapiro-Wilk $W$ normality test were significant for women ($W = .82, p = .000$) and men’s ($Shapiro-Wilk W = .78, p = .000$) score.
distributions. The Levene’s test for equality of variances showed that the variances of scores for the time fixating on the compass (%) were homogenous ($F(1, 58) = 3.08, p = .08$). Figure 67 shows that men ($Mdn = 3.8, SD = 4.80$) spent a greater time fixating on the compass (%) than women ($Mdn = 1.70, SD = 2.67$).

**Figure 67:** Median time that men and women fixated on the compass (%) with a 95% confidence interval.

![Median time that men and women fixated on the compass (%) with a 95% confidence interval.](image)

### 6.3.5.2 H4 results

The results of the statistical test were significant at a $p < .05$ level ($Mann-Whitney U = 306.00, p = .016$). The effect size as measured with the Pearson correlation coefficient was $r = -.27$, considered a small to moderate effect that explains between 1-9% of the total variance (Cohen 1988, 1992).

I found evidence to support the hypothesis that when learning a route, men would allocate a greater proportion of time fixating on the compass (%) than women.
6.3.6 Summary

The results of the statistical tests yielded a significant difference between men and women in the time fixating on landmarks (%). Additionally, I found evidence to support the hypothesis that on average men spent a greater time fixating on the compass (%) than women.

6.3.7 Hypothesis five - correlation between the time fixating on landmarks (%) and the number of written references to landmarks

I hypothesized that the time fixating on landmarks (%) would be positively correlated with the number of written references to landmarks. I first sought to establish if this correlation existed when men and women’s data were grouped. Then, I analyzed each sample population separately.

6.3.7.1 Analysis by group

I conducted a correlation analysis for the entire sample population as a single group regardless of gender.
Figure 68: Correlation between the time fixating on landmarks (%) and the number of written references to landmarks.

The scatterplot (Figure 68) shows a positive correlation between the time fixating on landmarks (%) and the number of written landmarks. The results of the normality test revealed that the grouped distribution of scores for the number of written references to landmarks deviated significantly from normality (Shapiro-Wilk $W = .91$, $p = .000$). The grouped time fixating on landmarks (%) did not significantly deviate from normality (Shapiro-Wilk $W = .99$, $p = .77$). Given the non-normal characteristics of the written directions data and the moderate size of the sample, I applied Spearman’s coefficient for ranked data to investigate the correlation between the two variables. The results of the tests indicated that at a $p < .001$ level, there was a significantly positive correlation between the time fixating on landmarks (%) and the number of written references to landmarks (Spearman’s rho = .65, $p = .000$).
6.3.7.2 Exploratory analysis by gender- women

I examined the correlation between the *time fixating on landmarks (%)* and the *number of written references to landmarks* using gender as a grouping variable. The scatterplot (Figure 69) shows a positive correlation between the two variables. As reported, the distribution of scores for the *time fixating on landmarks (%)* was normal (6.3.4.1) and the distribution of scores for women’s *number of written references to landmarks* was non-normal (6.3.1.1).

Figure 69: Correlation between women’s *time fixating on landmarks (%)* and number of written references to landmarks.

I used the Spearman’s coefficient for ranked data to examine the correlations. The results indicate that the *time fixating on landmarks (%)* was positively correlated with the *number of written references to landmarks* at a $p < .001$ level ($\text{Spearman’s rho} = .68, p = .000$).
6.3.7.3 Exploratory analysis by gender- men

The scatterplot (Figure 70) shows a somewhat positive correlation between men’s time fixating on landmarks (%) and the number of written references to landmarks.

Figure 70: Correlation between men’s time fixating on landmarks (%) and the number of written references to landmarks.

The distributions of men’s scores for the time fixating on landmarks (%) (6.3.4.1) and the number of written references to landmarks (6.3.1.1) were previously reported as normal. Thus, I used Pearson's correlation coefficient to test the bivariate relationship between the two variables. With a coefficient of $r = .56$, the correlation test was significant at a $p < .01$ level ($p = .001$). Therefore, I found positive correlation between men’s time fixating on landmarks (%) and the number of written references to landmarks.
6.3.8 Hypothesis six- correlation between time fixating on the compass (%) and the number of written references to cardinal directions

I hypothesized that the time fixating on the compass (%) would be positively correlated with the number of written references to cardinal directions. I first sought to establish if this correlation was significant when men and women were analyzed as a single group. I then conducted an exploratory analysis using gender as a grouping variable.

6.3.8.1 Analysis by group

The scatterplot (Figure 71) shows that, as a group, men and women seemed to share a positive correlation on the time fixating on the compass (%) and the number of written references to cardinal directions.

Figure 71: Correlation between the time fixating on the compass (%) and the number of written references to cardinal directions for men and women’s scores plotted as a single group.
Some participants did not make any references to cardinal directions and thus a few of the values appeared extreme. I had no reason to exclude these outliers and thus retained them for further analysis. The normality test for the written references to cardinal directions was significant (Shapiro-Wilk $W = .70, p = .000$). This same test was also significant for the time fixating on the compass (%) ($Shapiro-Wilk W = .77, p = .000$). Because the data deviated from normality and because of the large number of tied ranks in the data, I used Kendall's $\tau$ rank correlation coefficient to investigate the bivariate relationship between the time fixating on the compass (%) and the number of written references to cardinal directions. The results of the correlation test were significant at a $p < .001$ level (Kendall's $\tau = .56, p = .000$). Therefore, I found evidence that the time fixating on compass (%) was positively correlated with number of written references to cardinal directions when men and women were analyzed as a single group.

### 6.3.8.2 Exploratory analysis by gender- women

Only seven women made references to cardinal directions, so there was no clear correlation between the time fixating on the compass (%) and the number of written references to cardinal directions (Figure 72). From the few values graphed in the scatterplot, however, it appeared as if there was a positive correlation between the variables.
Normality tests had previously shown that women’s distribution of scores for the time fixating on the compass (%) (6.3.5.1) and the number of written references to cardinal directions (6.3.2.1) were non-normal. Therefore, I used Kendall’s tau rank correlation coefficient to investigate the correlation between the two variables. The results showed that the variables were significantly correlated at a $p < .001$ level ($Kendall’s\ tau = .54, p = .000$). The time fixating on the compass (%) was positively correlated with the number of written references to cardinal directions.
6.3.8.3 Exploratory analysis by gender- men

The scatterplot (Figure 73) of men’s data for the *time fixating on the compass (%)* and the *number of written references to cardinal directions* shows a positive correlation.

Figure 73: Scatterplot depicting the correlation between men’s *time fixating on the compass (%)* and the *number of written references to cardinal directions*.

A previous analysis yielded significant results for the normality tests performed on men’s *time fixating on the compass (%)*(6.3.5.1) and on the *number of written references to cardinal directions* (6.3.2.1). Thus, given the deviation from normality, I used Kendall’s *tau* rank correlation coefficient. I found a significant correlation between the two variables at a $p < .001$ level (*Kendall’s tau* = .50, $p = .000$). The *time fixating on the compass (%)* was positively correlated with the *number of written references to cardinal directions* in the men’s group.
6.3.9 Summary

The results of the correlation tests indicated that there was a significant positive correlation between the *time fixating on landmarks (%)* and the *number of written references to landmarks* when the two sample populations were analyzed as a single group. There was also a positive correlation between the *time fixating on landmarks (%)* and the *number of written references to landmarks* when men and women were analyzed separately.

I found evidence that the *time fixating on the compass (%)* was positively correlated with the *number of written references to cardinal directions* when men and women were analyzed as a single group. I found evidence of a positive correlation between women’s *time fixating on the compass (%)* and the *number of written references to cardinal directions*. Additionally, men’s *time fixating on the compass (%)* was also positively correlated to the number of *written references to cardinal directions*.

6.3.10 Overall summary: gender and route-learning strategies

As reported under the allocentric column in Table 15, I found support for the hypotheses that men and women differ in the number of written references cardinal directions, fixations on landmarks, and fixations on the compass. The differences in the number of written references to landmarks approached significance.
Table 15: Statistical results of the analysis investigating gender differences in virtual route-learning strategies.

<table>
<thead>
<tr>
<th>Dependent Variables</th>
<th>Independent Variable</th>
<th>W</th>
<th>M</th>
<th>Egocentric</th>
<th>Allocentric</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1 Number of Written References to Landmarks (avg)</td>
<td>&gt;</td>
<td>NS</td>
<td>p = .055</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H2 Number of Written References to Cardinal Directions (avg)</td>
<td>&lt;</td>
<td>NS</td>
<td>**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H3 Time Fixating on Landmarks (%)</td>
<td>&gt;</td>
<td>NS</td>
<td>**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H4 Time Fixating on Compass (%)</td>
<td>&lt;</td>
<td>NS</td>
<td>*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* p < .05  ** p < .01

As shown Table 16, fixating on landmarks was strongly correlated with making written references to landmarks and fixating on the compass was associated with providing written references to cardinal directions.

Table 16: Results of correlation analysis between eye fixations and written directions.

<table>
<thead>
<tr>
<th>Eye fixations</th>
<th>Written directions</th>
<th>Egocentric</th>
<th>Allocentric</th>
</tr>
</thead>
<tbody>
<tr>
<td>H5 Time Fixating on Landmarks (%)</td>
<td>+ Number of Written References to Landmarks (avg)</td>
<td>*</td>
<td>***</td>
</tr>
<tr>
<td>H6 Time Fixating on the Compass (%)</td>
<td>+ Number of Written References to Cardinal Directions (avg)</td>
<td>***</td>
<td>***</td>
</tr>
</tbody>
</table>

* p < .05  ** p < .01  *** p < .001

When I analyzed the data by gender (Table 17), the correlations between fixation data and written directions were significant. Fixating on landmarks was positively related to making references to landmarks; and fixating on the compass was positively correlated with making references to cardinal directions.
6.4 Gender, spatial abilities, and route learning

In this section, I report the results of the analysis examining the relationship between spatial abilities and route learning. As indicated in 3.2, I predicted that mental rotation would be positively associated with configurational route-learning strategies (compass fixations and references to cardinal directions) and object location memory would be positively associated with topographic strategies (landmark fixations and references). In addition, I conducted a correlation analysis of men and women’s data separately.

6.4.1 Hypothesis seven- object location memory

I hypothesized the women would, on average, score higher than men on tests of object location memory.

Table 17: Exploratory correlations by gender between eye fixations and written directions.

<table>
<thead>
<tr>
<th>Eye fixations</th>
<th>Written directions</th>
<th>Egocentric</th>
<th>Allocentric</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Women- Exploratory</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Fixating on Landmarks (%)</td>
<td>Number of Written References to Landmarks (avg)</td>
<td>*</td>
<td>***</td>
</tr>
<tr>
<td>Time Fixating on the Compass (%)</td>
<td>Number of Written References to Cardinal Directions (avg)</td>
<td>P = .01</td>
<td>***</td>
</tr>
<tr>
<td><strong>Men- Exploratory</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Fixating on Landmarks (%)</td>
<td>Number of Written References to Landmarks (avg)</td>
<td>NS</td>
<td>**</td>
</tr>
<tr>
<td>Time Fixating on the Compass (%)</td>
<td>Number of Written References to Cardinal Directions (avg)</td>
<td>***</td>
<td>***</td>
</tr>
</tbody>
</table>

* p < .05   ** p < .01   *** p < .001
6.4.1.1 Descriptive analysis

Figure 74 shows that on average women \( (M = 9.8, \ SD = 1.98) \) did score higher than men \( (M = 8.7, \ SD = 2.78) \) on the object location memory test. The overlap of 95% confidence intervals between the two groups was not large and suggested that the scores were drawn from significantly different populations.

Figure 74: Average score for men and women on the object location memory test with a 95% confidence interval. The total scores on this test were calculated by subtracting the incorrect answers from the correct ones.

As illustrated in Figure 75, the distributions of scores for men and women did not show large deviations. Women’s score distribution was positively skewed \( (Skewness = 0.02, \ SE = 0.43) \) and men’s scores were negatively skewed \( (Skewness = -0.30, \ SE = 0.43) \). The data distributions were platykurtic for women \( (Kurtosis = -1.03, \ SE = 0.83) \) and leptokurtic for men \( (Kurtosis = 0.12, \ SE = 0.83) \).
Figure 75: Frequency distribution of scores for the object location memory test.

The boxplots (Figure 76) show that men’s distribution had a larger dispersal of scores than women, but there were no outliers in the data and both distributions were more or less symmetrical.

Figure 76: Boxplots for the scores on the object location memory test.

The results of the Shapiro-Wilk $W$ tests of normality on scores of the object location memory test were not significant for women ($W = .942, p = .10$)
and men ($W = .965, p = .40$). Levene’s test for homogeneity of variances was not significant ($F (1, 58) = 1.30, p = .26$).

**Figure 77:** Average scores on the object location memory test with a 95% confidence interval.

As shown in the error graph (Figure 77), women’s ($M = 9.8, SD = 1.98$) average score on the *object location memory* test was higher than men’s ($M = 8.7, SD = 2.78$).

### 6.4.1.2 H7 results

The results of the Student’s *t*-test were significant at the $p < .05$ level ($t (58) = 1.869, p = .034$). The effect size as measured with the Pearson correlation coefficient was $r = .24$, which is a small to moderate effect that explains between 1-9% of the total variance (Cohen 1988, 1992). On average, women scored significantly higher on the *object location memory* test than men.
6.4.2 Hypothesis eight - correlation between scores on the object location memory test and the number of written references to landmarks

I hypothesized that scores on the object location memory test would positively correlate with the number of written references to landmarks.

6.4.2.1 Analysis by group

As a group, men and women’s scores on the object location memory test and the number of written references to landmarks did not appear to have a linear relationship (Figure 78).

Figure 78: Scatterplot for the grouped scores on the object location memory test and the number of written references to landmarks.

The previously reported test of normality on the grouped distribution of scores on the object location memory test was significant, indicating that the grouped distribution was non-normal (6.4.3.1). The grouped distribution of values for the number of written references to landmarks was also non-normal
Therefore, I used Spearman’s coefficient for ranked data to examine the correlations between the two variables. The results of the correlation test were not significant (Spearman’s rho = -0.11, p = .18). Thus, there was no evidence that the grouped scores on the object location memory test were significantly correlated to the number of written references to landmarks.

6.4.2.2 Exploratory analysis by gender- Women

The scatterplot (Figure 79) for women’s scores on the object location memory test and the number of written references to landmarks did not show a discernable correlation between the two variables.

Figure 79: Scatterplot for women’s scores on the object location memory test and the number of written references to landmarks.

The reported tests of normality for women’s scores on the object location memory test was not significant (6.4.1), but it was significant for the number of
written references to landmarks (6.3.1.1). Because the data did not meet assumptions of normality, I used the Spearman’s coefficient for ranked data to examine the correlations. The results indicated that women’s scores on the object location memory test were not correlated with the number of written references to landmarks (Spearman’s rho = -.11, p = .28).

6.4.2.3 Exploratory analysis by gender- Men

Figure 80 shows the correlation between men’s scores on the object location memory test and the number of written references to landmarks. I found no discernable linear relationship between the variables in this scatterplot.

Figure 80: Scatterplot for men’s object location memory and number of written references to landmarks.

As reported, the distribution of men’s scores on the object location memory test (6.4.1) and the number of written references to landmarks (6.3.1.1)
did not deviate from normality. Therefore, I used Pearson’s correlation coefficient to examine the correlation between the variables. With a coefficient of \( r = -0.232 \), the test was not significant \((p = .11)\). Thus, there was no evidence that men’s scores on the \textit{object location memory} test were correlated with the number of written references to landmarks.

6.4.3 Hypothesis nine- correlation between scores on the \textit{object location memory} test and the \textit{time fixating on landmarks} (%)

I hypothesized that scores on the \textit{object location memory} test would be positively correlated to the \textit{time fixating on landmarks} (%). That is, the higher the score on the \textit{object location memory} test, the higher the \textit{time fixating on landmarks} (%). I analyzed the data by grouping the scores of both populations and treating them as a single group. Then, I performed an exploratory analysis on each population separately.

6.4.3.1 Analysis by group

Figure 81 shows the correlation between the grouped scores on the \textit{object location memory test} and the \textit{time fixating on landmarks} (%). The scatterplot shows no indication of a positive correlation between the two variables.
The results of the Shapiro-Wilk $W$ test of normality indicated that the distribution of grouped scores on the object location memory test was non-normal ($W = .96, p = .048$). The distribution of scores for the time fixating on landmarks (%) was normal ($Shapiro-Wilk W = .99, p = .77$). Because of the deviation from normality of the object location memory test scores and the moderate size of the sample, I examined the correlation between the two variables using Spearman’s coefficient for ranked data. The results of the correlation test were not significant ($Spearman’s rho = .004, p = .49$). There was no significant correlation between scores on the object location memory test and the time fixating on landmarks (%) when the two sample populations were treated as a single group.
6.4.3.2 Exploratory analysis by gender- women

The correlation for women’s scores on the object location memory test and the time fixating on landmarks (%) is shown in Figure 82. There seemed to be a somewhat negative correlation between the two variables.

Figure 82: Correlation between women’s scores on the object location memory test and time fixating on landmarks (%).

As reported, the distribution of women’s scores on the object location memory test was normal (6.4.1). The distribution of scores for women’s time fixating on landmarks (%) was also normal (6.3.4.1). Given that the data met parametric assumptions, I used Pearson’s correlation coefficient to test the correlation between the two variables. With a coefficient of $r = -.18$, the correlation test was not significant ($p = .35$). There was no evidence that women’s scores on the object location memory test were positively correlated to the time fixating on landmarks (%).
6.4.3.3 Exploratory analysis by gender - men

Men’s distribution of scores on the *object location memory* test and the *time fixating on landmarks (%)* are shown in Figure 83. There was no detectable correlation between the variables.

Figure 83: Scatterplot showing the correlation between men’s scores on the object location memory test and the time fixating on landmarks (%).

As reported, men’s distribution of score on the *object location memory* test was normal (6.4.1). The distribution of scores for the *time fixating on landmarks (%)* was also normal (6.3.4.1). Therefore, I used Pearson’s correlation coefficient to investigate the correlation between the two variables. With a coefficient of $r = .05$, the results of the correlation test were not significant ($p = .79$). Thus, there was no evidence that men’s scores on the *object location memory* test were correlated with the *time fixating on landmarks (%)*.
6.4.4 Summary

On average, women scored significantly higher than men on the object location memory test. I found no evidence that scores on the object location memory test were significantly correlated to the number of written references to landmarks when men and women were analyzed as a single group or when they were analyzed separately.

I tested correlations between scores on the object location memory test and the time fixating on landmarks (%). I found no significant correlations between the two variables when men and women were analyzed as a single group or when the sample populations were analyzed separately.

6.4.5 Hypothesis ten- mental object rotation

I hypothesized that on average men would score higher than women on the mental object rotation test.

6.4.5.1 Descriptive analysis

The bar graph (Figure 84) indicated that on average men \((M = 12.2, SD = 5.35)\) scored higher than women \((M = 9.5, SD = 3.78)\) on the mental object rotation test. There was a slight overlap of the confidence intervals.
As illustrated in Figure 85, the deviation from normality did not appear significant. Women (Skewness = 0.13, SE = 0.43) and men's (Skewness = 0.28, SE = 0.43) data distributions were positively skewed. Women's distribution of scores was platykurtic (Kurtosis = -1.23, SE = 0.83) and so was men's (Kurtosis = -0.23, SE = 0.83).
The distributions of scores were symmetrical (Figure 86). Men’s distribution had a larger spread of scores than women’s. There were no severe outliers in the data.

The results of the Shapiro-Wilk $W$ test of normality on the mental object rotation test scores were significant for women ($W = .93, p = .04$) and non-
significant for men ($W = .97, p = .64$). Levene’s test for homogeneity of variances was not significant ($F(1, 58) = 1.77, p = .19$). Given the non-normal distribution of women’s scores, I used the Mann-Whitney $U$ to examine the statistical relationship between the two groups. Since the median is a more appropriate statistic than the mean for non-parametric tests, I reported this statistic in Figure 87. The graph (Figure 87) shows that men ($Mdn = 11.5, SD = 5.35$) scored higher than women ($Mdn = 9.5, SD = 3.78$) on the mental object rotation test.

**Figure 87:** Median score for men and women on the mental object rotation test.

6.4.5.2 H10 results

The Mann-Whitney $U$ test was significant at a $p < .05$ level ($U = 312.5, p = .04$) with an effect size of Pearson $r = -.21$, which is a small to moderate effect explaining between 1-9% of the total variance (Cohen 1988, 1992). Thus, men scored significantly higher than women on the mental object rotation test.
6.4.6 Hypothesis eleven- correlation between scores on the mental object rotation test and the average number of written references to cardinal directions

I hypothesized that scores on the mental object rotation test would be positively correlated with the number of written references to cardinal directions.

6.4.6.1 Analysis by group

The scatterplot (Figure 88) shows the correlation between men and women’s grouped scores on the mental object rotation test and the number of written references to cardinal directions. The scatterplot showed no obvious linear relationship between the variables.

Figure 88: Scatterplot for grouped scores on the mental object rotation test and the number of written references to cardinal directions.

As reported, the distribution of grouped scores on the mental object rotation test was normal (6.4.7.1), but the grouped number of written references
to cardinal directions deviated from normality (6.3.8.1). Therefore, I used Spearman’s coefficient for ranked data to investigate the correlation between the two variables. The results of the correlation test were not significant (Spearman’s \( \rho = .05, p = .30 \)). Thus, there was no evidence of a positive correlation between men and women’s grouped scores on the mental object rotation test and the number of written references to cardinal directions.

6.4.6.2 Exploratory analysis by gender- women

Figure 89 shows the correlation between women’s scores on the mental object rotation test and the number of written references to cardinal directions. Similar to the egocentric point of view experiment, there was a large number of scores with a value of 0 for the number of written references to cardinal directions. There was no clear correlation between the two variables.
As reported, women’s distributions of scores on the *mental object rotation* test (6.4.5) and on the *number of written references to cardinal directions* (6.3.2.1) were non-normal. Therefore, I tested the correlation between the two variables with Kendall’s *tau* rank correlation coefficient. The results of the test were not significant, but they showed a trend towards a positive correlation (*Kendall’s tau* = .24, *p* = .056). There was no conclusive evidence that women’s scores on the *mental object rotation* test were significantly correlated with the *number of written references to cardinal directions*.

### 6.4.6.3 Exploratory analysis by gender- men

The scatterplot in Figure 90 shows no discernable correlation between men’s scores on the *mental object rotation* test and the *number of written references to cardinal directions*. Yet, the linear relationship appeared to be
somewhat negative. Several scores on the number of written references to cardinal directions were 0.

Figure 90: Scatterplot for men’s scores on mental object rotation test and the written references to cardinal directions.

As reported, the distribution was normal for men’s scores on the mental object rotation test (6.4.5) and non-normal for their number of written references to cardinal directions (6.3.2.1). Therefore, I used Kendall’s tau rank correlation coefficient to examine the correlation between the variables. The results of the test were not significant (Kendall's tau=-.21, p = .07). There was no evidence that men’s scores on the mental object rotation test were significantly correlated with the number of written references to cardinal directions. Given the proximity to a significant level, however, it is worth noting that as the scatterplot suggested, Kendall’s tau coefficient was negative.
6.4.7 Hypothesis twelve- correlation between scores on the mental object rotation test and the time fixating on compass

I hypothesized that the scores on the mental object rotation test would be positively correlated with the time fixating on the compass (%).

6.4.7.1 Analysis by group

The scatterplot (Figure 91) shows the grouped scores on the mental object rotation test and the time fixating on the compass (%). There was no obvious linear relationship discernable from the graph, although a general positive correlation appeared to exist.

Figure 91: Scatterplot for scores on the mental object rotation test and the time fixating on compass (%).

The result of the Shapiro-Wilk W test of normality on the grouped distribution of scores for the mental object rotation test was not significant ($W = .97, p = .16$). As reported, the normality test for the time fixating on compass (%)
was significant (6.3.8.1). Because the data for the *time fixating on the compass* (%) did not meet parametric assumptions, I used Spearman's coefficient for ranked data to examine the bivariate relationship between the two variables. With a coefficient $\rho = .23$, the test was significant at a $p < .05$ level ($p = .04$). Thus, the grouped scores on the *mental object rotation* test were positively correlated with the *time fixating on compass* (%).

### 6.4.7.2 Exploratory analysis by gender- women

The correlation between women's scores on the *mental object rotation* test and the *time fixating on compass* (%) is shown on Figure 92. The correlation between the variables appeared to be positive.

**Figure 92:** Scatterplot for women’s scores on the mental object rotation test and the time fixating on the compass
As reported, women’s distributions of scores on the *mental object rotation* test (6.4.5) and the *time fixating on the compass (%)* (6.3.5.1) were non-normal. Given this deviation from normality, I used Kendall's *tau* rank correlation coefficient to investigate the bivariate relationship between the two variables. The results of the test were not significant (*Kendall’s tau* = .15, *p* = .14). Thus, there was no evidence that women’s scores on the *mental object rotation* test were correlated with the *time fixating on compass (%)*.

6.4.7.3 Exploratory analysis by gender - men

The scatterplot in Figure 93 graphs the correlation between men’s score on the *mental object rotation* test and the *time fixating on compass (%)*. I found no discernable linear relationship between the two variables.

**Figure 93:** Scatterplot for men’s scores on the mental object rotation test and the time fixating on the compass (%).
As reported, men’s distribution of scores on the mental object rotation test (6.4.5) did not deviate from normality. The data distribution for the time fixating on compass (%) (6.3.5.1) was non-normal. Thus, I used Kendall's tau rank correlation coefficient to examine the correlation between the two variables. The results of the test were not significant (Kendall's tau = .016, p = .45). There was no evidence that the scores of the mental object rotation test positively correlated with the time fixating on the compass (%).

6.4.8 Summary

On average men scored significantly higher than women on the mental object rotation test. I did not find evidence that when analyzed as a single group, men and women showed a positive correlation between scores on the mental object rotation test and the number of written references to cardinal directions. When I analyzed the groups separately, I did not find a significant correlation between the variables for women, but the results showed a trend towards a positive correlation. I did not find a significant correlation between the variables for men’s data, but there was a slight suggestion of a negative linear relationship.

As a group, men and women’s scores on the mental object rotation test were correlated with the time fixating on compass (%) was supported. When I analyzed men and women separately, I found no significant correlation between the scores on the mental object rotation test and the time fixating on compass (%).
6.4.9 Overall summary: gender, spatial abilities, and route learning

As illustrated in Table 18, men and women significantly differed on tests of spatial abilities and in the predicted direction. Women scored higher than men on the object location memory test, and men scored higher than women on the mental object rotation test.

Table 18: Results of statistical analysis on gender differences in spatial abilities.

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Dependent Variables</th>
<th>W</th>
<th>M</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>H7</td>
<td>Object location memory</td>
<td>&gt;</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>H10</td>
<td>Mental Object Rotation</td>
<td>&lt;</td>
<td>***</td>
<td>*</td>
</tr>
</tbody>
</table>

* p < .05  **p < .01  *** p < .001

Aside from one exception, I did not find support for a correlation between spatial abilities and route learning strategies (Table 19). I did find a positive correlation between mental rotation abilities and the time fixating on the compass.

Table 19: Results of correlation analysis between spatial abilities and virtual route-learning strategies.

<table>
<thead>
<tr>
<th>Spatial ability</th>
<th>Route learning</th>
<th>Egocentric</th>
<th>Allocentric</th>
</tr>
</thead>
<tbody>
<tr>
<td>H8</td>
<td>Object location memory</td>
<td>+</td>
<td>Number of Written References to Landmarks (avg)</td>
</tr>
<tr>
<td>H9</td>
<td>Object location memory</td>
<td>+</td>
<td>Time Fixating on Landmarks (%)</td>
</tr>
<tr>
<td>H11</td>
<td>Mental rotation</td>
<td>+</td>
<td>Number of Written References to Cardinal Directions (avg)</td>
</tr>
<tr>
<td>H12</td>
<td>Mental rotation</td>
<td>+</td>
<td>Time Fixating on the Compass (%)</td>
</tr>
</tbody>
</table>

* p < .05
As shown in Table 20, when I analyzed the correlations by gender, I did not find any positive correlations between spatial abilities and route-learning strategies.

Table 20: Exploratory correlations by gender between spatial abilities and route-learning strategies.

<table>
<thead>
<tr>
<th>Spatial ability</th>
<th>Route learning</th>
<th>Egocentric</th>
<th>Allocentric</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Women- Exploratory</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Object location memory</td>
<td>Number of Written References to Landmarks (avg)</td>
<td>* (-)</td>
<td>NS</td>
</tr>
<tr>
<td>Object location memory</td>
<td>Time Fixating on Landmarks (%)</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Mental rotation</td>
<td>Number of Written References to Cardinal Directions (avg)</td>
<td>NS</td>
<td>p = .056</td>
</tr>
<tr>
<td>Mental rotation</td>
<td>Time Fixating on the Compass (%)</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td><strong>Men- Exploratory</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Object location memory</td>
<td>Number of Written References to Landmarks (avg)</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Object location memory</td>
<td>Time Fixating on Landmarks (%)</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Mental rotation</td>
<td>Number of Written References to Cardinal Directions (avg)</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Mental rotation</td>
<td>Time Fixating on the Compass (%)</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

* p < .05
7: EXPERIMENT 1 - EGOCENTRIC VIEWPOINT 
DISCUSSION

7.1 Overview

In this chapter, I discuss the research questions and hypotheses in light of the experimental results obtained. I also discuss the implications of these results and their limitations. The experimental framework was designed to examine the relationship between gender, virtual route-learning strategies, and spatial abilities. Do men and women differ in the strategies they rely on when giving directions? The results from the egocentric viewpoint experiment showed that men and women did not significantly differ in the way that they gave directions. This was the case when I performed the analysis on the topographic elements (landmark references) and the configuration elements (cardinal direction references). However, a closer examination of the cardinal directions data revealed that most participants did not spontaneously use cardinal directions. When I analyzed only the participants who made references to cardinal points, I found a significant gender difference. Thus, while I found no gender differences in the number of written references to cardinal directions when data from all participants were analyzed, the post-hoc analysis suggest that differences may indeed exist and should be revealed with a specific experimental methodology that addresses the spontaneous use of cardinal directions. The findings on landmarks did not show the similar bimodal characteristics of cardinal directions data. The results showed that men and women did not differ in the number of
written references to landmarks. Therefore, when men and women viewed the route from an egocentric viewpoint, they did not differ in the type of written references they made.

Do men and women differ in the visual scanning strategies they use to learn a route in a 3D virtual environment? I did not find any gender differences in the visual scanning of landmarks and on the scanning of the compass indicator. As mentioned, however, only a few participants spontaneously made written references to cardinal directions. For this reason, I analyzed only the eye tracking data for those participants who made references to cardinal directions, and I found a significant difference between men and women in the proportion of time allocated to the compass. The limits of this post-hoc analysis did not make it possible to determine the validity and reliability of these results. Nevertheless, they suggest that differences between compass users and non-users should also be taken into account.

Is there a relationship between the way men and women explore a route in a virtual environment and the way in which they report written directions? I found a significant correlation between visual scanning of landmarks and written references to landmarks. A post-hoc analysis revealed that this relationship was only significant for women’s data. While all participants viewed and made written references to landmarks, these results indicated that the relationship between the two was particularly close in women’s data.

As for the relationship between scanning of the compass and reporting cardinal directions, I found that the relationship was significant for all participants,
even when I analyzed men and women separately. These findings were a strong indication that the visual exploration of configurational elements was related to the use of cardinal information when writing directions.

*Is there a relationship between spatial abilities and route-learning strategies in a virtual environment?* To answer this question, I first sought to establish if men and women differed on two spatial abilities that have been implicated in route learning—*object location memory* and *mental object rotation*. I found that indeed women scored significantly higher than men on *object location memory* tests and men scored significantly higher than women on *mental object rotation* tests. A correlation analysis between these spatial abilities and measures of route-learning strategies (fixations and written references) yielded mixed results. There was a significant relationship between *object location memory* and the *number of written references to landmarks* only in women’s data. The direction of the relationship was negative, which was contrary to expectations. Further results revealed no significant relationship between *object location memory* and the *time fixating on landmarks* (%) for the two sample populations as a whole and separately. Taken together, the results suggest that women’s ability to accurately recall the location of objects comes into play after landmark information has been visually integrated, and the higher their abilities in *object location memory* the lower the number of landmark references they make. Nevertheless, the relationship between object location memory and topographic route-learning strategies was minimal.
I found a correlation between mental object rotation abilities and providing references to cardinal directions for men and women’s grouped scores, but I found no differences when I analyzed men and women separately. I did not find a significant correlation between mental object rotation and scanning of the compass when I analyzed the grouped scores and when I analyzed them by gender. There are two main implications in these findings. First, I have found further evidence that mental object rotation plays a key role in the mental manipulation of cardinal information. And second, mental object rotation abilities appear to come into play after environmental information has been visually integrated.

These results provide insight into how men and women process and utilize virtual route information from an egocentric perspective, as well as the possible mental operations involved in the process. In the discussion that follows, I provide further detail on the findings of this experiment. I also provide thoughts on its limitations and on topics of interest that could provide the basis for further research.

7.2 Topographic strategy discussion

7.2.1 The number of written references to landmarks

I found no support for the hypothesis that after learning a route in a virtual environment, women would make a greater number of written references to landmarks than men. Several studies have found support for this hypothesis in studies that used 2D maps (e.g., Choi & Silverman, 2003; Dabbs et al., 1998;
Galea & Kimura, 1993; and MacFadden et al., 2003). Whether their findings generalize to virtual and real environments is still open to question. While 3D virtual environments are artificial constructs like maps, they are characterized by properties found in the real world such as motion, depth cues, and motion. It stands to reason that such an environment might be more likely to elicit real-world route-learning behaviour. In this particular study, I found no differences between men and women in the reporting of landmarks. These findings contradict past research, but they are in line with Ward et al.'s (1986) reasoning that landmarks are a “frequent prop” in direction giving and no difference in their usage should be observed between men and women.

To illustrate participants’ responses to the written directions task, I selected one sample from a woman and a man. These direction-giving samples are not meant to be ‘typical’ or ‘representative’ of a specific sample population. The samples show some of the participants made references to landmarks (italics).

Female participant:

Go straight and pass the following
• CN Railway
• Somerset Ave

After Marina Restaurant on the right side turn left to 285 ave. Go straight until you reach general hospital on your right hand side then turn right.

Male participant
Go down Louis st, past Burger King, see Louis Apartments till you reach 189th ave. Turn right and enter the Apple Tree country lane (Don't turn onto Louis lane, keep going on Willis Rd).

These samples reveal a variety of strategies and devices that men and women used to provide directions. Some participants wrote directions using a conversational tone; others were brief in their descriptions and preferred creating a list of items. A review of the post-test interviews indicated that participants engaged in a variety of visualization and memory strategies to learn the route. For instance, some participants mentioned that they tried to visualize a map with the location of important items; visualize the shape of the route itself while focused on street names and important landmarks; visualize themselves moving along the route as it had be shown in the video; and even use mnemonic strategies such as pegging the name of landmarks or street to familiar songs.

In a few cases, participants altered their direction giving strategies across the routes, which suggested that learning the route was not a consistent process. For example, participants might have reported a large number of landmarks after viewing the first route, but on subsequent routes they reported streets or cardinal directions. Sometimes participants switched back and forth between different strategies. A review of the post-test interviews indicated that some participants were aware of their shift in strategies and also of their rationale for doing so. One participant, for instance, mentioned that when learning a route, he attended to the name of buildings initially, but he had trouble recalling them when he had to write down directions. So, when learning the following route, he decided to
attend to street names instead. Indeed, some participants mentioned that landmarks were distracting, too numerous, or not helpful in providing accurate directions, so they minimized their use as the session progressed. Other participants, however, found landmarks useful and easy to remember, particularly landmarks at intersections. Some participants mentioned that landmarks between intersections were only used as a way to tell others that they were following the right direction. Landmark familiarity was important for some participants, who preferred to make references to recognizable landmarks such as restaurant names, lampposts, and traffic lights. Again, we see evidence that the use of landmarks is not a straightforward homogenous process, but one that is dynamic and varied.

It is also possible that some other variable besides gender influenced the use of landmarks. Characteristics such as age, culture, driving experience, video game experience, education level, handedness, and so forth could have also influenced the responses. As far as I am aware, these are variables that have been rarely, if at all, investigated in the context of route learning. In MIS (management information systems) research, it is known that gender differences exist in the context of TAM (technology acceptance model) and social presence. However, as Cyr, Gefen, and Walczuch (2009) posit, other socially constructed factors may be more predictive of information technology usage. While I gathered information variables associated with socio-cultural dimensions, a proper statistical analysis was beyond the scope of this project. In Table 21, I show sample data for the average number of written references to landmarks.
based on whether the participant’s first language was English. Of the 60 participants tested, 33 mentioned that they spoke English as a second language. In almost every instance, participants who spoke English a second language made a greater number of references to landmarks. It is likely that participants who speak a second language find it easier to report landmarks than other direction-giving techniques in English, possibly masking any gender differences that may actually exist.

<table>
<thead>
<tr>
<th>Demographic variable</th>
<th>Sample population</th>
<th>Number of participants</th>
<th>Average number of written references to landmarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>English as first language</td>
<td>All</td>
<td>27</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>11</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>Men</td>
<td>16</td>
<td>2.6</td>
</tr>
<tr>
<td>English as second language</td>
<td>All</td>
<td>33</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>19</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>Men</td>
<td>14</td>
<td>2.9</td>
</tr>
</tbody>
</table>

The results showed that gender differences in the reporting of written landmarks are not significant when route learning takes place in a virtual environment seen from a first person perspective. This raises the possibility that differences found in previous experiments may be the results of the setting (usually maps) that were used to examine men and women’s route giving behaviour. Creating abstracted versions of real-world environments to study direction giving is an experimental necessity, but it may also be maximizing
differences that do not exist in the real or in virtual environments. Increasing the realism of the environment, as was done in this experiment, may diminish gender differences to the point of non-significance.

7.2.2 Time fixating on landmarks (%)

I found no support for the hypothesis that when learning a virtual route, women allocate a significantly greater proportion of fixation time on landmarks than men. These findings are in line with the results from McFadden et al.’s (2003) map-reading study. Moreover, given the lack of significant gender differences in the number of written references to landmarks (7.2.1), then it is reasonable to expect any gender differences in time fixating on landmarks (%) would also be insignificant. Figure 94 shows two sample screenshots of the session.
Figure 94: Sample of screenshots of eye-tracking session
Given the complexity of recording eye movements, it cannot be ruled out that some aspect of the experimental design influenced the obtained results. For instance, the basic eye movement unit of measurement in this study was fixation duration, defined as the point where a viewer’s line of gaze remained relatively still for 200 ms. As far as I understand, there is no consensus regarding any standard definition of fixation as it relates to route-learning behaviour. In setting the threshold of fixation time at 200 ms or more, I sought to minimize incidental fixations caused by artefacts in the environment, low-level sensory and perceptual events unrelated to route-learning, or the inaccuracies of our visual processing system. Furthermore, route learning demands a high level of attention that includes selecting, reading, memorizing, searching, identifying, and planning. As Rayner (1998) points out, when “we read, look at scene, or search for an object” our eyes remain fixed for at least 200 ms. Therefore, defining a fixation at 200 ms or more seemed, on the face of it, reasonable. Nonetheless, in spite of the reasoning behind the use of 200 ms as the fixation threshold for route learning, the measure is not standardized and inaccuracies can results if, for instance, a lower or higher fixation threshold is more appropriate to investigate route-learning processes. In future research, it would be important to determine how different fixation duration thresholds affect similar route learning tasks.

As reported, the data distribution for women violated parametric assumptions. In part, these violations resulted from two outliers who spent a lower than average time fixating on landmarks (%). Both participants also had
deviant scores on several other measures, including the *time fixating outside the main regions of interest (%)*; the *number of written references to cardinal directions*; *mental object rotation* test scores; and scores on the *object location memory* test. It is reasonable to assume that the high proportion of time they spent fixating outside the main regions of interest is one of the main causes for their low *time fixating on landmarks (%)*. I did not find any evidence of a technical or analytical error that may have resulted in deviant scores. For this reason, I opted to include these data.

One of the reasons why route-learning experiments are rarely performed in outdoor environments is because of the complexity of the natural environment. While a virtual environment is more easily controlled than a naturalistic setting, the complexity of virtual environments is also rather high. To minimize complexity in the experimental setting, I did not use any landmark textures, realistic architecture, colours, realistic scale, natural lighting variations, vegetation, and so forth. Yet, even though the landmarks appeared relatively simple, they may have possessed enough graphical complexity to attract fixations unrelated to route-learning processes. For instance, a participant may have fixated on a building not because he/she intended to use it a route-learning aid, but perhaps because he or she found it interesting or odd looking (Figure 95).
Another complex aspect of virtual environments includes the changes in size and position of objects during motion. As the camera travels along the route during a route-learning task, small objects in the distance grow in size until they cover a large portion of the participant’s visual field. Because of this, unintended fixations may fall on landmarks. I do not know of any research that has addressed this issue in the context of eye tracking.
Figure 96: Object transformation during egocentric motion. The same object covers different sized portions and locations of the visual field as the viewpoint moves along the route.
All landmarks were tracked through the use of Lookzones, which are line shapes that surround the target landmark. The LookZone creation process was not automated, and I needed to do it manually. Each LookZone consisted of several connected line segments around a landmark. Eye trackers, and the visual system in general, contain inherent degrees of inaccuracies and imprecision (typically less than 1 degree), so it was important to draw the LookZone approximately 40 pixels away from the outer edges of the landmark. As the camera moved forward during the trial, the landmarks in the environment changed position, size, shape, and orientation. These spatial transformations required repeated adjustments to the LookZone for the length of time that its associated landmark was visibly available. In some cases, only minor adjustments (such as resizing or repositioning the LookZone) were required. If the graphical transformations were significant, however, I had to reposition each of the points-joining two line segments- at least 40 pixels away from the landmark. This was done approximately every 0.2 - 0.5 seconds for each landmark along the 4 viewed routes. Still, in spite of my diligence, the LookZones did not always precisely encapsulate the landmarks, particularly when the object underwent drastic spatial transformations within short periods of time. No doubt, there were limitations to the manual creation of LookZones, yet as far I am aware, there are no precise and scientifically validated methods of “LookZoning” landmarks. The process is often influenced as much by the technical limits of the software as the patience of the researcher and as such still remains a limit in experiments within dynamic and complex environments.
Other possible sources of variability were the sample populations themselves. In section 7.2.1, I discussed demographic variables related to performance on written directions. For the landmark fixation data, I performed a rudimentary analysis of demographic variables, but I did not find many indications that scores on these variables may have influenced the results. There was a moderate increase in the *time fixing on landmarks (%)* by women who played over 5 hours of video games per week. This was not the case for men. Yet this observation should be interpreted with caution because the unequal number of participants (when ‘hours playing video games’ was used as grouping factor) did not permit to conduct a meaningful statistical analysis of the data. Interestingly, when I analyzed the data by language, I found that the 33 participants who spoke English as a second language spent a higher proportion of *time fixing on landmarks* (17.7%) than the 27 participants whose first language was English (16.3%). The 19 women who spoke English as a second language spent a higher proportion of *time fixing on landmarks* (18.3 %) than the 11 women who spoke English as a first language (15.8%). The proportion of *time fixing on landmarks (%)* spent by men who spoke English as a first language and men who spoke English as a second language was virtually identical (17.3 and 17.1 respectively). These results did not necessarily *indicate* that culture had a significant influence on the results related to the percentage of time that participants spent fixating on landmarks. They do, however, *suggest* that cross-cultural navigation strategies may have influenced eye movement strategies in virtual navigation.
In spite of the limitations of the experiment, however, there is no conclusion we can draw from the results other than there was no difference in the scanning of landmarks between men and women. Not only was this consistent with previous research using maps but also consistent with the results obtained in this experiment on the number of landmarks references, which did not reveal gender differences either. Further, as reported in the following section, the correlation between eye fixations on landmarks and references to landmarks was significant. Therefore, this evidence indicates that in fact scanning of landmark elements during virtual route learning does not differ between men and women. Further, given some of the similarities between the virtual environment in this study and real-world environments, it is also possible that visuo-attentional differences in the scanning of landmarks do not exist in the real world either. Men and women equally attend to topographic elements of their environment when learning a route.

7.2.3 Correlation between time fixating on landmarks (%) and the number of written references to landmarks

When I analyzed men and women’s topographic data as a single group, I found support for the hypothesis that the time fixating on landmarks (%) and the number of written references to landmarks were positively correlated. In past research MacFadden et al. (2003) did not find significant support for a correlation between fixation on landmarks and landmark references after a map-reading task. It is not possible to say why the results from both experiments are at odds
with one another, though it may be possible that differences in experimental settings (map vs virtual environment) led to differences in responses.

To further explicate the differences between men and women, I conducted a post-hoc analysis on the data by gender. I found a significant positive correlation between time fixating on landmarks (%) and the number of written references to landmarks for women’s data only. The reason for the correlation in women’s but not men’s data is unknown. Possibly, men’s eye movements were distributed over the environment for reasons other than route learning, thus masking any correlation with written references to landmarks.

The significant correlations between the time fixating on landmarks (%) and the number of written references to landmarks for the grouped data and for women’s data furthers our understanding of route learning in the following manner:

1. Direction giving has been thought to be an indication of the ‘cognitive map’ that is developed after route information has been visually attended and encoded in memory. The present results show that written references to landmark elements are consistent with how virtual landmarks were visually scanned.

2. The results in this study suggest that cognitive operations performed during complex tasks with complex stimuli can be derived from the eye movement record. In this case, processing landmark elements visually was positively associated with providing
references to landmarks, which occurred after these elements had been cognitively elaborated.

3. The significant correlation between scanning data and written references provide insight into aspects of ocular behaviour that should be considered when conducting eye movement research in virtual environments. For instance, set at 200 ms, the fixation duration was adequate enough to capture attentional behaviour related to a given route-learning strategy (landmarks in the present case).

4. The non-significant results for the men’s data shows that there may be exceptions to ideas presented in points 1, 2, and 3. It may be the case that some types of eye movements capture behaviours unrelated to the task at hand. Perhaps men and women differ in some other fundamental way (such as the speed at which they acquire visual information), which the experiment was not designed to discern.

While the present results suggest that eye movements and direction giving are related to a certain extent, a more precise examination of the issue is needed. Future studies should seek to confirm this relationship at more fine-grain levels of detail and within a variety of experimental designs. For example, researchers could investigate whether landmarks that receive more fixation duration are more likely to be reported in directions. The graphical characteristics of these features can be manipulated to more precisely discern the role they play.
in route learning. It is clear from the results of this study that much research is needed to better understand the relationship between eye movements and direction-giving strategies.

7.2.4 Correlation between object location memory and the topographic route-learning strategy

Consistent with previous research (McBurney et al., 1997; Silverman et al., 2007; Silverman & Eals, 1992; Tottenham et al., 2003), I found that women scored significantly higher than men on scores of the object location memory test. Dabbs et al. (1998) and others have proposed that since topographic strategies require the memorization of the position of salient objects in the environment, then spatial abilities related to memory for the location of objects might promote the use of topographic strategies. Thus, I hypothesized that the scores on the object location memory test would be correlated with both the number of written references to landmarks and the time fixating on landmarks (%). When I analyzed the data for all participants as a single group, I found no significant correlation between scores on the object location memory test and the number of written references to landmarks. When I analyzed the data by gender, I found a significant negative correlation between these variables, but only for women’s data. The negative correlation in women’s data is at odds with previous research, which found a positive correlation between the two variables in a map-reading task (Dabbs et al., 1998). It is possible that women with low scores on object location memory were not as confident in their directions and therefore utilized a higher than average number of landmarks as a compensatory strategy.
Those participants who scored higher than average on the object location memory test may have been more confident in their directions and only used the necessary number of landmarks. Future research can determine if women with higher than average scores are more accurate in their use of landmarks.

The lack of a significant correlation between men’s scores on the object location memory test and the number of written references to landmarks may be an indication that object location memory is not relevant to how they process route information. Route travellers may rely on a different ability to maintain a structured configuration of the topographic elements of the environment.

I performed a correlation analysis on scores of the object location memory test and the time fixating on landmarks (%). I did not find any significant correlations when men and women’s data were analyzed as a single group or when analyzed separately. Generally, these findings suggest that object location memory may not be highly involved in how men and women visually process landmark location information, but it may be involved in how women process routes after the information has been visually integrated\(^2\) (as shown by the negative correlation between object location memory and written references to landmarks). Alternatively, it may also be possible that object location memory is only one aspect of a more encompassing topographic navigation strategy that includes abilities such as being able to accurately recall objects and other characteristics beside relative location (e.g., orientation, saliency, familiarity, or

\(^2\) It should be noted that, although the finding was not significant, women’s scores on the object location memory test were negatively correlated to the time fixating on landmarks (%). The correlations between object location memory and route-learning strategies were also negative in the allocentric experiment but were not significant.
location relative to one’s self). Be that as it may, the present study did not find support for the hypotheses that object location memory would be correlated with fixations on virtual landmarks. Therefore, this spatial ability does not play a major role in the visual processing of topographic elements.

7.3 Discussion- configurational strategy

7.3.1 The number of written references to cardinal directions

I found no significant difference between men and women on the number of written references to cardinal directions after learning a virtual route. This finding is contrary to previous research in non-virtual environments (e.g., Galea & Kimura, 1993; Dabbs et al., 1998; Choi & Silverman, 2003; MacFadden et al., 2003; Rahman et al., 2005), and it indicates that gender differences in the use of cardinal directions are either non-existent in virtual environments or some aspect of the experimental design masked the differences.

To illustrate how participants reported cardinal directions (italics), I provide two samples of written directions from a woman and a man:

Female participant: Go west on Genessa. Turn left onto 285th st. The hospital is on the north-west corner of 285th and Kentick.

Male participant: Westbound on Genessa. Left at 285th (South). The hospital is at the intersection of Kentick and 285th, to your right (west side).

As can be seen in these examples, the two styles of providing cardinal directions differed between the two participants, though it is not possible to tell whether there is an association with gender. An analysis of gender styles in
providing cardinal directions was not the intent of this project. Nevertheless, informal observations suggested that patterns of style in providing cardinal directions do exist. For instance, many participants gave cardinal directions only at the beginning of the route, while others provided cardinal directions at key junctions. It may be useful in future research to investigate any stylistic differences between men and women in giving cardinal directions, as they may also indicate how the configurational elements of the environment have been structure in the mind.

A close examination of the cardinal directions data revealed asymmetrical distributions caused in part by the low number of participants who actually used cardinal directions. A total of 10 women and 11 men used cardinal directions, while the rest of participants made no references to them whatsoever. Given that the majority of participants made no references to cardinal directions, then participants who did make references to them appeared as outliers. In some instances, for example, the total number of references to cardinal directions provided by some participant was only 3 or 4 per route. Although seemingly reasonable, these scores were nevertheless flagged as extreme scores because many other participants made no such references at all. Thus, there appeared to be two separate populations within each sample.

Because of the bimodal characteristics of the distributions, I decided to conduct a post-hoc analysis using data only from participants who made references to cardinal directions. The almost equal number of men and women who made references to cardinal directions facilitated the analysis. I randomly
discarded one of the 11 men, so that each group consisted of 10 participants.

Applying a t-test, I found a significant difference between men and women on the number of written references to cardinal directions. On average, men made a greater number of references to cardinal directions than women. Given the post-hoc nature of this analysis, the results do not constitute conclusive evidence that there is indeed a gender difference on the use of cardinal directions. Nonetheless, the results of this analysis suggest that the results of the analysis when all participants were included may have resulted from the bimodal nature of the data. The analysis also helps to demonstrate what some researchers, such as Ward et al. (1986) and MacFadden et al. (2003), have observed in this type of study: Many participants do not spontaneously use cardinal references when giving directions. One way to remedy this issue is by explicitly instructing participants to use cardinal directions, but such instructions create a strategy bias (emphasizing the use of cardinal directions) and thus need to be considered carefully before applying them. Future research on the use of cardinal directions, and possibly other configurational strategies (e.g., use of metric distances), should take into account that unlike the use of landmarks, people do not spontaneously make references to cardinal directions.

As Ward et al. (1986) showed, men and women are equally able to use cardinal directions when instructed to do so. So the question of using cardinal directions over another direction-giving scheme is not one of ability but of strategy. What reason might there be in this experiment for participants not to use a cardinal direction strategy? Of those participants who chose to make
references to cardinal directions after viewing the route from an egocentric perspective, 10 were women and 11 were men. The results of the allocentric experiment (6.3.2) revealed that 7 women and 17 men chose to use cardinal directions. The changes in direction-giving behaviour between the two experiments, suggest that the point of view from which participants viewed the environment (egocentric vs allocentric) might have influenced the choice of strategy. To illustrate, Figure 97 shows a screenshot of the virtual environment viewed from an egocentric perspective.

**Figure 97: Virtual environment seen from egocentric viewpoint**

As can be seen, landmark information was located more or less on the central area of the screen and therefore at the centre of the participant’s visual field, which was the natural ‘resting’ place for his or her line of sight. By contrast, the compass was located on the upper right corner of the screen, and on the periphery of the participant’s visual field. A participant relying on the landmark strategy needed only to make short saccadic eye movements to either side of the road. A participant who wished to use cardinal directions needed to make longer saccades towards the compass on the upper right corner. While the relative distances were not particular large, a closer analysis of the strategies shows that
there may have been a cost (in cognitive resources) associated with the use of landmarks versus the compass, influencing a participant’s route-learning strategy.

Generally, the landmark strategy entailed searching for the relevant objects (e.g., buildings and parks); identifying the objects; and encoding their relative positions along the route for later recall. The strategy based on cardinal directions required detecting the compass; identifying the cardinal markers; and determining direction of travel by aligning the compass with the landscape. The latter step was made particularly difficult by the compass design in Google Earth. As seen in Figure 97, the compass only had a North indicator, but the South, East, and West indicators were missing. While an alternate version of the compass provided labels for the South, East, and West indicators, it covered a large portion of the visual field and occluded objects on the horizon, which was not optimal for eye tracking. So, I chose the compass with only the North indicator, but this compass required participants to mentally figure out the South, West, and West coordinates. Although this task is not particularly difficult on static maps, in an ever-changing virtual environment it becomes somewhat challenging.

The compass had an additional complexity. That is, once a participant had decoded the layout of the cardinal directions (NSEW), she or he needed to align these indicators with the horizontal layout of the landscape. When using a real compass in the physical environment, determining direction is easily accomplished because the relationship between the layout of the compass and...
the layout of the environment is coplanar. In this virtual environment, however, the planes of the compass and the landscape were perpendicular to each other, and further steps were necessary to bring the two into alignment. To demonstrate, in Figure 97 the ‘North indicator on the compass pointed towards the right side of the screen. Based on this information, the participant needed to figure out that West was denoted by the indicator point towards the top of the screen. Further, the participant had to align the “up” trajectory of the West indicator with the *forward* view of the landscape. This procedure needed to be repeated whenever the participant wanted to know direction of travel, particularly when changes in direction took place. This peculiarity of the compass was characteristic of the egocentric view. In the allocentric view (Figure 98) the planes of the compass and the landscape were parallel, making direction of travel easily discernable.

**Figure 98: Virtual environment seen from a top-down perspective**

![Virtual environment seen from a top-down perspective](image)

It is not possible to say with certainty whether these differences between the egocentric and allocentric views influenced route-learning behaviour. The
evidence does suggest that the frame of reference from which the environment was viewed influenced participant route-learning behaviour.

Although I did not conduct a formal analysis of the interview data, some of the responses to my queries demonstrate how participants used the compass. Some of them stated that using the compass was too complicated, especially when changes in direction occurred. Others made comments indicating that they had been “too busy looking at the road” to attend to the compass; using the compass provided too much unnecessary information; using left and right was easier than using the compass; and the compass did not “catch” their attention. While I cannot make any substantive claims based on this informal analysis, they suggest that participants found it difficult to use the compass to determine the direction of travel and may have opted for an easier strategy based on landmarks and relative directions (e.g., left and right).

Determining the geometric configuration of the environment in terms of cardinal directions is a difficult task because the route can only be seen in segments. A less demanding strategy would require remembering only the relative position (left or right) of objects and route segments. A number of participants mentioned that using left and right was easier than using the compass. So, it is conceivable that in light of the difficulty of figuring out cardinal directions, most participants opted for a topographic strategy based on landmarks and relative directions.

The results of this study did not support the notion that men and women differ in the use of cardinal directions in virtual environment viewed from an
egocentric perspective. There is no clear indication as to why these results were not in line with previous research. However, it may be the case that characteristics of the environment itself might have biased most participants towards a non-cardinal strategy. The similarities between this particular virtual environment and real-world settings also raises the possibility that gender differences that have been found in the literature in the use of cardinal directions may be a consequence of the artificiality of the testing environment itself and not of some natural difference inherent in men and women's cognition.

7.3.2 Time fixating on compass (%)

I found no significant differences between men and women on the time fixating on the compass (%). This finding was consistent with previous research conducted by MacFadden et al. (2003) on cartographic maps. These results were also consistent with the finding in this experiment that men and women did not differ in the number of written references to cardinal directions (7.3.1). Figure 99 shows fixations allocated to the compass as the viewpoint moves southward (top) and westward (bottom).
Figure 99: Fixations on the compass.
As discussed in section 7.3.1, the majority of participants did not make references to cardinal directions. So, I conducted an analysis of only those participants who had made references to cardinal directions. The results (5.3.7) showed that men spent significantly more time fixating on the compass than women. This demonstrates that when it comes to using configurational elements of the environment during virtual route learning, there is another level of complexity that needs to be taken into account. That is, a large number of participants do not use cardinal directions when not prompted to do so.

Although only 10 women and 11 men made references to cardinal directions, all participants allocated fixations to the compass. Why would a participant fixate on the compass if she or he had no intention of using cardinal directions? There may be several explanations for this behaviour. The design of the environment, for example, may have resulted in incidental fixations. The compass was part of the information layer located ‘on top’ of the 3D environment. While most route information (e.g., landmarks and labels) was located in the central area of the screen, occasionally during playback, some information overlapped with the compass region (e.g., Figure 100).
When information overlapped, it was not possible to determine with certainty whether the recorded fixation landed on the compass or the information behind it. On such occasions, I treated fixations to these regions as if they had been made to the compass. I made this decision because the compass was located on the topmost layer, so it made more sense that fixations in that location were compass related.

The allocation of fixations towards the compass, in spite of the lack of intention to use it, could also be explained by changes in strategy on the part of the participants. In the interview, some participants mentioned that they tried using the compass but found it too difficult to keep track of all the information along the route, so they chose not to use cardinal directions. If they tried to use the compass, then there was a high probability that they allocated fixations to it. Another possibility is that that participants simply looked at the compass out of
curiosity and not because of any route-learning strategy. Unfortunately, it was not possible to determine why participants fixated on the compass even though they did not intend to use a cardinal strategy.

While there were no significant differences between men and women on the proportion of fixation time allocated to the compass, a more targeted analysis of the 20 participants who made references to cardinal directions indicated that men spent a significant greater percentage of time fixating on the compass than women. These findings seem to indicate that the data had bimodal characteristics, which did not permit an appropriate statistical analysis. As with the analysis on cardinal directions, there is a suggestion that the use of configurational elements is not a common strategy and few people may rely on it. Future research into this area needs to take into account this complexity to get a better understanding of how we process configurational information of the environments. The results reported here, however, indicate that men and women do not differ on how they scan the compass in a virtual environment. These findings also include the possibility that in the real world men and women do not differ in the manner in which they distribute attention to learn the configuration of the environment.

7.3.3 Correlation between time fixating on the compass (%) and the number of written references to cardinal directions

I found a significant positive correlation between the time fixating on the compass (%) and the number of written references to cardinal directions when the two sample populations were analyzed as a single group and separately.
The longer a participant (man or woman) scanned the compass, the higher the frequency of his or her references to cardinal directions. MacFadden et al. (2003) found such a correlation in map reading, but only in women’s data. It is possible that the difference between their results and mine stem from the differences in the environmental format (cartographic map vs. virtual environment). A traditional map displays the entire layout of the route and surrounding environment. To learn the geometric layout of the map environment, a navigator only needs to allocate fixations on the route cues, without the need to ‘travel’ the route. Under such conditions, the navigator gleans the cardinal coordinates of the environment by scanning the compass, which is static and typically aiming its North indicator towards the top of the page. In contrast, a virtual environment, seen from an egocentric perspective is encountered piecemeal, so a navigator learns its layout mainly by travelling through it. Like the compass in a static map, the virtual compass delineates the Euclidean configuration of the environment. Yet unlike a map compass, the virtual compass may require constant visual vigilance as the navigator travels along the route and changes in direction take place. Of course, it is possible that a virtual navigator might learn the cardinal structure of the environment without the need to constantly allocate fixations to the compass. Yet, this strategy is more complex and difficult to implement in a dynamic virtual environment. So, it is likely that constant vigilance of the compass must be maintained to learn the geometric configuration of the virtual route. Thus, the correlation between scanning of the environment and providing cardinal directions is stronger.
Whether the correlation between scanning of configurational cues and reporting cardinal directions exists when travelling along real-world routes is open to question. In the natural world, we use a variety of cues to determine the cardinal coordinate system. We may use such cues as the location and orientation of distal cues like mountains, the grid-like layout of streets, and other subtle cues like the geometry of rooms (e.g., location of windows). Thus in the real world, constant visual fixations to configurational cues are not necessary to learn the cardinality of the space, especially since these cues are often salient enough to be observed peripherally or experienced kinaesthetically (e.g., left or right of one’s egocentric frame of reference). This is not the case in a virtual environment. The interactive, graphical, and embodied constraints within a desktop-based virtual environment require that a navigator consistently allocate visual attention to the graphical objects that provide configurational information— the virtual compass being one of the most important. Therefore, a correlation between fixations and written directions may be more direct in a virtual environment than in the real world.

Theoretically, one of the key aims of this research was to understand how virtual routes are processed and encoded by our sensory and cognitive systems. Eye movement and direction-giving paradigms do not necessarily provide a direct view into the cognitive maps developed during and after virtual route learning. Indirectly, however, a correlation between these two factors offers a glimpse into the sensory processes and cognitive operations at work when a navigator learns a route. At the sensory level, route information related to the
configurational elements of the environment must be held under visual scrutiny during travelling to integrate it into a cognitive map. The results obtained in this study, show that the longer the compass information is visually attended, the more likely that it will be referenced in written directions. Though, it should be kept in mind that compass fixations do not necessarily cause the reporting of cardinal directions and vice versa. Yet a positive correlation does exist, indicating that it is possible to know the type of strategy that navigators apply when learning a route by examining the eye movement record. Conversely, direction-giving strategies, as gleaned from the written record, are good indications of how the compass information was visually attended during travelling. Further, the results indicate that integration of cardinal coordinates into the cognitive map is not the merely the result of post-visual processes but also of sensory and perceptual operations taking place at the moment the virtual route is visually scanned.

The significant correlation between compass fixations and cardinal directions references demonstrated that participants did not solely rely on local information (e.g., landmarks and left-right transpositions at intersections) to construct a configurational model of the route. Instead, they actively sought to extract cardinal information from the compass, which mapped onto a world-wide coordinate systems. In practical terms, these findings suggest that the design of a virtual environment should contain the cues that will more efficiently and effectively aid the navigator in building up a cognitive model of the environment’s geometric configuration. Navigators willingly spend attentional resources to
encode world-coordinate data from compass (and possibly other sources), and so the design of the virtual environment should help maximize the sensory, perceptual, and cognitive resources allocated to these mental operations during route learning.

7.3.4 Correlation between mental rotation and the configurational route-learning strategy

On average, men scored significantly higher than women on the mental object rotation test. This finding was consistent with previous literature on spatial abilities related to mental rotation of visualized objects (Voyer et al., 1995). It has been proposed that mental rotation may be associated in the processing of environmental information in general (e.g., Aretz & Wickens, 1992; Galea & Kimura, 1993; Lanca, 1998; and Silverman et al., 2000) and the use of cardinal directions in particular (Dabbs et al., 1998; Rahman et al., 2005). To test this idea, I performed a correlational analysis between mental rotation scores and references to cardinal directions. When I analyzed all participants as a single group, I found a significant correlation between scores on the mental object rotation test and the number of written references to cardinal directions. The correlation was not significant when I analyzed women and men’s data separately. This indicated that while mental object rotation was positively related to the use of cardinal directions, men and women might not differ in this respect. Even though men scored significantly higher than women on the mental rotation test, it was not possible to determine whether mental rotation was associated with a more effective and efficient implementation of a route-learning strategy.
That is, does a higher score in mental rotation increase the accuracy and precision of the reported cardinal directions?

When investigating the relationship between mental rotation and visual scanning of the environment, I found no significant correlation between scores on the mental object rotation test and the time fixating on the compass (%). This was the case when I analyzed the two sample populations as a single group and when I analyzed men and women’s data separately. I am not aware of any studies that have conducted this type of analysis, so it is not possible for me to determine whether these findings are consistent or not with previous literature. The results suggest that if there is a functional relationship between mental rotation and cardinal information, it is activated after virtual route information has been visually processed.

If mental rotation was not associated with viewing the compass in a virtual environment, then other spatial mechanisms may underlie the process of structuring cardinal information in the mind. Or perhaps developing a mental model of the cardinal virtual space was not a simple matter of fixating on the compass, but involved other operations that came into play after all pertinent elements (e.g., landmarks, compass, and direction of motion) had been visually processed. In Figure 101, for example, the participant made repeated saccadic jumps between elements along the road and the compass. By combining these elements in the mind, the participant might have been able to determine direction of travel from a cardinal frame of reference. This process of repeated saccadic
jumps between the environment and the compass may be more closely
associated with mental rotation than compass fixations alone.

**Figure 101:** Fixations on route elements and saccadic eye movements towards the compass.

The precise operations involved in the use of mental rotation for route
learning are unknown. Researchers have proposed that this spatial ability is
used in order to align the frames of references associated with different
viewpoints in the environment. Lanca (1998), for instance, posits that the
reading of contour maps requires the mental visualization of the terrain. This
mental visualization is then manipulated (i.e., rotated) to examine the
environment from different perspectives. This operation is similar to the mental
manipulation required to solve mental object rotation tests. Aretz and Wickens (1992) postulate that when two different frames of references (e.g., egocentric and allocentric) are misaligned, mental rotation abilities are engaged in the congruence of the frames of reference. For instance, an egocentric forward view may have to be mentally aligned with a world-referenced frame through the use of mental rotation. Conversely, the allocentric reference frame may have to be transformed and brought into alignment with the egocentric reference frame-a process that may also require the use of mental rotation abilities (Aretz and Wickens, 1992; Aubrey and Dobbs, 1990). Beyond map reading, researchers have also proposed that navigation through a realistic environment requires the ability to develop and update a “bird’s-eye view” of the route (Dabbs et al., 1998; Silverman et al., 2000), including virtual routes (Moffat et al., 1998). The task of maintaining the integrity of the space, as Silverman et al. (2000) propose, may require the use of mental rotation as well. In the present study, I found no relationship between mental rotation ability and compass scanning. Yet, the relationship between mental rotation and reporting cardinal directions was significant. Together, these findings suggest that mental rotation is primarily utilized to determine the cardinal space of the virtual environment after, not during, the processing of route information. Though the possibility still exists that some unknown visual process may require the use of mental rotation abilities during route learning.
7.4 Discussion- summary

In this study, I aimed to examine the relationship between gender, virtual route learning, and associated spatial abilities. Route learning is a process that engages a host of sensory, perceptual, and cognitive operations. Investigating route learning in naturalistic settings is fraught with difficulties, and much remains unknown about the strategies and mental operations involved in the process. Virtual environments afford us the opportunity to investigate route learning within pseudo-realistic settings that can be designed to resemble natural environments or more abstract spaces. Yet while research using virtual environments appears to have increased in recent years, the specific factors involved in route learning are not fully understood.

I found no significant differences in the amount of time participants spent looking at landmarks and no differences in the number of written references to landmarks. The scanning of landmarks was significantly correlated with the number of written references to landmarks. A post-hoc analysis revealed that the correlation was significant for women’s but not men’s data. Bearing in mind the technical, theoretical, and experimental limitations discussed in the preceding sections and Chapter 9, these results imply that men and women equally utilized the topographic strategy scanning the environment and when giving directions. Visual scanning was correlated with references to topographic elements, particularly for women.

Analysis of variables related to the utilization of a configurational strategy yielded not significant differences between men and women on the scanning of
the compass and on the number of references to cardinal directions. These data, however, contained unusual distribution characteristics, which resulted from the fact that the majority of participants—men and women—did not make any references to cardinal directions. Closer examination of the data revealed that there were two distinct groups within each sample population. One group used cardinal directions and the other did not. *Post-hoc* analysis of only those participants who made references to cardinal directions revealed significant gender differences. Men looked at the compass significantly longer than women, and men also used a higher number of cardinal directions than women. Taken together, the findings yielded ambiguous answers about whether men and women differ in the acquisition and use of configurational route knowledge. On the one hand, no significant differences were found in the sample population as a whole. On the other hand, the configurational strategy was used only by handful of participant within the sample populations, suggesting that the configurational strategy might not be commonly utilized during route learning.

A correlation analysis revealed that the participants’ proportion of time scanning the compass was significantly related to a higher number of references to cardinal directions. This finding held even when a *post-hoc* analysis was conducted on men and women’s data separately. The results provide further evidence that perceptual and cognitive operations related to the processing of cardinal information within virtual environments can be gleaned from the eye-movement and direction-giving record. Moreover, they strongly indicate that the
operations involved in the extraction of cardinal information from the route are engaged during and after the visual processing of the route.

The nature of spatial abilities associated with virtual route learning has not been thoroughly explicated, and I sought to understand the extent that some of these abilities were associated with route-learning strategies. Researchers have proposed that the use of a topographic strategy is related to a navigator’s ability to remember the location of objects (e.g., Dabbs et al., 1998). Therefore, I hypothesized that there should be a significant correlation between scores on the object location memory test and the two measures of topographic strategy (eye fixations and written references). Yet, I only found a significant relationship between object location memory and written references to landmarks in women’s data. The relationship was negative, indicating that high scores on the object location memory test were correlated with lower numbers of written references to landmarks. Analysis of the relationship between object location memory abilities and the proportion of time that participants fixated on landmarks did not yield significant results. These findings showed that object location memory abilities were related to the way that women gave directions after they had visually integrated the virtual landmarks. Further demonstrating that even though men and women did not differ in the actual implementation of the topographic strategy, they differed in how mental abilities were employed in the processing of virtual landmarks.

Researchers have also proposed that the configurational strategy requires the visualization, alignment, and consistent maintenance of multiple frames of
reference (e.g., egocentric and allocentric), which is a task similar to the manipulation of visualized 3D figures (as measured with the mental object rotation test). Since mental object rotation abilities are thought to mediate the processing of configurational knowledge, I hypothesized that there would be a correlation between scores on the mental object rotation test and measures of configurational strategies (compass fixations and cardinal direction references). The relationship between mental rotation abilities with the number of references to cardinal directions was significant when all participants were analyzed as a single group but not when they were analyzed separately by gender. I found no significant relationship between mental rotation and compass fixations. It may be the case that mental rotation only comes into play after cardinal information has been visually integrated. This finding is similar to the significant correlation between women’s object location memory and the number of written references to landmarks. In general, spatial abilities are not significantly correlated with the visual integration of routes, but to a small extent they are associated with the production of written directions.
8: EXPERIMENT 2- ALLOCENTRIC VIEWPOINT
DISCUSSION

8.1 Overview

In this experiment, I applied the exact experimental procedure as in the egocentric viewpoint experiment, but I changed the camera angle so that participants viewed the route from an allocentric perspective. This view shares similarity with traditional cartographic maps, which present route information from a top-down viewpoint. Unlike maps, however, the virtual environment was seen in parts because the camera showed only portions of the route at any given time. In this chapter, I present the results of the allocentric study and discuss them in the context of the research questions and hypotheses. Where appropriate, I compare the results of this study with those obtained in the egocentric viewpoint experiment.

*Do men and women differ in the strategies they rely on when giving directions?* The results of the analysis comparing men and women’s responses in the number of written references to landmarks showed that women made a greater number of references to landmarks and the difference trended towards significance. Indirect evidence suggests that the viewpoint from which the environment was viewed may have altered the strategies that the participant used to learn the route, thus potentially increasing the difference in the number of references to landmarks between men and women. Men seemed to have relied
more on the topographic strategy in the egocentric viewpoint experiment than in the allocentric viewpoint experiment, resulting in a smaller difference between men and women. The findings were in closer alignment with established research in which men and women have been found to differ in their use of landmarks.

*Do men and women differ in the visual scanning strategies they use to learn a route in a 3D virtual environment?* Men and women significantly differed in the *time fixating on landmarks (%)*. Women allocated a greater proportion of fixation time on landmarks. This provides further evidence that the trend towards significance found in landmark references was not merely an anomaly. The difference also demonstrates a key element of virtual route learning: Differences in the use of a landmark strategy in allocentric frames of reference begin at the moment in which the virtual route is processed.

*Is there a relationship between the way men and women explore a route in a virtual environment and the way in which they report written directions?* I found a significant positive correlation between the *time fixating on landmarks (%)* and *number of written references to landmarks*. This correlation was significant when I analyzed all participants as a single group and when I analyzed them separately. In the egocentric viewpoint experiment, the correlation was significant when I analyzed participants as a single group. When I analyzed the data by gender, I only found a significant correlation between the two variables for women’s data. Nonetheless, the combined evidence from the two
experiments showed that generally visual scanning of landmarks is associated with providing written references to landmarks.

*Is there a relationship between spatial abilities and route-learning strategies in a virtual environment?* I tested two spatial abilities—*object location memory* and *mental object rotation*. Women scored significantly higher than men on scores of the *object location memory* test. I found no significant correlations between scores on the *object location memory* test and the *number of written references to landmarks* when I analyzed men and women as a single group and separately. I did not find a significant correlation between scores on the *object location memory* test and the *time fixating on landmarks (%)* when I analyzed men and women as a single group and separately. Therefore, spatial abilities associated with memory for the location of objects was not associated with the use of a topographic strategy.

Men scored significantly higher than women on the *mental object rotation* test. This spatial ability was not significantly correlated to the *number of written references to cardinal directions* when I analyzed men and women as a single group and separately, though women’s correlation between the two variables approached significance at *p = .056*. When I analyzed the scanning data for all participants, I found a significant correlation between scores on the *mental object rotation* test and the *time fixating on the compass (%)*. I did not find a significant correlation when I analyzed men and women separately. Generally, the results of the study showed that mental rotation was not associated with the use of a configurational route-learning strategy, but this spatial ability was related to visual
scanning of the compass. Although men and women differed significantly in mental rotation abilities, there were no gender differences in correlations between mental rotation and route-learning strategies.

Viewing the route from an allocentric perspective yielded results that were in alignment with theorized expectations. Men and women differed in their use of cardinal directions and, to some extent, references to landmark; they differed in their scanning behaviour of landmarks and the compass; their visual scanning strategies correlated with their direction giving strategies; and aside from a few significant results, the relationships between spatial abilities and route-learning strategies were generally not extensive.

8.2 Discussion - topographic strategy

8.2.1 The number of written references to landmarks

On average, women made a greater number of references to landmarks when providing written directions, and the results trended towards significance. In the egocentric experiment, participants viewed the environment from a first-person perspective. In that experiment, men made a greater number of references to landmarks than women, but the difference was not significant. In the allocentric experiment, participants viewed the environment from a top-down perspective and women made a greater number of references to landmarks with the results approaching significance. The top-down perspective lacks many of the depth cues found in an egocentric frame of reference, and it is more map-like in appearance. The similarities between the top-down perspective of the virtual
environment and typical cartographic maps may be one of the reasons why the results of this experiment are in closer alignment to previous research (e.g., Choi & Silverman, 2003; Dabbs et al., 1998; Galea & Kimura, 1993; and MacFadden et al., 2003).

The following quotes were taken from two participants and illustrate how participants provided landmark directions (italics).

Female participant

- At Mercy Elementary go straight until you pass the high school, when you reach 282 st turn right and go straight you’ll pass a burger king on your left. Just keep going straight until you hit Brayer st. Turn left on Bryer until you hit 128, turn left on 128, you’ll come across the airport and then stop.

Male participant

- Drive straight up street
- Left at shell gas station
- Right at ABC Restaurant
- Straight up Kentick Ave
- Arrive at Oyster Race Track

These samples are not necessarily representative of any differences between men and women. All participants regardless of gender varied in strategy. The written direction samples show that some participants preferred to
use a conversational tone while others prefer to describe the route using a list-like approach. I have not conducted a formal analysis of direction-giving styles between men and women, but some of the responses to interviews questions revealed information that is useful in understanding how participants approached the route-learning task. Some women mentioned that they started using landmarks at the beginning of the route but found them difficult to remember, and so they decided to memorize street names instead. Eventually some of them settled on a mixed strategy of using landmarks and streets, along relative directions (left and right). Some women mentioned that there were too many landmarks and so they used them as secondary aids, particularly at the beginning of the route and at crossroads. Other women mentioned that turns in orientation were disorienting and made it difficult to remember the layout of the route. A strategy that some women used to remember the route was visualizing the shape of the road like a “picture.” Among men, some found that landmarks were a challenge to remember, distracting, and not helpful, so they altered their route-learning strategy. They tried to memorize significant (e.g., hospital) or familiar landmarks (e.g., Burger King). They used several strategies to remember the route, including the creation of mental maps, mnemonics, or repeating the names of streets and buildings in the sequence that they encountered them. I cannot make any quantitative claims as to whether or not there were differences in the styles that men and women approached direction giving. Yet, it was clear that all participants used a variety of strategies to learn the virtual route.
Unlike the egocentric experiment, women’s data distribution did not meet assumptions of normality, but aside from an outlier who scored relatively high in the number of written references to landmarks, there was nothing to indicate any abnormal responses. Nonetheless, theoretical (e.g., landmark definition), experimental (e.g., lab setting), and technical limitations (e.g., eye tracker accuracy) may have influenced the results (see Chapter 9 for a discussion). These limitations of the experiment should be taken into account when interpreting the results.

There were demographic factors besides gender that may have influenced participants’ performance. It was not possible to conduct a thorough investigation of these demographic factors, but in Table 22, I report differences in the language spoken by participants. To compare with previous findings, I added results from the egocentric view experiment in brackets. While descriptive data did not allow me to make any definite statements about the results, it is interesting to note that there was a level of consistency in the findings. In both experiments, participants who spoke English as second language were more like to make references to landmarks than participants whose first language was English. Time limitations did not allow me to delve deeper into the influence of demographic variables on direction-giving performance, but this area requires further exploration in route learning research.
Table 22: Demographic data related to the number of written references to landmarks

<table>
<thead>
<tr>
<th>Demographic variable</th>
<th>Sample population</th>
<th>Number of participants</th>
<th>Average number of written references to landmarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All</td>
<td>26 (27)</td>
<td>2.2 (2.5)</td>
</tr>
<tr>
<td>English as first language</td>
<td>Women</td>
<td>9 (11)</td>
<td>2.8 (2.2)</td>
</tr>
<tr>
<td></td>
<td>Men</td>
<td>17 (16)</td>
<td>2.0 (2.6)</td>
</tr>
<tr>
<td>English as second language</td>
<td>All</td>
<td>34 (33)</td>
<td>2.6 (2.7)</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>21 (19)</td>
<td>3.0 (2.6)</td>
</tr>
<tr>
<td></td>
<td>Men</td>
<td>13 (14)</td>
<td>2.1 (2.9)</td>
</tr>
</tbody>
</table>

Note. The values enclosed in brackets are results from the egocentric experiment.

The results related to the frequency of references to landmarks showed that women made a greater number of references to landmarks than men, and this difference approached significance. This finding is in closer alignment to past research than the findings in the egocentric experiment. Given that previous studies have used maps, which present information allocentrically, then these similarities in perspective between the allocentric viewpoint in virtual environments and maps may be the reason for the similarity in results.
8.2.2 Time fixating on landmarks (%)

I found a significant difference between men and women in the time fixating on landmarks (%). On average, women spent a greater proportion of time fixating on landmarks. This finding is contrary to the non-significant results found in the egocentric experiment. In the egocentric experiment, landmarks looked somewhat realistic because they were viewed from a ground-level viewpoint. Besides realistic geometry, the landmarks in the egocentric experiment underwent changes in size and shape as the camera moved along the route. In the present experiment, the allocentric view only permitted the participants to view the top of landmarks, which were characterized by relatively simple geometry (Figure 102).

Figure 102: Fixations on the environment seen from a top-down perspective.
The landmarks seen from an allocentric viewpoint did not undergo dramatic changes in size or shape when the camera moved along the route. It is possible that the viewpoint in the egocentric experiment made it more likely that participants would look at landmarks for reasons other than route learning. In the allocentric view, the architecture of the buildings was simpler and may not have attracted attention beyond what was necessary to complete the route-learning task. Moreover, the consistency of landmark size and shapes made it less likely that the tracker captured “accidental” fixations. In a sense, the data in the allocentric experiment may be “cleaner” than in the egocentric experiment.

Figure 103: Landmarks retained their shapes and sizes as the viewpoint moved along the route.
Other aspects of the top-down perspective may have elicited different responses in men and women. For instance, the allocentric perspective may have increased reliance on landmark by women. Men, on the other hand, may have minimized a landmark-based strategy while increasing their use of an alternate configurational strategy. Examination of the data revealed that the number of women using cardinal directions decreased in the allocentric experiment, but the number of men using cardinal directions increased in the allocentric experiment. This demonstrates that a shift in strategy may have accounted for the gender differences in the scanning and use of landmarks between the two experiments.

As far as I understand, this is the first instance in which gender differences in visual scanning of landmarks have been found. The simple nature of the top-
down environment may have yielded metrics that were less prone to technical errors resulting from complex geometrical transformations of route elements. So, it is possible that the allocentric viewpoint permitted the eye tracker to capture “purer” route-learning behaviour related to landmarks. Yet, it may also be the case that differences in frame of reference elicited differences in landmark fixations. Why would this be the case? Indirect evidence suggests that the results of this study may have been caused by the shift in route-learning strategy that occurred as a consequence of viewpoint. In particular, men shifted away from a landmark strategy to a cardinal strategy. The number of women using cardinal directions decreased and for this reason they may have relied more on landmarks. Having found significant gender differences in the scanning of landmarks within a virtual route, I believe that this area of research require further investigation to determine whether the results extend to other types of virtual environments and tasks.

8.2.3 Correlation between time fixating on landmarks (%) and the number of written references to landmarks

I found a significant positive correlation between the time fixating on landmarks (%) and the number of written references to landmarks. The longer a participant fixated on landmarks the greater the number of references to landmarks. I found a significant correlation when I analyzed men and women as a single group and when I analyzed them separately. In the egocentric experiment I found a significant correlation when I analyzed men and women as
a single group, but when I analyzed them separately, the correlation was only significant for women's data.

These results provide further evidence that the differences between men and women in the use of a topographic strategy represent an encompassing set of operations that include the visual processing of landmarks and direction-giving strategies. In other words, differences in the use of landmarks are not solely the end result of a post-attentional cognitive operation but it is also related to visuo-attentional strategy at the moment that the virtual route is travelled (at least when seen from an allocentric frame of reference). The results also provide further validation for the use of eye tracking system to glean complex cognitive operations from the eye movement record, particularly the extraction of useful topographic information. They also strengthen the rationale for using the direction-giving paradigm to understand how participants may have perceptually processed the routes.

8.2.4 Correlation between object location memory and topographic route-learning strategy

Consistent with the results in the egocentric view experiment, as well as previous research (McBurney et al., 1997; Silverman et al., 2007; Silverman & Eals, 1992; Tottenham et al., 2003;), women scored significantly higher than men on the object location memory test. I hypothesized that scores on this test would be positively correlated to the number of written references to landmarks and the time fixating on landmarks (%). I did not find a significant correlation between scores on the object location memory test and number of written references to
landmarks when men and women were analyzed as a single group and separately. The correlation between scores on the object location memory test and the time fixating on landmarks (%) were not significant when women and men were analyzed as a single group and separately.

The results indicate that the spatial ability associated with one’s ability to remember the location of objects is not particularly associated any route learning strategy. It may be that object location memory is part of a more complex strategy. After all, when providing directions based on landmarks, it is necessary to remember the location of those landmarks in relation to each other and in relation to the route.

8.3 Discussion- configurational strategy

8.3.1 The number of written references to cardinal directions

On average, men made a significantly greater number of written references to cardinal directions than women. Unlike the non-significant results in the egocentric viewpoint experiment, the significant results in the allocentric viewpoint experiment were consistent with prior research (Choi & Silverman, 2003; Dabbs et al., 1998; Galea & Kimura, 1993; MacFadden et al., 2003; Rahman et al., 2005). However, it should be noted that just like in the egocentric experiment, most participants in the present study did not spontaneously make reference to cardinal directions. Seven women and seventeen men made references to cardinal directions. Given the great disparities between men and women in the number of participant who made references to cardinal directions, I
opted not to do a further analysis of only those participants who made references
to cardinal directions as I did in the egocentric viewpoint experiment. As
discussed, these results showed that in the allocentric experiment more men
made references to cardinal directions and a lower number of women did so.
This suggests that participants, men in particular, shifted their direction-giving
strategies in the allocentric viewpoint experiment to emphasize configurational
elements. Just why this might have been the case is not possible to tell.

I have selected two samples from a woman and a man in which they make
references to cardinal directions (italics).

Female participant

- Drive west down Genessa drive and continue past the intersection
down Pickwick Avenue. It should change back to Genessa Drive.
- When you reach 285 st, turn left. There should be a Texaco gas on
  your right.
- Once you reach the hospital, turn right.

Male participant

West on Louis St.

Follow until it turns into Willis st

Turn right heading NW

On Apple Grove

On the right.
The two quotes demonstrate how some participants approached the configurational strategy. The female participant used the cardinal point (west) only at the beginning of the route. Both women and men relied on this particular strategy. Notice how the directions also contain redundant information. For instance, the female participant wrote the directions “drive west down”, even though the word “down” is not necessary. This redundancy was a common device used by participants from both sample populations. The sample from the male participant shows that he used cardinal directions at the beginning and later in the route. This strategy was not gender specific as both men and women were inclined to use it.

The post-test interviews revealed that some women saw the compass but chose not to use it. They mentioned that it was too much information to keep track of, it was unnecessary or unimportant, not useful, confusing, and alternate strategies were easier (e.g., streets). Some of them mentioned that they never think in terms of cardinal directions, which one participant equated with being “bad with directions”. Some women used the compass at the beginning but then they gave up. Others used them throughout the sessions because they found the compass useful to “get their bearings” or thought that cardinal directions were more “globally recognized”. One international participant mentioned that in the Ukraine the roads wind and twist, so it is not effective to use cardinal directions. The extent to which cultural background influences the use of cardinal directions is unknown but an interesting area for future research.
Some men did not use the compass because they found it confusing, particularly because it rotated whenever a change in direction took place. Several participants in the egocentric viewpoint experiment made similar comments, demonstrating that this strategy was particularly difficult to implement. Other participants indicated that they were focusing on the center of the screen so the compass did not enter their attention. Some said they preferred alternate strategies such streets or left-right directions. Others mentioned that they usually did not use cardinal directions in real life. Some men indicated that they had tried using the compass at the beginning of the trials but they altered their strategy later. The participants who used the compass mentioned that it helped them orient themselves, particularly at the beginning of the route. Other participants did not see the compass at all or saw it at the beginning of the trials and then forgot that it was there as the session went on.

Gender was the main variable of interest in the present experiment, but gender was only one of several factors that may affect direction-giving strategies. As in the discussion of the results in the egocentric viewpoint experiment, I report descriptive data on the use of cardinal directions when the participants’ language (Table 23). The numbers in brackets represent values from the egocentric viewpoint experiment. Interestingly, the values remained relatively consistent across the two experiments. The language date showed that participants who spoke English as a first language made more references to cardinal directions. I must emphasize that I have not conducted a proper statistical analysis of these data and the results may not hold statistical significance. Differences at this level
of detail should be viewed with suspicion because of the low number of participants who made references to cardinal directions, yet they serve to illustrate some demographic factors may also influence direction-giving strategies.

Table 23: Sample demographic data related to the number of written references to cardinal directions

<table>
<thead>
<tr>
<th>Demographic variable</th>
<th>Sample population</th>
<th>Number of participants</th>
<th>Average number of written references to cardinal directions</th>
</tr>
</thead>
<tbody>
<tr>
<td>English as first language</td>
<td>All</td>
<td>26 (27)</td>
<td>0.6 (0.5)</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>9 (11)</td>
<td>0.4 (0.1)</td>
</tr>
<tr>
<td></td>
<td>Men</td>
<td>17 (16)</td>
<td>0.7 (0.7)</td>
</tr>
<tr>
<td>English as second language</td>
<td>All</td>
<td>34 (33)</td>
<td>0.3 (0.2)</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>21 (19)</td>
<td>0.1 (0.2)</td>
</tr>
<tr>
<td></td>
<td>Men</td>
<td>13 (14)</td>
<td>0.5 (0.3)</td>
</tr>
</tbody>
</table>

Note. The numbers in brackets are the values for the egocentric viewpoint experiment.

The analysis of cardinal directions data yielded significant differences between men and women. Men made a greater number of references to cardinal directions than women. However, as in the egocentric viewpoint experiment, most participants did not make any references to cardinal directions. Nevertheless, the evidence does seem to indicate that there is a genuine difference between men and women in the frequency with which they report
cardinal directions after learning a virtual route, but further experimentation is required to settle the question in a definite manner.

8.3.2 Time fixating on the compass (%)

Men allocated a significantly greater proportion of fixation time on the compass than women. While this is consistent with the gender differences in the use of cardinal directions discussed in the previous section, it is not consistent with the results found in the egocentric viewpoint experiment. Yet, the significance of this test provided further evidence that gender differences in the use cardinal directions may be a real phenomenon, at least when the route is viewed from an allocentric viewpoint. Figure 104 show examples of participant’s fixations on the compass.
The fixation data were non-normal, so I employed a non-parametric test to conduct the analysis. Only 24 participants out of 60 made references to cardinal
directions, yet only 3 participants did not fixate on the compass. This means that some of the fixations that landed on the compass were not necessarily the result of a route-learning strategy. They might have been incidental fixations associated with the proximity of the compass indicator to other features of the route such as landmarks. While it is not possible to tell if a given fixation on the compass was part of a strategy to extract cardinal information or the consequence of some other unrelated process, the aggregate duration of all fixations on the compass is likely the result of self-directed compass viewing.

Unlike the compass in the egocentric viewpoint experiment, the compass in the allocentric experiment was easier to read. There was no ambiguity about which direction represented a particular cardinal point because the cardinal plane and the surface of the landscape were parallel to each other. In the egocentric experiment, to denote the forward direction, the compass pointed towards the top of the frame that encapsulated the environment. The participant had the added task of bringing the compass reference frame into alignment with the egocentric reference frame. This difference between allocentric and egocentric viewpoints may be one of the reasons why men increased their use of cardinal directions in the allocentric viewpoint experiment, though it would not explain why women decreased theirs. Regardless, the results showed unequivocally that on average men spent a greater proportion of time fixating on the compass than women.
8.3.3 Correlation between time fixating on the compass (%) and the number of written references to cardinal directions

I found evidence that the *time fixating on the compass (%)* was positively correlated with the *number of written references to cardinal directions* when data for men and women were analyzed as a single group and separately. This results further strengthen the previous results in which men and women were found to differ in the *number of written references to cardinal directions* and the *time fixating on the compass (%)*. The significant correlation between the two variables indicates that the longer a participant looked at the compass, the greater the number of written references to landmarks they made when giving directions. The results are also consistent with the results found in the egocentric viewpoint experiment. Thus, the configurational strategy is used not only after the route has been viewed but also at the moment in which it is being visually scanned.

These results provide further evidence that eye movements are reliable indicators of complex route learning behaviour. Additionally, direction-giving measures are not only indicators of a cognitive strategy but may also reveal how route information was initially processed during travelling. The results showed that participants did not necessarily integrate the configurational structure of the environment in a way that made it unnecessary to look at the compass. On the contrary, the more they looked at the compass the more likely it was that they were engaging in a configurational strategy. This was probably the result of the dynamic nature of the environment in which turns in orientation were followed by corresponding rotations of the compass, forcing participants to fixate on the
compass to establish the correct direction. However, it should also be kept in mind that some participants allocated fixations to the compass even though they did not use cardinal directions. So, it is also the case that not all fixations to the compass were related to configurational route-learning strategy.

The present findings showed that there was a significant correlation between time spent looking at the compass and the number of references to cardinal directions. These results demonstrate the usefulness of eye-tracking and direction-giving measures. They also strengthen the idea that using a configurational strategy in a virtual environment is an active process initiated at the moment the route is being attended.

8.3.4 Correlation between mental rotation and the configurational route-learning strategy

Consistent with the findings in the egocentric view experiment and previous research (see Voyer et al., 1995 for a review), men scored significantly higher than women on the mental object rotation test. It is assumed that this ability is related to the use of a configurational strategy. If this is the case, there ought to be a close linear relationship between mental rotation abilities and measures of configurational route-learning strategies. However, I found no significant correlation between scores on the mental object rotation test and the number of written references to cardinal directions. A post-hoc analysis revealed that when the data were analyzed by gender, the correlation was not significant either, but women’s correlation results approached significance at $p = .056$. 
These findings indicate that mental rotation is not closely associated with the communication of allocentric route information based on cardinal directions.

To further explicate the role of mental rotation in the processing of configurational information, I analyzed mental rotation abilities and eye movements. I found a significant positive correlation between scores on the mental object rotation test and the time fixating on compass (%) when the two sample populations were analyzed as a group. I found no significant correlation when I analyzed men and women separately. Nevertheless, the correlation between mental rotation and fixation on the compass in the grouped samples indicates that mental rotation does indeed come into play when configurational information is visually processed from an allocentric perspective.

8.4 Discussion- summary

In this study, I examined the relationship between gender, virtual route learning, and spatial abilities when participants interacted with the environment from an allocentric perspective. I found significant correlations between gender and route learning strategies, but the results of the relationship between spatial abilities and route-learning strategies were not as significant as predicted. The differences in direction giving were significant for cardinal directions (favouring men) and approached significance for landmarks (favouring women). These results were consistent with previous research in which maps were the primary environments, although they contrasted with the results in the egocentric viewpoint experiment in this project. In the allocentric experiment, men tended to scan the compass significantly longer than women and women scanned
landmarks significantly longer than men. This is an indication that the differences in strategies begin early on in the route-learning process. Furthermore, the general correlations between the eye movement and direction giving data were significant, not only when I analyzed men and women as a single group but also when I analyzed them separately. These findings suggested that the differences found between men and women in the visual scanning of environment and direction giving were part of an overall difference in route-learning strategy at the attentional and post-attentional levels.

The results of the analysis on the relationship between gender, route learning, and spatial abilities were less significant than predicted. Men and women differed in several measures of spatial abilities, as predicted in the literature. Women scored higher than men on the object location memory test, and men scored higher than women on the mental object rotation test. It stands to reason that the ability to remember the location of object might be correlated with remembering and viewing the location of landmarks along a route, yet I found no such relationship within and between groups. Mental rotation was not significantly correlated with the use of cardinal directions within the sample population. When analyzed by gender, the relationship approached significance for women only. I found a significant correlation between mental rotation abilities and scanning the compass within the sample population, but not when I analyzed the data by gender. These findings suggest that mental rotation is generally related to the use of a configurational strategy, and there is no difference in how men and women utilize this strategy.
The extent to which the present findings generalize to real-world route learning was not fully explored. However, past research (Lloyd et al., 2009) has found that the route-learning strategies deployed in a virtual environment are equivalent to those employed in a real environment. Moreover, the strategies transferred across two distinct environments, indicating that the strategies assessed in a virtual environment were general enough to represent route-learning aptitude in the real world (Lloyd et al., 2009). These results imply that the findings reported in this dissertation may likely transfer to real-world environments. Of particular importance are the findings that in the egocentric experiment men and women did not differ in route-learning strategies. Therefore, it should be expected that in an environment that requires navigation from a first-person perspective (e.g., driving a vehicle through city streets), men and women should not significantly differ. In an environment that requires integrating the environment from an allocentric perspective (e.g., large-sized areas), men and women will rely on different strategies to integrate a path.

Also of interest is the relationship between spatial abilities and route-learning strategies. It has been predicted by various research that gender differences in early hominid evolution led to differences in the use of spatial abilities during real-world wayfinding. The results in this experiment imply that in the real world the role of spatial abilities (i.e., object location memory and mental rotation) is limited. After learning a route, women rely on object location memory when recalling topographic information. Mental rotation abilities are also generally used when recalling configurational information learned from a route.
seen egocentrically, but no gender differences in this ability exist. Furthermore, when a route is viewed allocentrically, mental rotation plays a role in the visual processing of configurational elements, but no gender differences exist.

In summary, these results indicated that when the environment is viewed from an allocentric perspective, gender difference in route-learning strategies become significant. Viewing specific elements of the environment correlated with providing written references to those elements. Moreover, spatial abilities were only slightly correlated with route-learning strategies.
9: LIMITATIONS

9.1 Overview

Route learning involves the interaction of various sensory, perceptual, and cognitive operations. The complexities of investigating route learning increase as the behaviour is examined at fine-grain levels of detail, including those that involve ocular responses. One way to control the effects of variability in psychological research is to simplify the experimental tasks and the lab environment, thus minimizing the amount of “noise” in the procedure. However, in doing so, the ecological validity of the tasks and the setting are diminished. In this project, I increased the complexity of the tasks and the environment to a greater degree than previous research. However, by increasing the complexity of the experiment, the number of theoretical, technical, and experimental limitations was also increased. I was aware some of these limitations at the outset of the experiment, while others only revealed themselves as I proceeded to more closely examine the results.

9.2 Theoretical limitations

To understand gender differences in virtual route learning, I examined participants’ eye movement behaviour, direction giving strategies, and spatial abilities. The relationship among these factors is not thoroughly understood. I assumed that there was a functional relationship between fixation duration and attention. Moreover, I also assumed that we voluntarily control eye movements. However, it is also known that attention can be disengaged from eye movements.
and in some instances they are not under our conscious control (Muller & Rabbitt, 1989). Therefore, even though it is reasonable to expect that fixation on an object during route learning is a measure of attention, the issue has not been completely settled.

Since attentional focus is necessary to process elements in the environment during route learning, I further assumed that eye fixations would be associated with a specific route-earning strategy (topographic and configurational). Yet it is possible that eye fixations on a particular element along the route were unrelated to the learning task. A participant could have fixated on a given element because of some affective or physiological response. The ambiguous relationship between eye movements and route learning remains a limitation in this study. As far I know, these issues on the relationship between eye movements and virtual route learning have not been systematically addressed in past research. As we employ novel eye tracking techniques to understand how humans process virtual routes, we need to keep these and other limitations in mind, as they are crucial factors in our understanding of navigation processes.

One particular limitation of importance is the assumption that the same strategies and abilities that we use to learn routes in a real environment are also implicated in virtual route learning. The logic behind this assumption is reasonable considering that the route-learning and spatial abilities we now possess have been in development for millennia. It is seemingly unlikely that we would radically alter or develop new fundamental strategies and abilities over the
span of a few decades, which is the time that virtual environments have been in existence. Moreover, past research has also demonstrated the equivalency between route learning in real and virtual environments (e.g., Lloyd et al., 2009). Nevertheless, the extent of transference between real and virtual environments is unknown, limiting the generalizability of the present results.

Route learning is a complex process that engages a wide variety of mechanisms. I have discussed some of the factors that limit the present study but many more still remain. These include the effect of other factors beside gender (e.g., culture, video game experience, and education background) that may have influenced the results; the nature of cognitive maps; the influence of verbal abilities; and the role of memory. It was not possible for me to address all these factors in an empirical manner, and so they represent limitations of this study.

9.3 Technical limitations

While laboratory settings provide a larger measure of control over the experimental variables than real-world settings, there are also a series of technical limitations that need to be considered. In particular, I relied on an eye tracking system to measure eye fixations. Although eye trackers have improved over the years, they still have several operational limits. For instance, during testing, I needed to vary ambient light levels to minimize recording disruptions. As a consequence, participants completed the task in a dimly lit room, which is not necessarily a naturalistic way of interacting with a computer or travelling a route in the real world. Furthermore, low levels of light could have increased
anxiety in participants, possibly leading to a greater reliance on landmarks than usual (Schmitz, 1997). Whether or not this was the case, I do not know, but the example serves to illustrate one of the technical limitations associated with eye tracking.

Another technical limitation was the eye tracker’s spatial accuracy and precision, which were less than one degree, which is fairly good but nevertheless leaves room for error. This technical limitation was compounded by the complexity of the visual system (e.g., pupil responses to light) and human behaviour in general (e.g., looking away from the screen). It is not possible to determine with accuracy if a significant number of errors accumulated over the experimental sessions and influenced the results. I made every attempt to systematize the eye tracking procedure to avoid such errors, but each session involved a complex interplay of experimenter, participant, and instrumental factors that could have resulted in accuracy and precision errors. It should be noted, however, that this particular limitation is not unique to this study.

One particularly limiting issue was the LookZone creation process. Drawing borders around dynamic 3D objects while compensating for system inaccuracies was a complex procedure. There was no automated way to maintain exactness and consistency when repositioning the LookZones. When travelling the route from an egocentric frame of reference, elements not only change position along the horizontal and vertical axes, but they also change size and shape. The LookZones had to be manually moved, resized, and reshaped every 200-500 ms to account for these spatial transformations. An extrapolation
function permitted the smooth tracking of objects. I measured the altered
LookZone with a digital ruler so that each side was 40 pixels from the landmark it
tracked. In some instances the physical and spatial transformation of the
landmark itself was highly complex, particularly during turns when the LookZone
could not be accurately updated. This posed restrictions on the tracking of
objects and the accurate measurements of eye movements. As far I know, there
is no software tool that can automatically update LookZones around 3D objects
with error-free precision and accuracy.

The participants viewed the virtual environment in a 19” monitor with a
1024 x 768 resolution. These technical specifications limited the amount of
information that participants could view at any given time. Differences in display
sizes have been shown to influence gender differences in spatial abilities and
orientation (Tan et al., 2003). It was not possible to determine the extent of the
influence of display size on route learning behaviour, and it thus remains a
limitation of the study.

There is no question that in spite of advances in eye tracking
technologies, many technical limitations still remain. A thorough explanation of
these limitations is beyond the scope of this project, but I refer you to Schnipke
and Todd (2000), who have documented some of the “trials and tribulations” of
using an eye tracker.

9.4 Experimental limitations

When learning a route, we engage a number of biophysical and mental
processes. As was the case in this study, it is often necessary to indirectly measure these processes. To measure attention, for instance, I relied on eye movements; to measure the internal representation of the route, I relied on written directions; and to evaluate spatial abilities, I administered pencil-and-paper tests. To what extent do these methods validly and reliably measure the mental processes associated with route learning? As is often the case when investigating psychological processes, the matter is far from settled.

I limited my exploration of cognitive maps to the direction-giving paradigm. More specifically, I focused on written rather than oral direction giving. The exact characteristics of direction giving are still not well understood, and the nature of the relationship between written directions and mental constructs also remain unknown. Similarly, the exact relationship between eye movements and attention is sometimes ambiguous and has yet to be fully delineated. As demonstrated in this project, written directions and eye movements are useful measures of route learning behaviour, but our understanding of them remains limited. Thus, they present a limitation to the generalizability of the results in the present experiments.

I measured spatial abilities through the administration of mental object rotation and object location memory tests. The relationship between measures of spatial ability and route-learning strategies have not been unambiguously established. The results of this experiment indicated that mental rotation played a slightly more significant role than object location memory in virtual route learning. Yet, it should be observed that measures of spatial ability were
conducted using pencil and paper, and therefore remain a key experimental limitation. Future research on spatial abilities could take advantage of the computational power now at our disposal and develop robust digital versions of pen-and-paper tests.

The sample population in the present experiment was limited to university students at the School of Interactive Arts and Technology. While the use of university students is common practice in psychology, one aspect of the SIAT population that is unique is the greater than average enrollment in technical courses. Several of these courses are based on digital interaction with virtual environments in general and the manipulation of 3D graphics in particular. Not only could this experience affect their virtual route-learning behaviour, but also may lead to an improvement in spatial abilities associated with it. If so, this could have influenced the results in the experiment, and therefore limit the scope of the results.

The experimental limitations of studies such as the ones reported in this dissertation are many. There is simply no way of minimizing the complexity of route learning without affecting its ecological validity. Some of the most relevant experimental issues that limit the results are as follows

- The direction of travel in the experiment was always from East to West. This could have prompted participants to rely on one specific strategy. The analysis of the data showed that many participants who used cardinal directions did so only at the beginning of the route. Using more complex directional turns could have led to
different route learning behaviour. Therefore, the use of a single
direction of travel poses a limit in the conclusions drawn from this
study.

• I restricted participants to passively viewing the environment or to a
  specified trajectory movement, as it is called in the literature
  (Bowman et al., 2005). Actively choosing the route may lead to
differences in behaviour. My assumption was that the mental
operations required to learn the route remain consistent whether or
not the participant was actively engaged in choosing the path to
follow.

• I tried to minimize experimenter bias through the use of written
  material when providing explanations and instructions to
  participants. Yet, in a study about gender differences, it cannot be
  overlooked that as a male, my presence could have somehow
  affected responses given by men and women.

• I made several experimental errors that likely influenced the
  outcome of some parts of the experiment. Testing participants with
  an eye tracker is easier with modern instruments, yet the
  procedures are still rather complex, particularly in complex studies
  of this nature. In addition, I made timing errors in some of the
  procedures associated with the spatial ability tests. Although, it
  bears mentioning that across both experiments, the results of the
  spatial ability tests yielded significant results in the predicted
directions. Nonetheless, all these limitations should be kept in mind when interpreting the results of these experiments.
10: CONCLUSION

The proliferation of virtual environments across a variety of socio-economic areas has made it necessary to develop virtual environments that possess effective and efficient navigation designs. Many issues related to navigation within virtual environments have yet to be resolved. Unlike a typical 2D graphical user interface, a 3D virtual environment is characterized by dynamic and naturalistic spatial metaphors and configurations. It is thus reasonable to expect that, to a certain extent, similar navigation strategies and abilities used during real-world navigation are operating when we learn a path within a 3D virtual environment. To better understand the nature of these path integration strategies and abilities, wayfinding researchers have examined differences in route learning between men and women. Their findings showed that men and women tend to differ in their route learning strategies under a variety of lab settings. In this project, I built on prior research to determine if gender differences also extend to virtual environments. By doing so, I sought to further our understanding of the strategies and abilities that humans employ to integrate a path during virtual route learning.

Do men and women differ in the strategies they rely on when giving directions? Given the difficulty of conducting research in natural settings, much research on gender differences in wayfinding has been conducted using maps, which present information from an allocentric perspective. This is different from...
the egocentric perspective in which information is usually encountered in natural settings. To take into account some of these differences in frames of reference, I conducted two experiments in which participants encountered route information from egocentric and allocentric viewpoints. The results showed that when participants learned the route from an egocentric perspective, there were no significant gender differences in the use of landmarks when providing written directions. However, the results approached significance when participants viewed the route from an allocentric perspective. These findings tentatively suggest that the use of a given strategy to communicate directions using landmarks depends on the point of view from which the environment is viewed.

Results related to the configurational strategy showed that men and women did not differ significantly in the use of cardinal directions when they viewed the route from an egocentric perspective. Yet, a post-hoc analysis showed that the data distribution was severely skewed, possibly resulting from the fact that the majority of participants did not make any references to cardinal directions. When I conducted an analysis of only participants who made references to cardinal directions the differences between men and women were significant; men made more references to cardinal directions than women. The analysis of the data in the allocentric experiment showed that men made a significantly greater number of references to cardinal directions than women. Yet, the allocentric viewpoint data also contained similar bimodal characteristics as those of the egocentric viewpoint experiment. That is, the majority of participants did not make any references to cardinal directions. While previous
researchers have made similar observations in the past, to my knowledge they have not conducted systematic analysis of the issue. The results indicate that men and women do in fact differ in the use of cardinal directions regardless of frame of reference. They also show that the use of configurational elements requires investigation that takes into account the spontaneous use of cardinal directions, as the majority of participants chose not to use them.

Taken together, the analysis of direction-giving strategies did not reveal any gender differences in the use of landmarks and cardinal directions. However, the data related to cardinal directions suggest that within a given population the use of cardinal directions is limited to a handful of cases. These latter findings showed that the use of configurational elements is a strategy that is not often employed by both men and women alike and requires further investigation.

_Do men and women differ on the visual scanning strategies that they rely to learn a route in a virtual environment?_ When participants learned the virtual route from an egocentric perspective, they did not significantly differ on the proportion of time that they fixated on landmarks. On the other hand, when participants learned the virtual route from an allocentric perspective, women allocated a significantly greater proportion of fixation time on landmarks than men. I measured the configurational route-learning strategy by analysing the proportion of time that participants allocated to the compass. When participants viewed the route from an egocentric perspective, men and women did not differ significantly in the amount of time they spent scanning the compass. Yet, as
mentioned, only a few participants made actual references to cardinal directions. Analysis of these participants showed that men and women differed significantly in written references to cardinal directions and in the proportion of time scanning the compass. Men spent a greater amount of time looking at the compass than women. Analysis of the eye movement data in the allocentric viewpoint experiment resulted in a significant difference between men and women. Again showing that men allocated a greater proportion of fixation time on the compass.

The results of the analysis of landmark and compass scanning data showed no differences when the environment was viewed from one frame of reference (egocentric), but the differences were significant in the other (allocentric). These findings present a more complex attentional process associated with the deployment of visual strategies than can be gleaned from past literature. They suggest that allocation of attention when learning a virtual route shifts according to the orientation from which the environment is viewed.

*Is there a relationship between the way men and women visually explore a route in a virtual environment and the way in which they report written directions?* The results from the direction-giving and eye-movement data were relatively consistent. When participants viewed the route from an egocentric perspective, their fixation time on landmarks significantly correlated with the number of written references to landmarks. Further analysis of the data by gender showed that the correlation was only significant between women’s fixations and written directions. When participants viewed the route from an allocentric perspective, their fixation time on landmarks significantly correlated with the number of written references
to landmarks. The significance of the results held even when men and women’s data were analyzed separately. The results from both studies provide evidence that eye fixations on virtual topographic features are closely associated with written references to similar features. In essence, eye movements and direction giving appear to be indicators of how a virtual route is learned.

Analysis of the configurational data gathered in the egocentric viewpoint experiment, yielded a significant positive correlation between time fixating on the compass and the number of written references to landmarks. The results were consistent even when I performed the analysis on men and women separately. I obtained similar results when I analyzed data gathered in the allocentric viewpoint experiment. The positive correlation was significant when I analyzed all participants as a group and separately by gender. The results from the two experiments showed that the configurational route-learning strategy was employed not only after participants had integrated the route but also at the moment that they fixated on its various elements.

In general, the correlation analyses demonstrated that eye-movement and direction-giving measures were positively related in both the topographic and the configurational route-learning strategies. For the most part (egocentric landmarks being the exception), these correlations were observed even when the data were analyzed by gender. At the technical level, these findings provide support for the notion that eye tracking methods are useful in understanding complex navigation behaviour. At the theoretical level, these findings suggest that cognitive operations are at work early in the route-learning process and they
remain active even after the route has been visually processed and integrated into a ‘cognitive map’.

_is there a relationship between spatial abilities and route-learning strategies in a virtual environment?_ Learning a route for later recall must require the mental manipulation of the spatial characteristics of the environment. For instance, it is not enough to remember that there was a landmark when the route was travelled; it is also necessary to remember where this landmark was located in relation to other landmarks, one’s point of view, the route itself, and other elements of the environment. Also, figuring out a direction of travel in light of orientation changes is believed to require the visualization and manipulation of the environment in a three-dimensional manner. Yet, rather surprisingly, I found little correlation between spatial abilities and virtual route learning.

I focused on two spatial abilities- object location memory and mental object rotation. I first sought to establish if indeed men and women differed in these spatial abilities. Then I performed a correlation analysis on whether these abilities were related to route-learning measures. The results of the tests showed that women in both experiments scored significantly higher than men on the object location memory test. As well, in both experiments, men scored significantly higher than women on tests of mental object rotation. These findings were consistent with results obtained in past research.

In the egocentric viewpoint experiment, I did not find a significant correlation between score on the object location memory test and the number of written references to landmarks when I analyzed data for all participants. When I
conducted the same analysis by gender, I found a significant relationship between the two variables for women’s data only. The relationship was negative, meaning that the higher the score on the object location memory test the lower the number of written references to landmarks women made. This finding contradicts previous ideas (e.g., Dabbs et al., 1998) on the relationship between object location memory and route-learning strategies, which was thought to be positive. In the allocentric experiment, I found no significant correlation between object location memory and number of written references to landmarks. These results remained non-significant even when I analyzed men and women’s data separately. The findings from both experiments suggest that the ability to remember the location of objects may not be play a significant role in direction giving. One thing to keep in mind, however, is that the object location memory test not only measures the number of objects the participant is able to recall but also the accuracy of recall. Erroneous answers were subtracted from the correct ones. The analysis of the written directions, on the other hand, did not take accuracy into account. I counted all landmarks regardless of whether or not they were accurately recalled. This difference may have minimized any actual relationship between object location memory scores and written references to landmarks.

Performing the analysis on the eye movement data, I found that when participants viewed the route from an egocentric perspective there was no significant relationship between scores on the object location memory test and time fixating on landmarks (%). The results remained constant when I analyzed
all participants together and separately by gender. I obtained similar results when I analyzed the data from the allocentric viewpoint experiments. These findings provide further evidence that participants’ ability to recall the location of objects was not related to the way that they visually scanned landmark in the environment.

With one exception, the topographic strategy as measured by written references to landmarks and eye fixations on landmarks did not have a close relationship to object location memory. This result was rather surprising, as it is reasonable to expect that the ability to remember the location of objects is necessary to give accurate directions. Nevertheless, for the most part, there was no correlation between object location memory and written directions.

The configurational route-learning strategy is believed to require the ability to mentally manipulate visualized objects. Therefore, I conducted a correlation analysis of scores on the mental object rotation test and measures of the configurational strategy (written references to cardinal directions and time fixating on the compass). In the egocentric experiment, I found a significant positive correlation between scores on the mental object rotation test and number of written references to cardinal directions. The results were only significant when I analyzed the grouped data but not when men and women’s data were analyzed separately. I did not find a significant relationship between these two variables when participants viewed the route from a top-down perspective. When I analyzed the data by gender in the allocentric viewpoint experiment, I found that women’s data trended towards significance. These results indicated that there
was only a small relationship between spatial abilities related to mental rotation of objects and the likelihood a participant would use cardinal directions. Furthermore, there did not appear to be any major differences between men and women in their mental rotation abilities and propensity to use cardinal directions.

The analysis of the relationship between eye movement data and mental rotation abilities yielded a non-significant relationship when participants viewed the route from an egocentric viewpoint. These results were consistent when the analysis was performed on all participants as a group and separately by gender. The results of the analysis on data gathered from the allocentric experiment yielded a significant positive correlation between scores on the mental object rotation test and time fixating on the compass (%). The results were only significant when I performed the analysis on participants’ grouped data but not when I performed the analysis by gender. These results indicated that, in a general sense, spatial abilities related to the mental rotation of visualized objects was related to eye fixations on the compass. These findings differed from the findings in the egocentric experiment, indicating that the frame of reference from which a route is viewed influences the relationship between spatial abilities and eye movements on configurational elements of the route.

The role of spatial abilities in route learning is not well understood. There are a variety of abilities that have received attention in the spatial cognition literature (Voyer et al., 1995), some of which have shown gender differences. In this study, the results showed that aside from a few exceptions, spatial abilities did not play a major role in route learning.
What are the implications regarding the evolutionary development of route learning? Thus far, I have focused on the proximate mechanisms that explain route-learning behaviour. These findings also have implication in our understanding of the ultimate causes of route learning. Evolutionary theory predicted that given the differences in the size of activity ranges between men and women, they developed different mental strategies to cope with their environment. When participants learned a route from a typical egocentric viewpoint, there were no gender differences in route-learning strategies. Further, the results suggest that route learning strategies are only partly associated with differences in spatial abilities. To some extent, the findings from the egocentric viewpoint experiment contradict the idea that evolutionary pressures between men and women led to differential route-learning strategies and abilities. At least, a more exact reframing of the evolutionary model of route learning is required.

Results from the allocentric study tell a different story regarding evolutionary processes influencing route-learning strategies. When participants viewed the route from an allocentric perspective, gender differences in route-learning strategies reached or approached significance. These results are in lined with the idea that differential evolutionary pressures has led to differences between men and women in route-learning strategies. Why do the two experiments contradict each other in this regard? Ecuyer-Dab and Robert (2004) posited that since ancient male hominids tended to encounter a more varied environment than females, it is likely they were able to adapt to different
conditions. This would result in an ability to use one strategy over the other according to the conditions encountered. For example, in a familiar environment males may rely on a landmark strategy but in a less familiar environment, they could instead rely on global coordinates of the environment. Likewise, in the present experiments, when the environment was seen from an egocentric perspective, it may not have been advantageous to use a configurational strategy and thus all participants relied on a topographic strategy instead. Thus, differences between men and women were minimized. In the allocentric experiment, however, it might have been advantageous to rely on a configurational strategy, thus increasing the differences between men and women. If this conjecture is correct, then the results of this study suggest that insofar as evolutionary pressures led to sexually dimorphic route-learning strategies, the gender differences will express themselves only in particular environmental conditions associated with viewing orientation.

10.1 Practical implications

To design virtual environments with effective navigation schemes, it is important to understand how humans process information in these environments. The spatial complexity of virtual environments has increased in recent years with the development of 3D technology, which allows the creation of virtual environments that closely resemble the spatial characteristics of the real world. Although much remains unknown about how we process routes, it is reasonable to assume that the same perceptual and cognitive strategies that we rely on to navigate virtual environments are, to some extent, similar to those we use in real-
world settings. Arguments abound about whether or not physical interaction is necessary to integrate a route. Or whether in the absence of physical interaction, the results are relevant to interactive experiences. While the current experiments did not test any form of physical interaction, the results obtained in the study still have practical implications for the development of virtual environments. Further refinement of these investigations can incorporate interactive elements to test these assumptions.

I focused on two main route-learning strategies: topographic and configurational. To maintain experimental consistency with previous research, I designed an environment that resembled a real-world setting. In this environment, participants could rely on the topographic route-learning strategy by allocating visual attention to recognizable objects like buildings and parks. A configurational strategy was possible by extracting cardinal information from the compass located on the upper right corner of the display. The results showed that participants did not employ these strategies equally across experiments, as differences between men and women became significant when they viewed from an allocentric perspective. These results suggest that it is possible for humans to alter their strategy depending on the orientation from which they view the virtual environment. Thus, designing navigable virtual environments is not a matter of knowing only what strategies the navigator will rely on, but also knowing how those strategies will be implemented in different viewing conditions.

It should be kept in mind that while the present experiments suggest that the deployment of topographic and configurational route-learning strategies
change according to the point of view, they did not demonstrate whether these changes in strategies hindered or supported the integration of a route. Nevertheless, assuming that the use of specific strategies is important for the successful integration of virtual paths, then the results suggest that it is important to address differences in how users employ them across different frames of reference. For instance, in the egocentric experiment gender differences in the use of the compass and cardinal directions were not significant. If using the compass or cardinal directions is advantageous in some way, then neither men nor women hold an advantage over the other in this particular case. In the allocentric experiment, however, men and women differed in the use of the compass and cardinal directions. To the extent that use of a configurational strategy is indicative of effective and efficient virtual route learning, men hold an advantage over women under these viewing conditions. Conversely, women hold an advantage over men in the use of topographic elements when the environment is seen from an allocentric perspective. *Addressing these gender disparities should be an important consideration when designing virtual environments that present information from an allocentric frame of reference.*

How exactly should this be done? The scope of this experiment was not designed to provide an explicit answer to this question, but some of the findings hint at several possibilities.

The results from both experiments showed that scanning landmarks was positively associated with making references to landmarks. This means that the design of the landmarks, and possibly any salient virtual object for that matter,
should facilitate visual processing, retention, and recall. Visually, for example, objects seen from a top-down perspective may not possess as many salient properties (e.g., shape and size) as objects seen from a first-person perspective. So, they may not look very distinct from one another and may be difficult to distinguish visually. Characteristics such as colour, shape, position, and size could be manipulated to make topographic objects more distinct and easily processed visually. Since the results of the studies also showed a positive correlation between scanning of landmark and landmark references, then it is also necessary to design topographic elements that facilitate recall. This may be done in a number of ways. The virtual environment used in the experiment, for example, contained familiar landmarks such as McDonald’s and Burger King, which may be more memorable than a generic “fast-food restaurant”. Of course, adding specific familiar landmarks is not always appropriate. For instance, it would make no sense to put a Burger King in a virtual environment like World of Warcraft. Yet, the general idea still applies. The characteristics of topographic elements seen from an allocentric frame of reference should facilitate recall after the route has been travelled.

When participants viewed the environment from an allocentric frame of reference, gender differences in visual scanning of the compass and cardinal directions were significant. It is possible that using a configurational strategy when the environment is viewed from a top-down perspective is advantageous. Therefore, relying on configurational elements would facilitate the learning of a route. If this is the case, it is necessary that the design of a virtual environment
include the necessary navigation aids that ease the acquisition and integration of configurational elements. Because the results showed that different frames of reference increased gender differences in the use of the compass and cardinal directions, then we can assume that the change in viewing orientation may be associated with a change in strategy. The interview responses from participants revealed that in the egocentric experiment, they found it difficult to determine cardinal directions. This difficulty may be have been enhanced by the design of the compass, which was two-dimensional. Determining cardinal directions could have been eased if the compass had been oriented three-dimensionally and thus parallel with the 3D orientation of the environment. Several other navigation aids can be implemented to ease the processing of configurational elements. Some video games, like World of Warcraft, allow the user to access a map of the environment showing the location of important information. Some environments like the 3D modelling software Google Sketchup show coloured guides that clearly demarcate the x, y, and z-axes of the environment, which facilitates understanding of the configurational dimensions of the space. Other environments like Google maps and Microsoft’s Bing Maps allow the user to manipulate the viewing angles of the environment and thus align it to a preferred view. Clearly, there are many ways in which the processing of configurational information can be improved and as shown some of them have already been implemented. However, it has yet to be determined to what extent these schemes help in minimizing potential gender differences and more research is required to address this issue.
10.2 Future research

As demonstrated by the size of the video game industry and the development of advanced geospatial systems like Google Earth, the technologies associated with the design of virtual environments continue to advance at a rapid pace. Yet research into path integration—particularly where gender differences are concerned—is still in its infancy. Virtual route learning is the result of the interaction between a navigator and the virtual environment that he or she traverses. Therefore, the learning of a virtual route should be investigated in terms of the internal (physiological and mental) and external representations, mechanisms, and processes involved.

10.2.1 Internal representation, mechanisms, and processes

The internal factors associated with a cognitive map of the virtual route can be investigated in terms of the systems and operations that lead to the acquisition, integration, and communication of route elements (Hegarty et al., 2006). It is unlikely that the internal representation of a route is a faithful copy of the external one, yet both representations do have some elements in common. These elements need to be acquired somehow using our sensory and perceptual mechanisms. In this dissertation, I focused on eye movements as overt attentional indicators of a virtual route learning strategy. In particular, I examined the role of fixation duration in acquiring route elements. In some cases the results showed a significant relationship between this metric and other measures of route learning. Further research should more accurately explicate the role of fixation duration and the acquisition of route elements. Fixation duration,
however, is not the only ocular metric of interest. Saccadic eye movements could also be investigated in the role they play in the acquisition of virtual route elements. The visual integration of a route is not simply a matter of attending to discrete elements of the route, but it also requires that one understands how those elements are laid out in relation to the observer, the route, and other elements of the environment. As we try to determine direction of travel, for instance, we not only attend to the compass cardinal indicators but also seek to determine how those indicators are positioned in relation to other elements of the environment. This requires the allocation of eye movements across multiple elements in the viewed scene. Such patterns of saccadic eye movement can be identified and investigated using eye tracking methods. This would give us a more comprehensive view of route learning strategies than fixation duration alone.

One of the limits of this project was the absence of physical actions from participants. Few virtual environments nowadays require naturalistic physical input but new technologies (e.g., Nintendo Wii and Microsoft Kinect) are beginning to appear that require user motor control. Artificial methods of interactions are of interest because they allow us to manipulate and learn virtual routes in ways that engage our psychomotor systems. There are many issues still unsolved about the transference of route-learning strategies from the real world, in which physical actions are necessary, to virtual worlds, where physical actions are usually constrained. New technologies that facilitate bodily
interaction make it necessary to take into account kinesthetic variables to better understand virtual route learning.

The role of spatial abilities such as object location memory and mental object rotation are two abilities that have received attention in the literature. Many other abilities associated with our ability to cognitively manipulate spatial elements of the route still remain to be more widely investigated. For example, navigation may also include an ability to visualize our viewpoint displacement along a path; shift between frames of reference; and visualize information at different scales. How is this accomplished? What methods should we use to investigate it? There are many other spatial abilities that given the scope of this project could not be addressed in the current experiments. The results of the study, however, do indicate that spatial abilities are important to some extent and further research is required to better understand the role they play in virtual navigation.

We learn a route not for the sake of learning it but because in some way we need to utilize it. We do so by communicating route elements either to oneself or to someone else. In this research, I focused on written methods of communication and on a more informal basis, verbal methods as well. The direction-giving method showed that the content of participants’ written directions were useful in determining whether men and women differed in the elements that they found most important to accurately communicate the route. Further, written directions were also shown to have linear relationships with eye movements and some spatial abilities. Though I focused my analysis on written references to
landmarks and cardinal directions, informal analysis of written directions suggested that participants used other direction-giving schemes (e.g., streets, time, maps, and relative directions). Research into the direction-giving paradigm is necessary to develop more comprehensive and accurate methods to investigate virtual route learning. For instance, accuracy of directions was not tested in this project. Yet given that accuracy is an important aspect of route-learning performance then it should be investigated further.

These examples are but a few of the internal mechanisms that can be investigated to be understand virtual route learning. It is beyond the scope of this project to address them all but I hope that they are sufficient to demonstrate the many possibilities that exist in the study of gender differences in route learning.

10.2.2 External representation, mechanisms, and processes

As the word implies, the external representation of the route refers to the actual graphical structure of the virtual environment. There are a wide variety of structural elements that can be investigated in future research, and I propose research into three factors associated with the visual, spatial, and metaphorical aspects of the environment’s design.

Virtual environments provide a greater measure of control than natural settings, but their complexity can also pose difficulties to experimental design. Take for instance their graphical complexity. Realistic landmarks tend to be characterized by a variety of visual features such as colour, texture, size, shape, function, and so forth. How do these features influence our route-learning
strategies? I did not directly address this question in my own research, but it is an area that should receive further empirical attention.

The results this research showed that participants responded differently depending on whether they viewed the environment from an egocentric or allocentric viewpoint. These differences in response may be the result of differences in spatial characteristics between multiple viewpoints. For instance, the network of streets that make up the route is different when seen from a first-person perspective than when seen from a top-down perspective. Does this difference influence which route-learning strategy a man or a woman perform route-learning tasks? What other aspects of the frame of reference influence navigation strategies? Answers to these questions are important because modern virtual environments differ in how they orient the viewing trajectory of the user. If these differences affect performance in any way, then they should be examined closely, so we learn how to minimize their impact.

A virtual route and the surrounding environment create a cohesive global structure that covers the space between the origin and the destination. When a traveller traverses the route, elements in the environment provide the necessary information by which this structure becomes apparent to her/him. The compass (if one is available), landmarks, terrain topography, and even lines where edges meet provide information that could be used to learn a route. To gain an understanding of the geometry and topography of a virtual space, it is necessary to move through it. This movement can be accomplished in different ways such as “grabbing” elements toward or away from one’s viewpoint; by moving through
it; and by performing complex spatial manoeuvres in any given axis. Unlike real-world environments, the spatial constraints of a virtual environment are fewer and can lead to disorientation. It is essential that future research aim to understand how user controlled displacement in virtual space can be accomplished in the most effective and economical manner.

Lastly, in our attempt to understand the external representation of the environment, we must take into account the metaphors that we use in order to convey information. I created a 3D model of a 2D sketch map and so by necessity, many of the virtual elements metaphorically emulated real-world elements such as churches, restaurants, streets, and even the presence of gravity. As the video game industry illustrates, there are seemingly countless ways to design virtual environments. Each environment uses a unique metaphor with varying levels of realism and abstraction. Metaphors are not only useful to define the structural elements of the environment, but also those elements that require dynamic changes. For example, one may use a “driving” metaphor to move fast and a “walking” metaphor to slow down movement. The use of a particular metaphor may influence how the route is learned. If so, further research is necessary to understand the role of metaphors in virtual route learning.

10.2.3 Beyond gender

As Cyr et al., (2009) postulate, biological sex is but one dimension that predicts technology usage and acceptance, and other socially constructed factors may be stronger predictors. Past research has shown that virtual
navigation performance is influenced by video game experience and spatial abilities (Feng, Spence, and Pratt, 2007; Moffat et al., 1998; Terlecki, Newcombe, and Little, 2008). In several cases, it has been observed that gender differences on measures of virtual navigation disappear when video game experience is taken into account (Richardson, Powers, and Bousquet, 2011). These findings offer the possibility that as Cyr et al. (2009) posit, social factors are stronger predictors of technology usage than biological sex.

Another area that could be pursued is that of culture or more specifically region of origin. Lawton (2001), for instance, found that participants who lived in the Midwest/West made more references to cardinal directions than participants who lived in the Northeast/South. Further, participants who lived in areas where the roads were arranged in a grid-like pattern were also more likely to use cardinal directions (Lawton, 2001). These findings are an indication that the environment that a person lives in also affects the spatial referents used in direction giving. In the present experiments more than half of the participants spoke English as a second language, indicating that many of them came from regions outside of Vancouver. It is possible that differences between countries can lead to differences in how people learn virtual routes. Investigating these differences can also give us a better understanding of how humans in general process environmental information when integrating a path.

10.2.4 Last words

The investigation of route-learning strategies and abilities is not a simple matter of knowing whether a person uses landmarks or cardinal directions. They
are indeed important aspects of how we integrate the environment into a cohesive mental structure, but as the findings in this study indicate, route learning is a highly complex process that involves a host of sensory, perceptual, and cognitive mechanisms. Internal and external factors intermingle to allow a user to effectively and efficiently move from location to another. Moreover, these factors are not necessarily homogenous but express themselves in a variety of ways, as shown by the gender differences found across multiple points of view in the present experiments. This complexity makes it difficult to investigate route learning in virtual environments in a controlled manner. Yet, the increasing complexity of virtual environments also provides an opportunity to better understand how we process spatial information under a variety of conditions. This knowledge not only has practical implications for the design of virtual environments, but it also gives us a better understanding of how we as a species continue to develop, sustain, and evolve our capacity to learn the spatial structure of our environment.
REFERENCES


APPENDICES
Appendix A: Recruitment script

In an effort to understand how men and women learn routes in a 3D virtual environment, I am conducting an eye tracking study at the School of Interactive Arts and Technology. I invite you to participate in this study.

Students who wish to participate must fit the following characteristics:

• You do not wear glasses
• If you wear contact lenses, lenses must be soft not hard.

For your participation, you will receive $20.

**Where:** Usability lab located in the SFU Surrey campus

**When:** September through November.

**Duration:** 1 hour.

If you are interested in participating, please contact Hector Larios:

hlarios@sfu.ca
Appendix B: Consent Form

Information and Consent Form for Participants

The University and those conducting this research study subscribe to the ethical conduct of research and to the protection at all times of the interests, comfort, and safety of participants. This research is being conducted under permission of the Simon Fraser Research Ethics Board. The chief concern of the Board is for the health, safety and psychological well-being of research participants.

Should I wish to obtain information about my rights as a participant in research, or about the responsibilities of researchers, or if I have any questions, concerns or complaints about the manner in which I was treated in this study, I will contact the Director, Office of Research Ethics by email at hweinber@sfu.ca or phone at 778-782-6593.

Title: Gender Differences in Virtual Route Learning
Investigator Name: Hector Larios (PhD candidate)
Investigator Department: Interactive Arts and Technology

Risks to the participant, third parties or society:

There are no risks to the participants, third parties, or society.

Procedures:

• I have been informed that the goal of the study is to understand how people learn routes in a virtual environment. The study also aims to understand the relationship between learning a virtual route and spatial abilities.
• I will be asked to view a virtual environment on a monitor while my eye movements are tracked. The eye tracking equipments consists of a small camera that sits under the monitor and records my line of gaze as I view the monitor.
• After viewing the routes, I will be asked to provide written directions on a piece of paper.
• I will complete 2 paper tests of spatial abilities that will determine my ability to visualize 3D figures and ability to examine simple line drawings on a piece of paper. The performance data will consist of the number of correct answers I score on these tests.
• The investigator will ask me informal questions about the strategies that I use to learn a route.
• The study will last 1 hour
Benefits of study to the development of new knowledge:

In participating in this experiment, I will contribute to the understanding of how people learn routes in virtual environments. This knowledge will be useful in the design of such environments.

Also, I may obtain copies of the results of this study, upon its completion by contacting:

Hector Larios
E-mail: hlarios@sfu.ca
Tel: (604) 329-2308

I understand that I may withdraw my participation at any time without prejudice or adverse effects to my grades or evaluation in the classroom or coursework. I also understand that I may register any complaint with the Director of the Office of Research Ethics.

Director, Office of Research Ethics
8888 University Drive
Simon Fraser University
Burnaby, British Columbia
Canada V5A 1S6
778-782-6593.
email: hweinber@sfu.ca

The information in this study will be kept confidential to the full extent permitted by the law. Knowledge of my identity is not required in any experimental material. The format of the materials is paper and will be maintained in a secure location. This location will be a locked cabinet within a restricted area of the campus. Access to this area requires an electronic card and a key. These materials will be kept by the investigator for 2 years and will be shredded afterwards.
My signature on this form will signify that I have read this consent form and understood the investigators descriptions of the procedures, the absence of any risks, and the benefits of this research study, that I have received an adequate opportunity to consider the information and that I voluntarily agree to participate in the study.

Please complete the following:
Participant Name _______________________
Participant Contact Information (email):
_____________________________________
Participant Signature ____________________________
Investigator Signature

Date (MM/DD/YYYY)

Appendix C: Participant information

Background information:

Please type an X under the appropriate answer.

1. Male ___  Female ___

2. Age :
   under 20 ___
   20-25 ___
   26-30 ___
   over 30 ___

3. Do you play video games? Yes____  No_____

4. If you answered yes to the above questions, how many hours a week do you play video games?
   a) 5 hours or less _____
   b) 5-10 hours ______
   c) More than 10 hours ______

5. Is English your first language?  Yes ____  No ____

6. If you answered no to the previous question, what’s your first language?

7. Are you right-handed or left-handed?  Right_____  Left _____

8. How many years have you held a driver’s license? _____ years

9. How many hours per week do you drive? _______ hours

10. Are you a graduate or undergraduate student?  Grad ___  Undergrad_____
Appendix D: Task description and instructions

Description of familiarization trial (read out loud to participant)

I am going to show you a video of a virtual environment. I would just like you to examine it and familiarize yourself with the information depicted (e.g., the objects, the icons, the words, and so on). Do you have any questions?

Description of main trial (read out loud to participant)

“I am going to show you a video of a fictional virtual town. I am going to take you on an imaginary Sunday afternoon drive [that someone took] and I want you to try to remember the drive as best you can.”

Do you have any questions?

Task Description (read by participant on response sheet)

Please give directions from the start point and the end point. Give only the information that another person would need to know in order to travel the route.

Spatial ability instructions

The validity and reliability of the object location memory and mental object rotation tests is based on the participant not having experience with them. I have opted not to show these tests but the relevant information can be found in a variety of sources including Dabbs et al. (1998), Silverman and Eals (1992), and Peters et al. (1995).

Opening interview query

Please tell me about the strategy that you used to learn the route.
Appendix E: Demographics for egocentric viewpoint experiment

Table 24: Demographic data of all 60 participants as a group and by gender

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**Dominant hand - All**

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**Dominant hand - Men**

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**Number of years with a driver’s license - All**

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
<th>Mean</th>
<th>Median</th>
<th>Std. Error of mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3.0</td>
<td>3.0</td>
<td>0.339</td>
</tr>
</tbody>
</table>

**Number of years with a driver’s license - Women**

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
<th>Mean</th>
<th>Median</th>
<th>Std. Error of mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2.3</td>
<td>2.0</td>
<td>0.336</td>
</tr>
</tbody>
</table>

**Number of years with a driver’s license - Men**

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
<th>Mean</th>
<th>Median</th>
<th>Std. Error of mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3.7</td>
<td>3.0</td>
<td>0.570</td>
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</tbody>
</table>

**Driving hours per week - All**

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
<th>Mean</th>
<th>Median</th>
<th>Std. Error of mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5.0</td>
<td>2.0</td>
<td>0.736</td>
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</table>

**Driving hours per week - Women**

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
<th>Mean</th>
<th>Median</th>
<th>Std. Error of mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>4.2</td>
<td>0.75</td>
<td>1.093</td>
</tr>
</tbody>
</table>

**Driving hours per week - Men**

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
<th>Mean</th>
<th>Median</th>
<th>Std. Error of mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5.78</td>
<td>3.0</td>
<td>0.983</td>
</tr>
</tbody>
</table>

**Education level - All**

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undergraduate</td>
<td>58</td>
<td>96.7</td>
</tr>
<tr>
<td>Graduate</td>
<td>2</td>
<td>3.3</td>
</tr>
</tbody>
</table>

**Education level - Women**

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undergraduate</td>
<td>29</td>
<td>96.7</td>
</tr>
<tr>
<td>Graduate</td>
<td>1</td>
<td>3.3</td>
</tr>
</tbody>
</table>

**Education level - Men**

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undergraduate</td>
<td>29</td>
<td>96.7</td>
</tr>
<tr>
<td>Graduate</td>
<td>1</td>
<td>3.3</td>
</tr>
</tbody>
</table>
Appendix F: Demographics for allocentric viewpoint experiment

Table 25: Demographic data of all 60 participants as a group and by gender

<table>
<thead>
<tr>
<th>Age- All</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 20</td>
<td>11</td>
<td>18.3</td>
</tr>
<tr>
<td>20-25</td>
<td>36</td>
<td>60</td>
</tr>
<tr>
<td>26-30</td>
<td>8</td>
<td>13.3</td>
</tr>
<tr>
<td>Over 30</td>
<td>5</td>
<td>8.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age- Women</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 20</td>
<td>4</td>
<td>13.3</td>
</tr>
<tr>
<td>20-25</td>
<td>18</td>
<td>60</td>
</tr>
<tr>
<td>26-30</td>
<td>5</td>
<td>16.7</td>
</tr>
<tr>
<td>Over 30</td>
<td>3</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age- Men</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 20</td>
<td>7</td>
<td>23.3</td>
</tr>
<tr>
<td>20-25</td>
<td>18</td>
<td>60</td>
</tr>
<tr>
<td>26-30</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Over 30</td>
<td>2</td>
<td>6.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plays video games-All</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>Yes</td>
<td>45</td>
<td>75</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plays video games-Women</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>13</td>
<td>43.3</td>
</tr>
<tr>
<td>Yes</td>
<td>17</td>
<td>56.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plays video games-Men</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>2</td>
<td>6.7</td>
</tr>
<tr>
<td>Yes</td>
<td>28</td>
<td>93.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hours playing video games per week-All</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does not play video games</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>Less than 5 hours</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>Between 5-10 hours</td>
<td>11</td>
<td>18.3</td>
</tr>
<tr>
<td>Over 10 hours</td>
<td>4</td>
<td>6.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hours playing video games per week-Women</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does not play video games</td>
<td>13</td>
<td>43.3</td>
</tr>
<tr>
<td>Less than 5 hours</td>
<td>11</td>
<td>36.7</td>
</tr>
<tr>
<td>Between 5-10 hours</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>Over 10 hours</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Hours playing video games per week-Men</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Does not play video games</td>
<td>2</td>
<td>6.7</td>
</tr>
<tr>
<td>Less than 5 hours</td>
<td>19</td>
<td>63.3</td>
</tr>
<tr>
<td>Between 5-10 hours</td>
<td>5</td>
<td>16.7</td>
</tr>
<tr>
<td>Over 10 hours</td>
<td>4</td>
<td>13.3</td>
</tr>
<tr>
<td>English is second language-All</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>26</td>
<td>43.3</td>
</tr>
<tr>
<td>Yes</td>
<td>34</td>
<td>56.7</td>
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<tr>
<td>English is second language-Women</td>
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</tr>
<tr>
<td>No</td>
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<td>30</td>
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<tr>
<td>Yes</td>
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<td>70</td>
</tr>
<tr>
<td>English is second language-Men</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>17</td>
<td>56.7</td>
</tr>
<tr>
<td>Yes</td>
<td>13</td>
<td>43.3</td>
</tr>
<tr>
<td>Dominant hand- All</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>5</td>
<td>8.3</td>
</tr>
<tr>
<td>Right</td>
<td>55</td>
<td>91.7</td>
</tr>
<tr>
<td>Dominant hand- Women</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>2</td>
<td>6.7</td>
</tr>
<tr>
<td>Right</td>
<td>28</td>
<td>93.3</td>
</tr>
<tr>
<td>Dominant hand- Men</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Right</td>
<td>27</td>
<td>90</td>
</tr>
<tr>
<td>Number of years with a driver’s license- All</td>
<td>Mean = 4.5</td>
<td>Median = 3.0</td>
</tr>
<tr>
<td>Number of years with a driver’s license- Women</td>
<td>Mean = 4.7</td>
<td>Median = 3.0</td>
</tr>
<tr>
<td>Number of years with a driver’s license- Men</td>
<td>Mean = 4.4</td>
<td>Median = 3.5</td>
</tr>
<tr>
<td>Driving hours per week-All</td>
<td>Mean = 4.1</td>
<td>Median = 2.0</td>
</tr>
<tr>
<td>Driving hours per week-Women</td>
<td>Mean = 3.5</td>
<td>Median = 1.0</td>
</tr>
<tr>
<td>Driving hours per week-Men</td>
<td>Mean = 4.6</td>
<td>Median = 2.5</td>
</tr>
<tr>
<td>Education level-All</td>
<td>Undergraduate</td>
<td>43</td>
</tr>
<tr>
<td>Education level-All</td>
<td>Graduate</td>
<td>16</td>
</tr>
<tr>
<td>Education level-Women</td>
<td>Other</td>
<td>1</td>
</tr>
<tr>
<td>Education level-Women</td>
<td>Undergraduate</td>
<td>19</td>
</tr>
<tr>
<td>Education level-Women</td>
<td>Graduate</td>
<td>10</td>
</tr>
<tr>
<td>Education level-Women</td>
<td>Other</td>
<td>1</td>
</tr>
<tr>
<td>Education level-Men</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Undergraduate</td>
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<td>80</td>
</tr>
<tr>
<td>Graduate</td>
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<td>20</td>
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