The Effect of Familiarity and Complexity of Environments, and Mode of Wayfinding on Gaze and Memory

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Author's Declaration

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

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Abstract

Whether we travel the well-known route to work or unfamiliar streets in a new city, we use wayfinding in order to determine and follow a route to get to our destination. Wayfinding is dependent on cognitive processes, specifically attention and memory which has been reinforced in the observation of challenges in wayfinding among individuals who have suffered cognitive dysfunction as the result of neurologic injury or diseases (eg stroke or Alzheimer's). The studies are focused on advancing the understanding of the role of visual attention, associated gaze behaviour, and memory on the control of wayfinding. The first study focused on determining how changes in the familiarity and complexity of an environment influence visual attention during wayfinding. The second study investigated how the method of learning an environment, either actively or passively, would influence gaze behaviour.

The results from study 1 showed that both novel and visually complex environments were characterized by an increase in the number of fixations, and therefore the amount of directed attention towards landmarks when wayfinding. Study 2 revealed that when learning an environment actively there is an increase in fixations and directed attention when compared to learning an environment passively. However this increase in the number of fixations did not lead to better wayfinding performance when attempting to repeat the route, or an ability to recall landmarks from memory.

By understanding what components of an environment, and how we learn an environment influence the allocation of attention and the ability to store our

surroundings into memory in healthy individuals we may reveal potential tools for designing rehabilitation techniques for cognitively impaired populations.

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Chapter 1: Introduction

1.1 Background

The process of determining and following a route from an origin to destination is wayfinding (Golledge, 1999) and we perform this task every day when we move through our environment no matter how far or familiar the route we plan on taking is. Literature in this area has looked at different strategies involved in wayfinding (Andersen, Dahmani, Konishi, & Bohbot, 2012; Bohbot, Lerch, Thorndycraft, Iaria, & Zijdenbos, 2007; Livingstone-Lee et al., 2011), and reviews have looked at cognitive processes that are involved in the performance of wayfinding (Allen, 1999; Wiener, Büchner, & Hölscher, 2009; Wolbers & Hegarty, 2010).

Of these cognitive processes, attention and memory play a vital role in our ability to wayfind. Visual attention plays an important role in wayfinding as it directs perception and processing towards objects in the environment (Desimone & Duncan, 1995; Posner & Boies, 1971; Posner & Petersen, 1989), and shifts in visual attention can be inferred from gaze (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler, Anderson, Dosher, & Blaser, 1995). For example, recent studies investigating gaze during wayfinding have focused on determining wayfinding strategies from gaze differences between sexes (Andersen et al., 2012; Mueller, Jackson, & Skelton, 2008). A focus on advancing understanding of the role of attention during wayfinding, as reflect by gaze, is importantly influenced by the characteristics of the visual scene. More specifically, the complexity of the visual scene likely has an important influence on the characteristics of gaze behavior and attention. Similarity, the familiarity of the visual environment would presumably influence the gaze characteristics (Greene & Rayner, 2001). Experimental approaches that often require repeated exposure of simulated visual scenes are therefore potentially susceptible to influences of these two factors: complexity and familiarity. Surprisingly there is relatively little understanding about how these factors may influence gaze behavior during wayfinding.

Just as attention is important so is memory specifically to store an internal representation of the environment (O'Keefe & Nadel, 1978) by storing landmarks and other visual information about the visual scenes (Hamid, Stankiewicz, & Hayhoe, 2010). The ability to store environments into memory is vital in the ability to plan routes and monitor our progression when wayfinding, and examining the interaction between attention and memory when wayfinding may lead to a better understanding of how we build these internal representations.

One factor that may be specifically important to forming internal representations is the active involvement in wayfinding in contrast to passive exposure to a visual environment. As an example, does the activity of actually driving a car, as opposed to being a passenger, improve the ability to store internal representation that would benefit subsequent wayfinding? This matter of active versus passive influences is also relevant to the use of virtual wayfinding as a method for rehabilitation for traumatic brain injury, stroke and Alzheimer's disease. This can be accomplished two separate ways, by actively wayfinding through an environment or by having someone passively wayfind by having another person control the movement through the environment. There has been a disagreement in the literature on the effect of active versus passive wayfinding on memory (Brooks, Attree, Rose, Clifford, & Leadbetter, 1999; Gaunet, Vidal, Kemeny, & Berthoz, 2001; Hahm et al., 2007; Wilson, 1999). Examining how these two modes of wayfinding influence both attention and memory will advance understanding of the cognitive determinants, such as attention and memory.

This thesis is composed of two studies. The first examined how familiarity and complexity of an environment influence attention as reflected by gaze behaviour. This work is essential as a precursor to the second study by informing about the appropriate selection of characteristics of the environments and the influence of trial repetition. The second study investigated the effect of active and passive wayfinding on attention, memory, and the interaction between the two cognitive processes.

Chapter 2: Literature Review

2.1 Defining Wayfinding

Whether it be going to work every day or finding our way through a new, unfamiliar city we are constantly monitoring the position of ourselves, our end goal, and planning or updating the path of how we get there. This is known as wayfinding, and is defined as the process of planning and following a route or path from an origin to a destination (Golledge, 1999). As simple as going from point A to point B may seem, wayfinding is a complex process that is comprised of many different strategies and requires several cognitive processes to be completed successfully.

Wayfinding as defined by Golledge (1999) has been separated into various tasks depending on our goals and our knowledge of the environment (Allen, 1999). Allen (1999) proposed that wayfinding could be subdivided into three main tasks: commuting, exploring and questing. Commuting involves travelling an extremely familiar route such as going to work every day, exploring consists of travelling through an unfamiliar environment with no specific end point selected and is used for the purpose of learning about an area, and questing involves travelling from a known starting point to an unfamiliar end point, where a route must be created and planned.

These different tasks can describe a majority of wayfinding behaviour, but these ideas were expanded on based on the amount of information known about the environment (Wiener et al., 2009). Wiener (2009) theorized that a different wayfinding tasks are performed based on the person's knowledge of three levels of spatial information: whether the location of the destination is known or unknown, the knowledge of the route from start point to end point, and survey knowledge which is whether the information regarding the entire region or area is known. Having no knowledge of the destination leads to two possible types of wayfinding according to Wiener (2009), uninformed search and informed search. If the person has no survey knowledge then they are performing an uninformed search as they do not know the area or where the destination is, whereas if they have survey knowledge of the area but they do not know the precise location of the destination they can make an informed search of the likely place the destination would be.

Knowing both the destination and the route leads to route following, merely follow the known route to the known destination. However if the route is unknown it could lead to two possibilities depending on the person's survey knowledge. They can either plan a route if they have survey knowledge of the area, or they must discover a route if they do not have survey knowledge of the region. This taxonomy also includes exploration as in Allen (1999), however this exploration is split depending on whether or not the person is out in a familiar area and travelling for the purpose of leisure such as taking a walk, or in an unfamiliar area where they are trying to acquire survey knowledge and learn the area such as being a tourist in an unfamiliar city.

The work of Wiener et al (2009) took the commuting, exploring, and questing tasks of Allen (1999) and subdivided them further based on the information the person has of the environment around them. Exploring was split in to two separate tasks based on whether the person is familiar with the surrounding area, questing involves either planning a route when the surrounding area is known or searching for a route when the surrounding area is unfamiliar and commute stayed relatively unchanged, with following a known route to a destination. This thesis investigates directed wayfinding which involves travelling to a known destination (Wiener et al., 2009), and therefore the task of exploring is not to be examined.

The taxonomies of Allen (1999) and Wiener (2009) can be simplified into two main tasks when performing directed wayfinding: path planning and path following. Path planning can be defined as the process of determining the correct route to get from a starting point to a destination. Path following is the updating of this planned route based on sensory inputs from the environment, and this updating is used in order to keep track of the current location within the route, to ensure the person is still on the route and to determine if changes need to be made to the planned route.

These two sub-divisions of wayfinding rely on several different spatial cues and cognitive processes in order to be performed efficiently and accurately. Route planning involves the use of distal and local landmarks, egocentric object-to-self distances, allocentric object-to-object distances, geometric structure of the environment, self-positioning and orientation, and stored representations of the environment in order to determine the best path to take in order to reach the destination (Wolbers & Hegarty, 2010). Route following uses the same processes as route planning in order to monitor the current location within the route, but also uses novelty detection to determine if the route is being deviated from, and self-motion detection in the form of optic flow in order to monitor the distance and speed travelled through the environment (Wolbers & Hegarty, 2010).

While these taxonomies have looked at classifying different types of wayfinding behaviour, further research has investigated different strategies associated with performing the task of wayfinding and separated the task into two strategies: allocentric and egocentric (Kolb, Sutherland, & Whishaw, 1983). Allocentric wayfinding uses the distances and relationships between objects within the environment in order to build an internal representation or cognitive map of the environment to aid wayfinding (O'Keefe & Nadel, 1978) while egocentric wayfinding involves using object-to-self distances and directions in order to reach a destination (Kolb et al., 1983; O'Keefe & Nadel, 1978). While some investigators believe these two strategies are not used in conjunction, but rather people wayfind using either one strategy or another (Andersen et al., 2012; Bohbot et al., 2007; Livingstone-Lee et al., 2011), it is more probable that people are constantly switching between strategies in order to successfully move from one location to another. An egocentric strategy can be used in order to monitor route progression and can also be used in route planning by updating the current location within the environment and the distance and direction of the destination in comparison to oneself, while an allocentric strategy is more likely used for route planning by using object-to-object distances and directions to map out the environment and plan the best possible route. Therefore using both an allocentric and egocentric strategy can be used to plan and monitor a route.

Successful wayfinding involves the use of both allocentric and egocentric strategies in order to perform the tasks of route planning and route monitoring using a large variety of input from the environment. The key to successful wayfinding is the ability to use landmarks in the environment for route planning and route following, and in order to properly use these objects they must be stored in memory so that they can be accessed for planning and monitoring.

At the core of performing the task of wayfinding are two cognitive processes: attention and memory. Memory allows us to store an internal representation of the environment that can be used to plan and monitor our progression along a route when wayfinding (O'Keefe & Nadel, 1978). In order to create this internal representation objects in the environment must be perceived and processed, which is controlled by visuospatial attention which directs perception and processing towards regions in visual space (Posner & Boies, 1971).

2.2 Role of Memory in Wayfinding

Memory has long been thought to have a vital role in wayfinding, with memory based areas in the brain such as the hippocampus being strongly tied to successful wayfinding (Maguire, 2000; Morris, Garrud, Rawlins, & O'Keefe, 1982; O'Keefe & Nadel, 1978). Specifically there are two memory systems that are connected but also independently important for wayfinding: visuospatial working memory and long-term memory (Squire, 2004; Tulving, 1972). Working memory is a system that can temporarily store and manipulate information during the performance of a task (Baddeley, 2003), and lasts from a few seconds to a few minutes, whereas long-term memory is a relatively permanent store involving information that has been consolidated from working memory (Atkinson & Shiffrin, 1968).

Visuospatial working memory is a limited capacity system that can be used for maintaining and manipulating visuospatial images (Baddeley, 1983) and when wayfinding the use of this system is critical for maintaining a representation of the environment (Wolbers & Hegarty, 2010). This is used in wayfinding by temporarily storing landmarks within the environment for use in both route planning and route monitoring, as these objects are used for the many factors as described in section 2.1 (Wolbers & Hegarty, 2010).

Visuospatial working memory can further be divided, as there is evidence for separate visual and spatial working memory systems (Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999; Hecker & Mapperson, 1997; Tresch, Sinnamon, & Seamon, 1993). This indicates that the visual representation of a landmark and its spatial location within the environment may be stored separately within working memory, however both of these memory systems would be necessary in order to maintain a representation of an environment.

Over repeated practice and consolidation the information that is being held in visuospatial working memory such as landmarks, their locations, and the geometric structure of the environment can be transferred to long-term memory (Baddeley, 1992). Long-term memory is divided into two systems, declarative memory which represents the ability for conscious recollection of facts and events and non-declarative memory which involves modifications of performance systems (Squire, 2004; Tulving, 1972). Declarative information regarding objects in the environment and their spatial location can be stored as an internal representation, or cognitive map (O'Keefe & Nadel, 1978). It has also been argued that information regarding the environment stored into long-term memory can be separated just as visuospatial working memory is, that memory for the items themselves and the spatial information about those objects can be held separately (O'Keefe & Nadel, 1978; Squire, Stark, & Clark, 2004). This may indicate two related but separate systems for storing an environment involving the visual components of a landmark and its spatial location within the environment starting from working memory and into long-term memory.

Non-declarative long-term memory can also be important in the process of human wayfinding as there are many sensorimotor components such as repetition of locomotor patterns and path integration (Allen, 1999). The continual repetition of a route can lead to non-declarative learning of these motor patterns or path integration that cannot be explicitly recalled and therefore are indicative of non-declarative learning that can be used in order to aid wayfinding.

The purpose of memory in wayfinding is to store an internal representation of the environment in order to plan routes, as well as to be used by comparing current sensory information with this representation in order to monitor the current location within the route (O'Keefe & Nadel, 1978). This is done by storing landmarks and the structure of the environment within visuospatial working memory for immediate use and then transferring this information into long-term memory to consolidate the internal representation of the environment into a more permanent store. Non-declarative information about motor patterns used and path integration can also be used in order to aid wayfinding but may not be as vital as declarative information.

While memory plays a key role in our ability to wayfind the way in which we learn an environment may influence our ability to store it into memory. An example there may be a potential benefit for storing an environment into memory if we actively participate in moving about the environment while learning it as compared to learning the environment by being passively moved through it.

2.3 Memory and the Influence of Active vs. Passive Wayfinding

Existing literature on the influence of active and passive wayfinding on memory have not found any effect of the method of wayfinding on both the ability to recall an object (Hahm et al., 2007; Wilson, 1999)or its spatial location within the environment (Brooks et al., 1999; Gaunet et al., 2001). These studies have not controlled well for the exposure to the environment across conditions, which may lead to the inability to see a difference in the ability to recognize or recall objects between environments that are learned actively and environments that are learned passively.

2.4 Role of Attention in Wayfinding

The building of an internal representation in visuospatial working memory which can then be stored into long-term memory is influenced by attention (Awh, Vogel, & Oh, 2006; Hollingworth & Henderson, 2002; Schmidt, Vogel, Woodman, & Luck, 2002). This is evident by the fact that taking attention away from a target impairs the ability to remember that target (Smyth & Scholey, 1994), and there is an abundance of evidence pointing to a functional overlap of visuospatial attention and working memory (Awh & Jonides, 2001; Theeuwes, Belopolsky, & Olivers, 2009) indicating that the two are closely tied to one another. This shows that attention plays a vital role in the ability to maintain information within visuospatial working memory, which can then be used for wayfinding.

Attention is a limited capacity system which involves detecting and orienting to sensory events for perception and processing, and maintaining a state of alertness or vigilance towards a stimuli (Desimone & Duncan, 1995; Posner & Boies, 1971; Posner & Petersen, 1989). Attention is sometimes referred to as a "spotlight" which can be directed to different areas within the surrounding environment, and the size of the area it is directed towards can be widened or narrowed (Treisman & Gormican, 1988).

There are two mechanisms for directing visual attention with attention being shifted either exogenously or endogenously (Corbetta & Shulman, 2002). Exogenous control of visual attention involves orientation to a sensory event that is unexpected or highly salient (Corbetta & Shulman, 2002). The extent to which an object stands out in its environment is referred to as saliency, and researchers have developed saliency maps in order to determine which objects within the environment are most likely to draw a shift in attention (Itti & Koch, 2000, 2001; Parkhurst, Law, & Niebur, 2002). Endogenous control of attention involves a cognitive selection of a target for a shift in attention based on knowledge or behavioural goals and is more consciously controlled (Corbetta & Shulman, 2002). Unlike exogenous control of attention endogenous control involves seeking out task relevant objects and the direction of attention towards those objects. It is generally agreed that both exogenous and endogenous control of attention occur in order to direct perception and processing of our environment (Corbetta & Shulman, 2002; Peters, Iyer, Itti, & Koch, 2005) although the extent to which each type of control contributes is not agreed upon (Henderson, 2007; Itti & Koch, 2000).

The role of attention in our ability to store a representation of the environment into memory is extremely important, but we need to be able to determine where our attention is allocated in the environment in order to determine what components of the environment are most likely to be stored in our internal representation.

2.5 Use of Gaze Location as Index of Attention

Where our attention is located in the environment can be inferred from where our gaze is located as there is evidence of a strong coupling between attention and gaze when a gaze shift occurs (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler et al., 1995). Attention is required in order to select a saccade target, therefore when a gaze shift towards a region occurs it indicates that attention is also being directed to that region and is termed an overt shift in attention. However once gaze is maintained at that location, it is possible to dissociate gaze and attention (Wundt, 1912) as objects in the periphery of vision can be perceived and processed (Munn & Geil, 1931) and this process of shifting attention without shifting gaze is referred to as a covert shift of attention.

The link between acquiring visual information and the associated attentional control is vital in gating the storage of information into visuospatial working memory (Awh et al., 2006; Hollingworth & Henderson, 2002; Schmidt et al., 2002), which can then be stored into long-term memory after rehearsal and consolidation (Atkinson & Shiffrin, 1968). This attentional control of vision is accomplished using both exogenous and endogenous control to direct attention towards salient and task relevant objects in the environment for perception, processing and storage into memory. Understanding of the underlying attentional focus can be revealed in part by the measurement of gaze.

While there are many different components to gaze behaviour (Land, 2006), three of these are important in the ability to perceive the environment around us: vergence, saccades, smooth pursuit movements and fixations. Saccades are rapid movements of the eyes used to bring a new region of the scene into foveal vision (Land, 2006; Rayner, 1978) and reflect an overt shift in attention (Henderson, 2003), smooth pursuit eye movements involve a smooth rotation of the eye maintaining foveal vision on a moving target (Lisberger, Morris & Tychsen, 1987), and a fixation which is a period of relative stability of the eye and on average last approximately 300 ms during the viewing of a scene (Buswell, 1935; Land, 2006). It is believed that visual information is processed during a fixation (Loftus, 1972) with the length of the fixation possibly reflecting the amount of processing that is occurring (Rayner, 1978).

The importance of all these components is to maintain foveal vision on a target as foveal vision plays an important role in the ability to perceive and process objects. The importance of maintaining foveal vision on a target is due to visual acuity being highest at the fovea (Anstis, 1974), with foveal vision corresponding to approximately 2° around the fixation point (Henderson & Hollingworth, 2003; Land 2006; Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981). Since acuity is highest in the fovea, being able to extract details about an object or region in space requires that are to be placed on the fovea (Anstis, 1974; Land, 2006). In order to perceive and process the world around us we need to shift foveal vision via a saccade to a location of interest and keep this location on the fovea via fixation or smooth pursuit in order to perceive and process the region of interest.

Studies of gaze in wayfinding have mostly investigated the use of different wayfinding strategies (egocentric or allocentric) and infer which strategy is being used by what regions of the scene or landmarks gaze is being directed towards

(Andersen et al., 2012; Bohbot et al., 2007; Livingstone-Lee et al., 2011), or to investigate sex differences in gaze while wayfinding between men and women (Andersen et al., 2012; Mueller, Jackson & Skelton, 2008). While much of the research in gaze behaviour during wayfinding looks to uncover strategies and sex differences, little has been done investigating how different characteristics, such as the familiarity or complexity of an environment, influence gaze and attention.

2.6 Familiarity and Complexity on Attention

Familiarity is the amount of knowledge one has about the environment, a novel environment is new to a person and they have very little knowledge of it where a familiar environment is well known, and after repeated exposure or practice a novel environment can become familiar. We encounter these types of environments all the time, whether it is the familiar route to work or our office, or the novelty of a new city or a new building we have never been in. Novel and familiar environments can have very different cognitive demands, which are most likely linked to the use of the internal representation or cognitive map proposed by O'Keefe and Nadel (1978).

An internal representation of the environment helps wayfinding by allowing us to use stored spatial relations between objects and ourselves to plan a route to our destination (O'Keefe and Nadel, 1978), but in order to use a stored representation of an environment there must be an existing knowledge of the environment. When an environment is novel we have no knowledge of the environment and therefore no internalized representation, so a representation must be built. In order to store information about the environment into memory, gaze and attention must be directed towards regions in order for them to be perceived and processed (Posner & Boies, 1971). These demands are very different than a familiar environment where visual information about the environment is being compared to what has already been stored in the representation in order to monitor progress through the environment. The differences between trying to build an internal representation in a novel environment, and comparing visual information to an existing representation may have very different effects on gaze and the allocation of attention.

Complexity refers to the amount of visual stimuli in an environment and the detail of those stimuli, and is a major factor that varies between different environments with a place such as Times Square in New York having far more stimuli than an open countryside and thus being more complex. The differences in the cognitive demands between a low and high complexity environment are linked to the amount of stimuli present within the environment, while in a high complexity environment there are far more stimuli that need to be perceived, processed and stored into memory than a low complexity environment and will result in more overt shifts in attention and therefore more shifts in gaze. These shifts in gaze will be driven by both exogenous control of attention to salient objects in the environment and endogenous control to task relevant objects within the environment (Corbetta & Shulman, 2002; Itti & Koch, 2000, 2001; Parkhurst, Law, & Niebur, 2002).

Little research has been conducted on how differences in the familiarity or complexity of environments influence gaze behaviour and the allocation of attention during wayfinding, although some research has been conducted in the field of visual search on the effect of familiarity. Familiar distracters in a visual search task result in a decreased number of fixations in order to find the target, with no change in the duration of fixations between the two conditions (Greene & Rayner, 2001). This may transfer to wayfinding as a familiar environment contains familiar objects within it and fewer gaze fixations may be required to extract information required to plan and follow a route. The understanding of how familiarity and complexity affect gaze and attention during wayfinding may help guide the selection of environments for further research, or for rehabilitation programs.

2.7 Objectives

This thesis contains two studies that are focused on the following research objectives, respectively:

Study 1: The effects of familiarity and complexity of the environment on the allocation of attention to landmarks as measured by gaze behaviour.

- To examine the effect of familiarity of an environment on gaze behaviour during wayfinding
- To examine the effect of complexity of an environment on gaze behaviour during wayfinding

Study 2: The influence of active or passive wayfinding through an environment on the ability to remember landmarks.

- To examine the influence of active and passive wayfinding on the ability to store an environment into memory.
- To examine if the allocation of attention when learning an environment influences the ability to store an environment into memory.

Chapter 3: Study 1

3.1 Introduction

Every day we move through our environment and vision plays an important role in guiding our movement, whether it is the avoidance of obstacles or planning our route to a destination. The process of determining and following a route or path between a destination and an origin is wayfinding (Golledge, 1999), and vision along with attention plays a critical role in successful wayfinding. Increasing the understanding of the role of vision and attention in wayfinding may lead to uncovering why certain populations such as dementia and Alzheimer's (Rainville, Passini, & Marchand, 2001), and stroke (van der Ham, Kant, Postma, & Visser-Meily, 2013) show difficulties with wayfinding. This study aims to learn how different features of an environment can influence how vision and attention is allocated when we navigate through an environment.

Vision is used during wayfinding for two main reasons: route planning and route monitoring. During route planning vision is used in order to perceive local and distal landmarks and use these landmarks to determine egocentric self-to-object differences and allocentric object-to-object distances (Wolbers & Hegarty, 2010). As with route planning, route monitoring uses landmarks for route progression, novelty detection and self-motion detection (Wolbers & Hegarty, 2010). The key to all these processes is the use of landmarks, as they are stored in memory in order to remember and environment (Hamid et al., 2010) or used to update an existing representation of the environment (O'Keefe & Nadel, 1978). In this study landmarks will be any object in the environment that could be used to determine the participant's location within the environment.

A shift in gaze to a region of a scene indicates an attentional shift towards that region (Deubel & Schneider, 1996; Henderson, 2003), and storing a representation of a scene is controlled by attention (Awh et al., 2006; Hollingworth & Henderson, 2002). This means that landmarks in the environment that are fixated on are attended to and therefore more likely to be stored into memory and used for wayfinding, and the link between gaze behavior and attention means that the direction of gaze can be used to infer the allocation of attention. Research has also found landmarks that are fixated on more frequently are more likely to be used in subsequent trials of wayfinding (Hamid et al., 2010), and once one of these landmarks are fixated on the duration of the fixation reflects the amount of processing that is occurring on that landmark (Rayner, 1978).

There are many potential factors that may affect gaze behaviour and therefore the allocation of attention during wayfinding, such as familiarity with the environment, the saliency of an object in the environment and the visual complexity of the environment. Much work has been conducted on the effects of saliency on vision, but there has been some disagreement recently. It has been thought that the saliency of objects drove gaze behaviour in naturalistic scene viewing (Parkhurst et al., 2002), but there has been some research pointing otherwise (Henderson, 2007). This study will focus on the familiarity and visual complexity of environments. Familiarity of an environment would relate to the participants knowledge of an environment, with more information known about an environment resulting in being more familiar with the environment. Visual complexity of an environment would relate to the amount of visual stimuli in the environment and the amount of detail in those stimuli. Therefore the purpose of this study is to determine how familiarity with an environment as well as the visual complexity of the environment can influence gaze behaviour, and therefore attention.

The effect of familiarity on gaze behaviour has been shown in visual search tasks showing that with more familiar distracters a lower number of fixations occur, and fixation duration is unaffected (Greene & Rayner, 2001). It has also been demonstrated that a preview of a scene prior to viewing led to a more effective search strategy, showing that familiarity with a scene resulted in fewer fixations to find a target and a shorter search time (Henderson et al., 2007). The complexity of a scene has also shown an effect on gaze behaviour, with more complex visual scenes resulting in higher saccade rates (Otero-Millan, Macknik, Langston, & Martinez-Conde, 2013), however no studies have examined the effect of complexity on fixation duration.

This leads to 4 main hypotheses for this study.

1) In novel environments, the number of gaze fixations on landmarks will be higher when compared to a familiar environment.

2) In complex visual environments there will be an increased number of fixations on landmarks compared to less visually complex environments.

3) Fixation durations will not change between task conditions.

4) Total fixation time (time spent fixating on objects/trial time) on objects in the environment will decrease with familiarity and less visual complexity as a result of decreased number of fixations on objects and no change in fixation durations.

3.2 Methods

3.2.1 Participants

Ten young healthy adults participated in the study (age 24.2±2.86). The group consisted of 5 male and 5 female participants. All participants were required to have normal or corrected to normal vision without eyeglasses, as the eye tracker system cannot fit over eye glasses.

3.2.2 Instrumentation and Data Acquisition

Gaze behaviour was collected using the ASL Mobile Eye-XG Eye Tracking System (Applied Science Laboratories, Bedford, Ma). The eye tracking system was calibrated to the computer screen which participants were performing the task on with the placement of icons at positions covering all corners and several intermediate positions on the screen. The eye tracking system collects x and y coordinates of eye position at a rate of 30 Hz and stored as a video. The scene in front of the participant is collected using a camera with a rate of 30 Hz and resolution of 1600x1200 pixels. The programs were presented to participants on a 48x27.2 cm computer monitor placed 60cm away from the participant.

3.2.3 Programs

Visual environments were selected or created using two computer programs; Google Earth (Google Inc, Mountain View, Ca.) and Minecraft (Mojang, Stolkholm, Sweden), with a total of 4 different environments used for each condition. Google Earth environments represented the complex visual situations, as there was more detail and visual stimuli present in these environments. Conversely, the Minecraft environments represented the low visual complexity trials as there was less detail and visual stimuli within these environments. The four environments that were selected for Google Earth were Mexico City, Toronto, Tokyo and Calgary while 4 environments were created in Minecraft that replicated a city block/grid structure.

Fig 3.1: High complexity Google Earth environment and low complexity Minecraft environment.

3.2.4 Experimental Procedure

The study was split into two sessions on two separate days to minimize fatigue that may occur with the tasks. The first day involved completion of all 4 environments on either the high or low visual complexity condition while the second session involved completion of all 4 environments on the second condition. The order of task complexity was counterbalanced across participants, and the order of the environments in each session was randomized.

Each session began with the participants performing a practice trial to familiarize themselves with the computer program. Participants were instructed to travel through a practice environment until they felt comfortable with the movement controls, which involved using the arrow keys on the keyboard and the mouse. Once participants felt comfortable with the movement controls they were fit with the eyetracker system, which was then calibrated to the computer screen.

Participants then travelled through each environment 4 times, resulting in a total of 16 trials per condition. Each trial consisted of the participant beginning at a starting point with an end point visible in the distance, which was represented by a large tower. The participant was instructed to make their way to the tower/endpoint and upon reaching it return to the starting point along the same route to the best of their ability. Upon reaching the starting point their view of the screen was obscured and the screen was reset to the starting position. This process was repeated until the participant completed the environment 4 times. Participants were allowed to take a break if needed between blocks of trials to relieve themselves of the eyetracking system which can result in some discomfort if worn for a prolonged period of time. After the break the glasses were placed back on the participant and re-calibrated before beginning the next environment. The high visual complexity task condition took approximately 2 hours to complete, while the low visual complexity condition took approximately 1.5 hours to complete.

3.2.5 Data Analysis

Initial data analysis of fixations was done using a custom Labview program (National Instruments, Austin, Tx). The program selected fixations by determining if the location of foveal vision did not differ by more than 7 pixels for 3 or more consecutive frames, which corresponds to 100 ms. The limit of at least 100 ms has been used in several studies (Andersen et al., 2012; Mueller et al., 2008), while the 7 pixel distance threshold is smaller than some studies (Mueller et al., 2008). The reason a smaller threshold was chosen is due to the close proximity of buildings in the Google Earth program, and a smaller threshold allows detection of small gaze changes between adjacent buildings.

Only trials 1 and 4 were analyzed for this study, as they represent the points when the environment is novel (trial 1) and familiar (trial 4). Once fixations were qualitatively determined they were manually confirmed using the video file from the eye tracking system. The manual confirmation was also used to label whether fixations fell on landmarks in the environment that could be used for wayfinding or if they fell on uninformative regions of the scene, such as the sky or ground.

Fixation rate was calculated by taking the number of fixations that fell on landmarks within the environment and dividing it by the length of the trial. Fixation rate was used as opposed to the total number of fixations as participant could take different routes, or may take longer using the same route, which would result in an increased number of fixations due to spending more time inside the trail. Average fixation duration was calculated using all fixations that fell on objects within the environment. Total fixation time was calculated by dividing the total time spent fixating on objects in the environment by the trial time, giving the percentage of the trial spent fixating on objects in the environment.

3.2.6 Statistical Analysis

An evaluation of the normality of distribution of residual errors was conducted to ensure the appropriateness of conducting parametric analysis. A three way repeated measures ANOVA with factors: visual complexity, familiarity and direction were conducted for fixation rate, fixation duration and total fixation time. Statistical significance was determined by value of $p<=0.05$.

3.3 Results

3.3.1 Fixation Rate

A main effect of familiarity was seen on fixation rate ($F_{(1,9)}$ = 161.01, p<0.0001) as well as main effects of complexity ($F_{(1,9)}$= 87.12, p<0.0001) and direction ($F_{(1,9)}$=87.12, p<0.0001). No interaction effect between familiarity and complexity was seen ($F_{(1,9)}$= 2.7, p=0.1345). Fixation rate in the familiar condition was significantly lower than the novel condition, with average fixation rates of 54.4±27.0 fixations/minute and 81.6±28.5 fixations/min respectively (Fig 2A). The low complexity condition showed a decrease in fixation rate when compared to the high complexity condition with average fixation durations of 48.8±22.7 fixations/min and 87.6±25.2 fixations/min (Fig 3.2B). The fixation rate when travelling to the tower (73.4±29.7 fixations/min) was significantly higher than returning to the starting point (62.6±31.1 fixations/min).

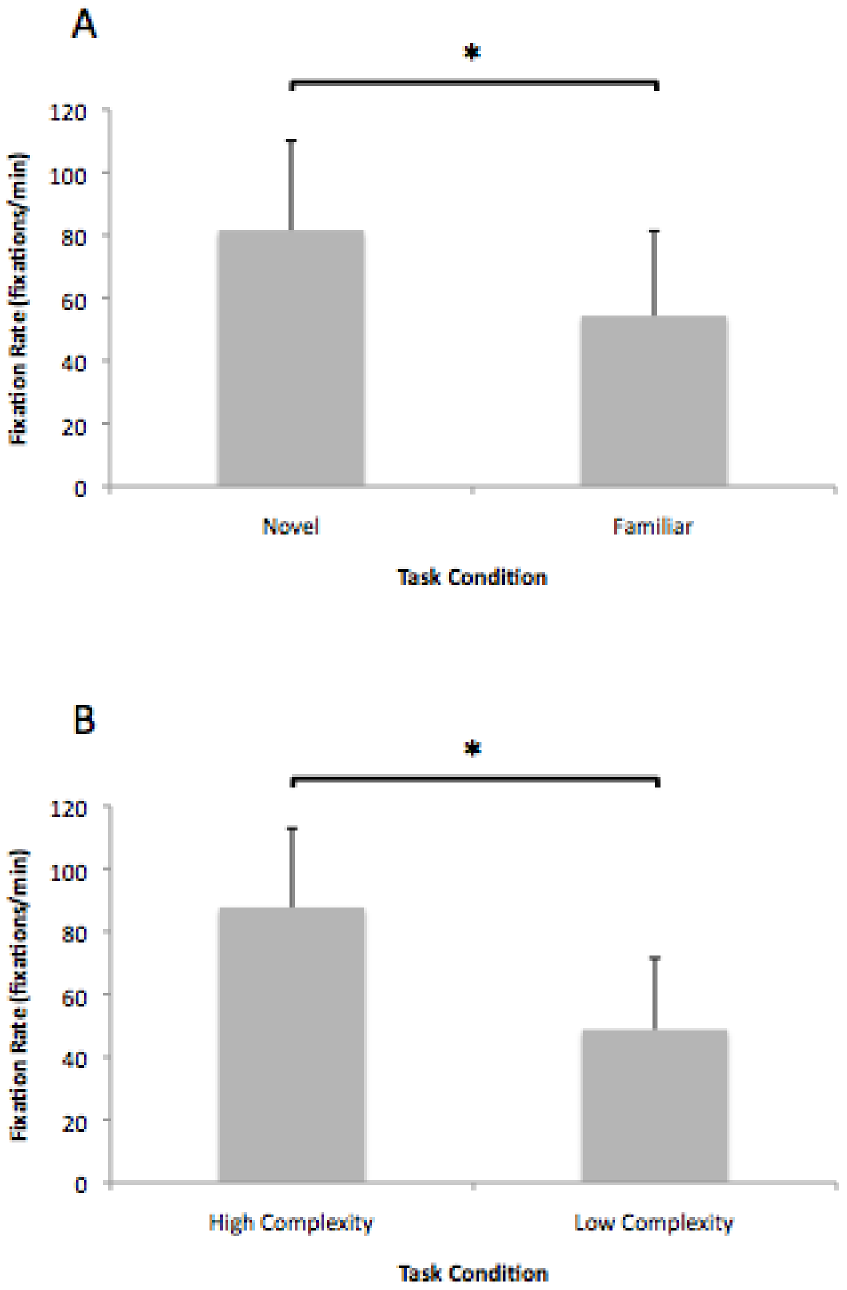

Figure 3.2: Effect of task condition on fixation rate: (A) Mean fixation rate for novel and familiar task conditions; (B) Mean fixation rate for high and low complexity task conditions; *denotes statistically significant differences ($p<0.05$).

3.3.2 Fixation Duration

A main effect of complexity ($F_{(1,9)}$=18.12, p=0.0021), and familiarity ($F_{(1,9)}$=23.04, p=0.001) was seen on average fixation duration, and an effect of direction approached statistical significance ($F_{(1,9)}$=4.74, p=0.0575). No interaction effect between familiarity and complexity was seen ($F_{(1,9)}$=0.24, p=0.6359). The high visual complexity condition showed an average fixation duration of 371.0±109.1 ms while the low visual complexity condition had an average fixation duration of 466.2±193.9 ms (Fig 3B). The average fixation duration for the novel task condition was 363.4±97.3 ms which was significantly lower than the familiar task condition showing an average fixation duration of 474.4±196.9 ms (Fig 3.3A). No significant difference in average fixation duration was seen between travelling to the tower or the starting point, with average fixations of 405.2±155.6 ms and 433.2±172.5 ms respectively.

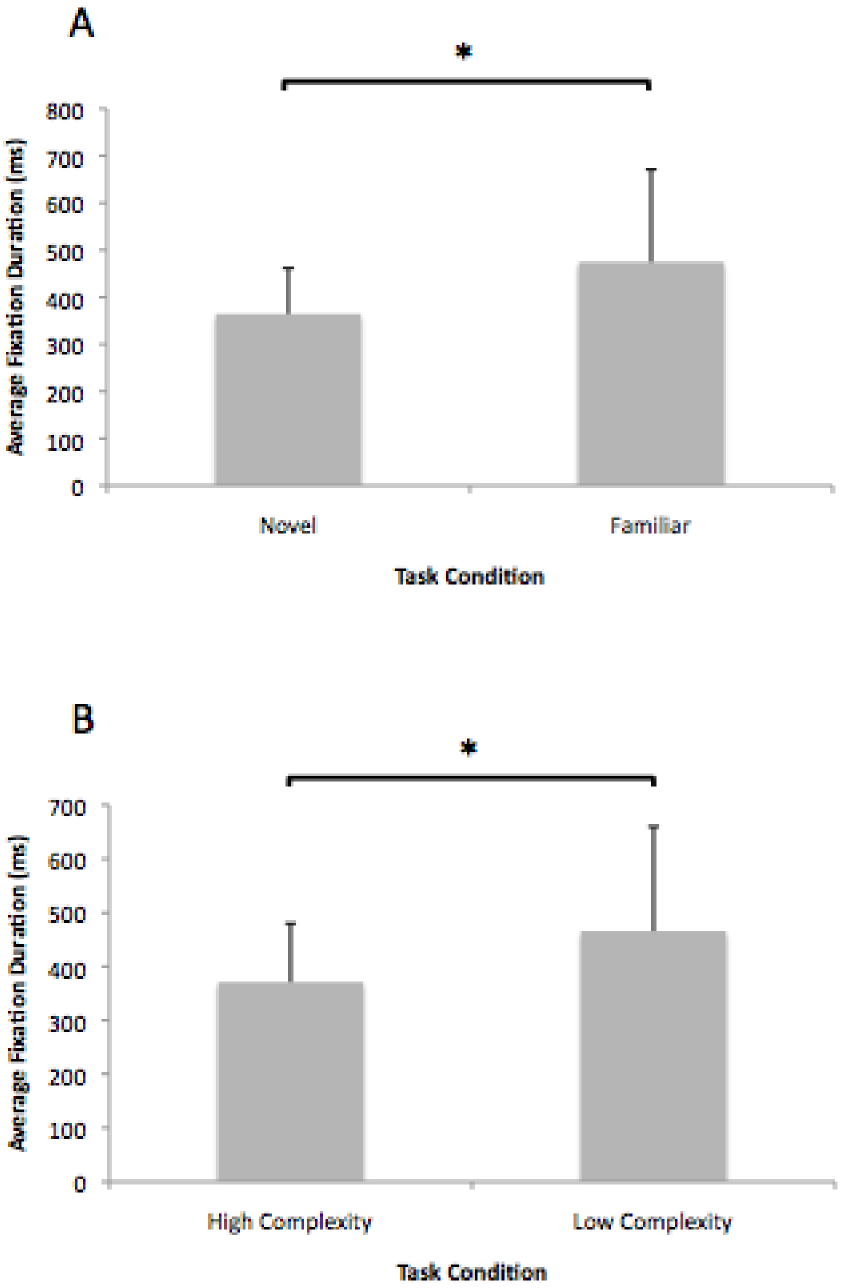

Figure 3.3: Effect of task condition on average fixation duration: (A) Mean average fixation duration for novel and familiar task conditions; (B) Mean average fixation duration for high and low complexity conditions; * denotes statistically significant differences ($p<0.05$).

3.3.3 Total Fixation Time

Main effects of familiarity ($F_{(1,9)}$=18.78, p=0.0019), complexity ($F_{(1,9)}$=64.03, p<0.0001) and direction ($F_{(1,9)}$=22.84, p=0.001) were seen on total fixation time. An interaction effect between familiarity and complexity was seen ($F_{(1,9)}$=12.42, p=0.0065). Total fixation time was significantly lower in the familiar compared to the novel task conditions with respective means of 39.8±18.8% of trial and 46.0±14.4% of trial (Fig 3.4A). The mean for the low complexity condition of 35.8±16.2% of trial was significantly lower than that of the high complexity condition at 50.2±14.6% of trial (Fig 3.4B). The total fixation time for travelling to the tower was significantly higher than the mean for travelling to the starting point with respective means of 45.4±16.7 % of trial and 40.5±17.0 % of trial.

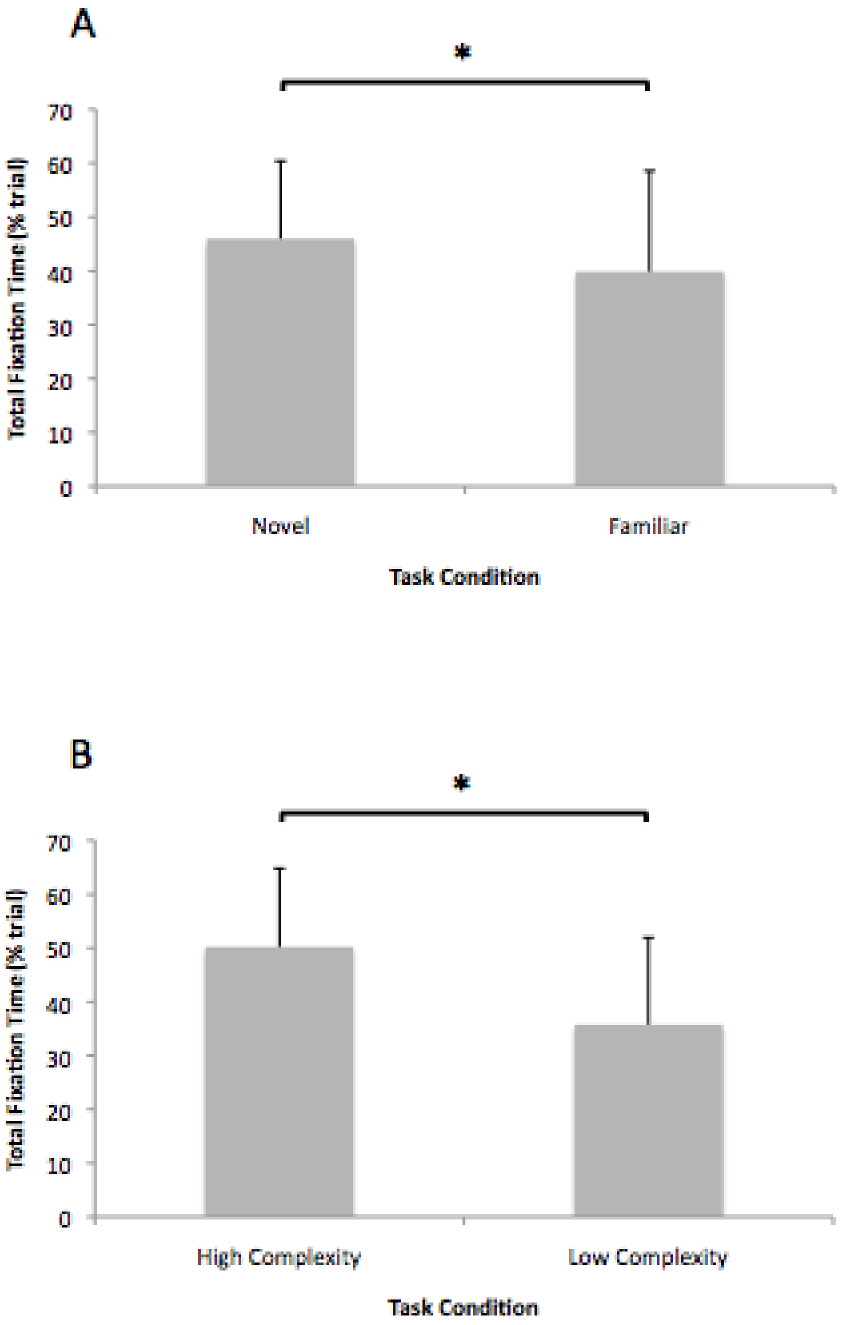

Figure 3.4: Effect of task condition on total fixation time: (A) Mean total fixation time for novel and familiar task conditions; (B) Mean total fixation time for high and low complexity task conditions; *denotes statistical significance ($p<0.05$).

3.4 Discussion

The results of this study support the hypotheses that with novel and more complex environments the number of fixations on landmarks increases. However in contrast to the second hypothesis fixation duration was longer for familiar and more complex environments when compared to novel and less complex environments. Overall, total fixation time on landmarks within the environment was greater for novel and more complex conditions. Since there is a strong link between a shift in gaze and a shift in attention (Deubel & Schneider, 1996; Henderson, 2003) it is assumed that increased fixations and total fixation time on landmarks reflects a task related increase in directed attention in novel and complex environments. An interaction effect was seen between familiarity and complexity when examining total fixation time. Little difference was observed between novel and familiar conditions in the high complexity environments while a large difference was seen between novel and familiar conditions within the low complexity environments. An effect of direction was seen on both fixation rate and total fixation time, with average fixation duration approaching significance, however no apriori hypotheses had been made regarding direction.

It was hypothesized that there would be no change in average fixation duration due to findings in visual search paradigms that duration was unchanged whether visual search targets were novel or familiar (Greene & Rayner, 2001).

3.4.1 Familiarity

The reason for increased number of fixations and attending to these landmarks in less familiar environments may be linked to the role of attention in gating what is stored into memory (Hollingworth & Henderson, 2002). When the environment is novel people may attend to many objects within the environment in order to try and store as many of these into their internal representation (O'Keefe & Nadel, 1978) as possible, which would result in a large number of fixations on these objects. Once the environment becomes familiar the internal representation of the environment is built and it is not necessary to attend to landmarks for the purposes of storing, and fixations on landmarks in the environment might then be used as references to monitor the current position on the route, and therefore fewer fixations on landmarks are needed.

With the environment remaining unchanged over the four trials the objects within the environment would remain the same and would transition from being novel to familiar. This would be the same as comparing novel and familiar objects within Greene & Rayner's (2001) visual search study that resulted in no change in the duration of the fixations. However in the current study average fixation durations were longer in familiar trials when compared to novel trials. Since the participant is familiar with the environment and the objects within it, an increase in the time to process information within the fixation is likely not the reason for the increase in average fixation duration. A more likely explanation may be that the fixations serve not just to extract information but as a stable gaze point during wayfinding that serves to anchor the visual scene. In this way foveal vision can be maintained and peripheral field information can be used to monitor self motion. This means that while the fixation duration is increasing, processing of the object may remain the same and attention may be directed peripherally to monitor progress along the route.

Fixation rate decreased with increased familiarity and even though fixation duration increased, total fixation time decreased. The interaction effect would indicate that this was largely due to the difference between novel and familiar environments in the low complexity task condition as there was little difference in total fixation time between novel and familiar trials within the high complexity task condition. Little difference in the total fixation time between novel and familiar task conditions in the high complexity environments even though a decrease in fixation rate was seen may be influenced by the increase in average fixation duration. As with fixation rate the decrease in total fixation time in the familiar task conditions particularly in the low complexity environment may be linked to the use of an internal representation of the environment as described by O'Keefe & Nadel (1978) to aid wayfinding, and therefore less total time is spent attending to and processing landmarks as they are likely being used as references to the person's current location within the environment instead of being used to construct the internal representation.

3.4.2 Complexity

In the less visually complex condition the observed decrease in fixation rate could be due to the fact that there is merely less stimuli in the environment. Less visual stimuli in the environment would mean fewer landmarks need to be stored into memory in order to remember the environment. With fewer objects needing to be stored, fewer fixations may be required in order to build an internal representation of the environment.

Although it was thought that fixation duration would remain the same between conditions, an increase in fixation duration was seen when comparing the low to the high conditions. This increase in fixation duration can be a result of increased processing in the form of planning the route ahead but it is also possible they are maintaining foveal vision in one section of the scene but are peripherally attending to the scene. The role of peripheral vision in wayfinding is related to the ability to build and monitor the spatial representation of the scene (Fortenbaugh, Hicks, Hao, & Turano, 2007; Turano, Yu, Hao, & Hicks, 2005), while the high acuity foveal vision is used for extracting features of specific objects (Anstis, 1974; Land, 2006). With fewer objects in the low complexity task conditions, fewer gaze shifts to move foveal vision across objects to feature extract are required, and vision is maintained at one location while peripheral vision is used to monitor spatial aspects of the environment resulting in an increase in fixation duration.

The hypothesis of decreased total fixation time in the less visually complex task condition was also supported even though there was an increase in average fixation duration and the increase in average fixation duration might suggest that there is more processing per fixation. However, as noted the fixations may be used as a mechanism to stabilize the visual field when navigating in order to monitor spatial aspects of the environment peripherally. The decrease in total fixation time was therefore driven by fewer fixations on landmarks which may be related to fewer objects in the environment that need to be processed.

3.4.3 Direction

A decrease in fixation rate and total fixation time was seen when participants are making their way back to the starting point when compared to the initial excursion out to the tower, while an increase in average fixation duration when travelling to the start approached significance. The differences in the number of fixations and total time spent fixating on objects in the environment could be related to the purpose that those fixations serve. For example, it has been shown in visual search that gaze behaviour changes when participants are searching a scene for an object compared to trying to store the environment into memory (Henderson, 2003). When travelling to the tower fixations may be used for selecting information for storage in order to build and internal representation of the environment, while when returning to the starting point fixations may serve the purpose of searching for previously stored information in order to determine the participant's location within the environment.

3.5 Conclusions

The results of this study indicate that when an environment is more familiar or not as complex less overt attention needs to be directed to landmarks in order to successfully complete wayfinding that is possibly due to the use of an internal representation of the environment and less stimuli within the environment respectively.

The tight coupling of attention and gaze during a gaze shift is the basis for inferring the allocation of attention from gaze in this study, however once gaze is maintained at a location it is possible that attention is directed to objects in the periphery and not where foveal vision is allocated (Munn & Geil, 1931, Wundt, 1912). This is supported in spatial learning tasks as occlusion of peripheral vision results in decreased performance on learning the spatial layout of an environment (Fortenbaugh et al., 2007). This shows that once vision is maintained on a location it is possible to dissociate gaze and attention, however a gaze shift towards a target indicates that attention is directed towards that target, as attention is required to select the target for a saccade (Deubel & Schneider, 1996). Therefore it can be concluded that increased familiarity and decreased complexity require less overt attention to and processing of objects within the environment in order to successfully wayfind.

Chapter 4: Study 2

4.1 Introduction

Travelling through our environment requires wayfinding, which is the process of planning and following a route from an origin to a destination (Golledge, 1999). Wayfinding involves the use of many sensory and cognitive processes (Wolbers & Hegarty, 2010), however the use of landmarks in the environment in order to build a representation of the environment and monitor the current location within the environment is possibly the most important aspect of successful wayfinding.

Landmarks are used in wayfinding for many reasons such as allocentric object-to-object distances and directions, egocentric self-to-object distances and directions, determining the geometric structure of the environment and novelty detection (Wolbers & Hegarty, 2010). In order to use these landmarks for these processes and to aid in wayfinding an internalized representation of the environment and landmarks needs to be maintained (O'Keefe & Nadel, 1978). This maintenance of an internal representation of the environment is initially accomplished with visuospatial working memory, which is a limited capacity system for maintaining visuospatial images in order to complete a task (Baddeley, 1983). Visuospatial working memory is divided into two separate systems, one system storing visual information about an object and the second storing spatial information with regards to an object (Della Sala et al., 1999; Hecker & Mapperson, 1997; Tresch et al., 1993).

After rehearsal and consolidation the information held in visuospatial working memory can be transferred to the more permanent long-term memory store (Baddeley, 1992) which is separated into declarative and non-declarative memory systems (Smyth & Scholey, 1994; Tulving, 1972). As with working memory, it has been thought that visual information about an object and spatial information related to it are held separately within declarative memory (O'Keefe & Nadel, 1978; Squire et al., 2004) indicating that there are separate memory stores for details of an object and spatial information regarding that object from working memory through to long term memory.

Attention selects information in the environment to be stored into memory (Awh et al., 2006; Hollingworth & Henderson, 2002; Schmidt et al., 2002) and the direction of attention towards an object leads to a better storage of that object into memory (Hamid et al., 2010; Loftus, 1972; Smyth & Scholey, 1994). The link between visuospatial attention and working memory indicates that if attention is directed towards certain landmarks then it is more likely for those landmarks to be stored into memory. Since there is a coupling between a shift in gaze and a shift in attention (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler et al., 1995) a shift in gaze towards an object likely indicates a shift in attention towards that object. The directing of attention, overtly or covertly towards an object could serve many purposes, whether it is for feature extraction of the object to store into memory or other purposes such as the guiding of movement. Regardless of the reason that attention is directed towards an object, it has been shown that this will result in an increased probability of this object being stored into memory.

Previous research has shown a relationship between the building of an internal representation and the allocation of gaze and attention (Phillips, 2014), with an important observation being that the familiarity of an environment shows an influence on gaze behaviour. With repeated exposure to environments, the number of fixations and the total time spent fixating on landmarks decreases. It was proposed that this shift over repeated trials is associated with the learning of the environment and an increased reliance on an internal representation of the environment. While a variety of factors can influence learning of an environment (individual or environmental factors) the focus of the current study is how the mode (active or passive) in which an environment is learned influences gaze behaviour and the allocation of attention. While little research has been performed on how gaze behaviour is influenced by the mode of wayfinding, actively learning an environment may increase engagement in the task which may lead to an increase in gaze towards task relevant objects.

Existing literature on the influence of actively or passively wayfinding through an environment showed an increase in wayfinding ability in actively learned environments (Farrell et al., 2003; Wallet & Sauzéon, 2008; Wallet, Sauzéon, Larrue, & N'Kaoua, 2013). However previous studies have failed to show a difference in the ability to recall objects in the environment (Hahm et al., 2007; Wilson, 1999) as well as the ability to learn the spatial layout of the environment (Brooks et al., 1999; Gaunet et al., 2001) between environments that are learned actively or passively. These studies however have not tightly controlled the amount of time that participants spend in the environments, which may lead to differences in exposure between task conditions. If the time that participants are exposed to each environment is more tightly controlled, changes in gaze behaviour between modes of wayfinding may influence the ability to store objects into memory as increasing fixations and directed attention towards objects increases the likelihood that they will be stored into memory.

The purpose of this study was to investigate if there are any differences in active or passive with respect to gaze behaviour and wayfinding performance. As noted, gaze behaviour and specifically fixations are considered to be an index of directed attention and in the case of learning have a role in storing of an internal representation of the visual environment. While wayfinding performance should improve with a better stored environment along with a reduction in fixations, there is no way in determining if fixations are being used for the storage of landmarks into memory. As a result the study aimed to explore relationship between learning (actively or passively) and declarative memory of landmarks within the environment. This improvement in declarative memory of landmarks should also be seen in an improvement of implicit memory of the environment, which is reflected by the expected increase in wayfinding performance and decrease in fixations on landmarks.

It is hypothesized that active wayfinding will be superior to passive wayfinding with respect to learning of an environment and associated wayfinding performance. This increased performance is expected to be associated with greater attention directed to relevant landmarks as reflected by an increased rate of fixation and an increase in recognition of landmarks and their spatial location. In the current study each trial was divided into two components: 1) the initial excursion (starting point to end point) used by the participants to develop an internal representation and 2) return wayfinding (end point to start point) used to determine the effectiveness of the stored representation.

The three specific hypotheses that were tested are:

1) there will be an increase in fixations on landmarks when comparing between active and passive wayfinding during the initial excursion (start point to end point);

2) there will be a reduction in fixations on landmarks and improved wayfinding performance in the return wayfinding (end point to start point) for active versus passive wayfinding.

3) there will be an increased performance on declarative recognition of landmarks and better spatial location recall for active versus passive wayfinding tasks.

4.2 Methods

4.2.1 Participants

Ten young healthy adults participated in the study (age 24.0±3.26). The group consisted of 5 male and 5 female participants. All participants were required to have normal or corrected to normal vision. A visual search task and the Corsi-block tapping test were administered prior to performing wayfinding trials as a means to evaluate potential individual differences in ability to perform visual search and visuospatial working memory.

4.2.2 Instrumentation and Data Acquisition

Gaze behaviour was collected using the ASL Mobile Eye-XG Eye Tracking System (Applied Science Laboratories, Bedford, Ma). The eye tracking system was calibrated to the computer screen on which participants performed the tasks, with the placement of icons at positions covering all corners and several intermediate positions on the screen. The eye tracking system collects x and y coordinates of eye position at a rate of 30 Hz and stored as a video with a resolution of 1600x1200 pixels.

Memory recognition information was collected using a custom Labview program (National Instruments, Austin, Tx) that displays landmarks from the environments as well as catch landmarks that were not present in the environments and records the response of whether the subject remembers seeing that landmark or not as well as which environment it was located in. Performance on return wayfinding was determined by the time taken to travel from the destination back to the starting point.

4.2.3 Programs

A custom Labview program was used to evaluate visual search. This program randomly displays 25 triangles in a grid (Figure 4.1), and requires participants to click the left mouse button when they detect the triangle that has the apex pointing down.

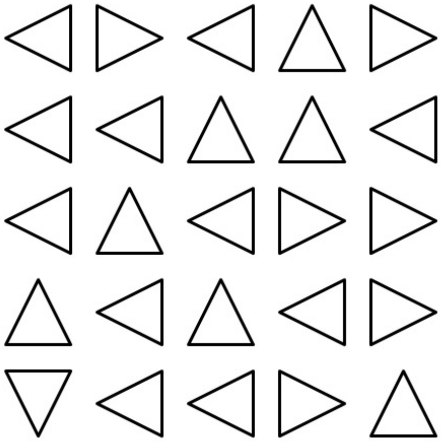

Figure 4.1: Example trial of the visual search task. Participants are required to detect the triangle with the apex pointing down (bottom left corner).

A custom Labview program was created to display the corsi-block tapping test on a 48x27.2 cm touch screen computer monitor. The program follows the corsi-block standardization of Kessels et al (Kessels, van Zandvoort, Postma, Kappelle & de Haan, 2000).

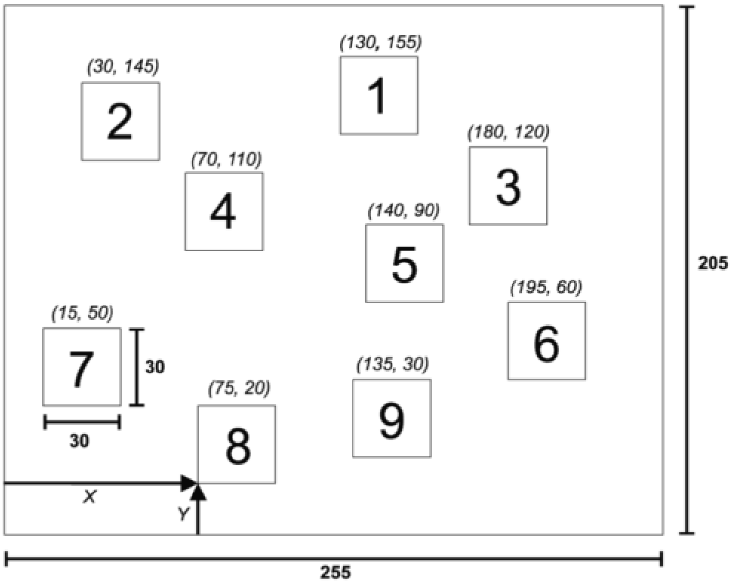

Figure 4.2: Dimensions and set-up of the Corsi-block tapping test. All dimensions are in mm. (From Kessels et al, 2000).

Five environments corresponding to five different cities were used from Google Earth (Google Inc, Mountain View, Ca.). Two routes were created in each of the environments with matching distances, turns and a mutual end point for a total of ten trials. Each route was designed with only one turn in order to keep the number of decision points equal across all routes. One reason for choosing this was that most individuals in study 1 adopted a route with limited number of turns leading to the concern that subjects might not return the same way they went to the target if one used a more complex path. Secondly, it was necessary to ensure, for the working memory tests, to have subjects experience the same landmarks and this was achieved in this study by constraining the path.

4.2.4 Experimental Procedure

Prior to performing the wayfinding trials, participants completed 40 trials of a visual search task which involves finding a triangle with the apex pointing down amongst 24 other triangles, and the Corsi-block tapping test as described by Kessels et al, 2000. Both the visual search task and the Corsi-block tapping test were administered on a 48x27.2 cm computer monitor placed 60cm away from the participant. The computer monitor had touch screen capabilities, allowing the participants to touch the screen to indicate their response for the Corsi task.

In the visual search task the participants were required to perform 40 trials that involve fixating on an initial fixation cross. After a random period of time between 1-3 seconds the fixation cross disappears and 25 triangles appeared. The participant was required to scan the triangles until they found the triangle with the apex pointing down at which point they press the left mouse button causing the the triangles to disappear and the fixation cross to reappear.

The Corsi-block tapping test involves the participants observing a sequence of squares light up on the monitor, which the participants must tap back. The blocks are displayed for 750 ms each, with an interstimulus interval of 200 ms. The sequence begins with two lights, working up to nine with two sequences being displayed at each level. The test is terminated when the participant incorrectly taps both sequences at the same level.

For the wayfinding trials participants traveled through five environments using Google Earth (Google Inc, Mountain View, Ca.) with two trials within each environment for a total of 10 trials. Each session began with the participant navigating through a practice environment in order to familiarize themselves with the controls of the program. Participants were then fit with the eye tracker system that is calibrated to the computer screen.

Within each environment one of the routes is an active wayfinding route while the other a passive wayfinding route. The selection of the active or passive routes was counter-balanced across subjects. The order that the participants perform the 10 routes was randomized prior to the beginning of testing.

In active wayfinding trials participant were placed in front of the starting point of the wayfinding trial and instructed that upon reaching the end point they would have to return to the start. They are then instructed to move through the environment to the best of their ability without stopping, and are given verbal directions (Appendix A) on how to reach the end point. Upon reaching the end point they were instructed to return to the origin along the same route to the best of their ability. No feedback was provided during return wayfinding.

In passive wayfinding trials, the participants were instructed that they are about to observe themselves being moved through a route, and upon reaching the end point they would have to return themselves to the starting point using the same route, to the best of their ability. While being passively moved through the environment, the same verbal instructions as the active trials are given to the participants (Appendix A). Upon reaching the end point they were instructed to return to the starting point along the same route, and no specific feedback was provided during return wayfinding.

Upon completion of the ten trials, each participant was presented a series of 60 landmarks, 30 of which were landmarks that were present along routes they had just completed. The other 30 were not present in any of the routes. Participants respond yes or no using the right or left arrow keys to indicate whether or not they recognize the object from any of the routes. Upon completing the 60 objects, objects that received a yes response are re-presented along with an image of the 5 destinations for the 10 trials (2 trials per destination). Participants were then required to select which environment the object displayed belonged to by pressing the corresponding number on the keyboard.

4.2.5 Data Analysis

Data analysis of fixations was done using a custom Labview program (National Instruments, Austin, Tx). The program selects fixations by determining if the location of foveal vision does not differ by more than 7 pixels for 3 or more consecutive frames, which corresponds to 100 ms. The limit of at least 100 ms has been used in several studies (Andersen et al., 2012; Mueller et al., 2008), while the 7 pixel distance threshold is smaller than some studies (Mueller et al., 2008). The reason a smaller threshold was chosen is due to the close proximity of buildings in the Google Earth program, and a smaller threshold allows detection of small gaze changes between adjacent buildings. The fixations were then manually confirmed using the video file from the eye tracker system and the number of fixations that land on landmarks used in the recall stage were then counted. The manual confirmation was also used to label whether fixations fell on objects in the environment that could be used for wayfinding or if they fell on uninformative regions of the scene, such as the sky or ground.

As noted, each trial was divided into two portions, the initial excursion to the destination and the return to the starting point. The number of fixations in each portion was divided by the time for either the initial excursion or the return component.

The number of correct and incorrect responses for both the landmarks present within the environment, the catch landmarks and the environment in which the landmarks were located were determined.

4.2.6 Statistical Analysis

An inspection of normality of residual error was conducted to ensure normality of distribution. A two-way repeated measures ANOVA's for main effects of condition (active vs. passive wayfinding) and environment (5 environments used for the 10 trials) was run for fixation rate during the initial excursion and the return wayfinding, time to complete return wayfinding, object recognition and object recall. A Tukey HSD post-hoc was used to determine which environments were significantly different. Statistical significance was determined to be $p<0.05$.

4.3 Results

4.3.1 Fixation Rate

Learning of an Environment (Initial Excursion)

There was a main effect of task condition (active versus passive) on fixation rate on objects in the environment during initial learning of an environment ($F_{(1,9)}$=6.1, p=0.0357). Fixation rates on objects within the environment in active and passive conditions were 105.6±22.9 fixations per minute and 101.6±20.3 fixations per minute respectively (Fig 4.3A). The effect of environment on fixation rate approached significance ($F_{(4,9)}$=2.59, p=0.054). Mean fixation rate for each of the environment is shown in Figure 4.3B. An interaction effect between condition and environment also approached significance ($F_{(4,9)}$=2.39, p=0.0732).

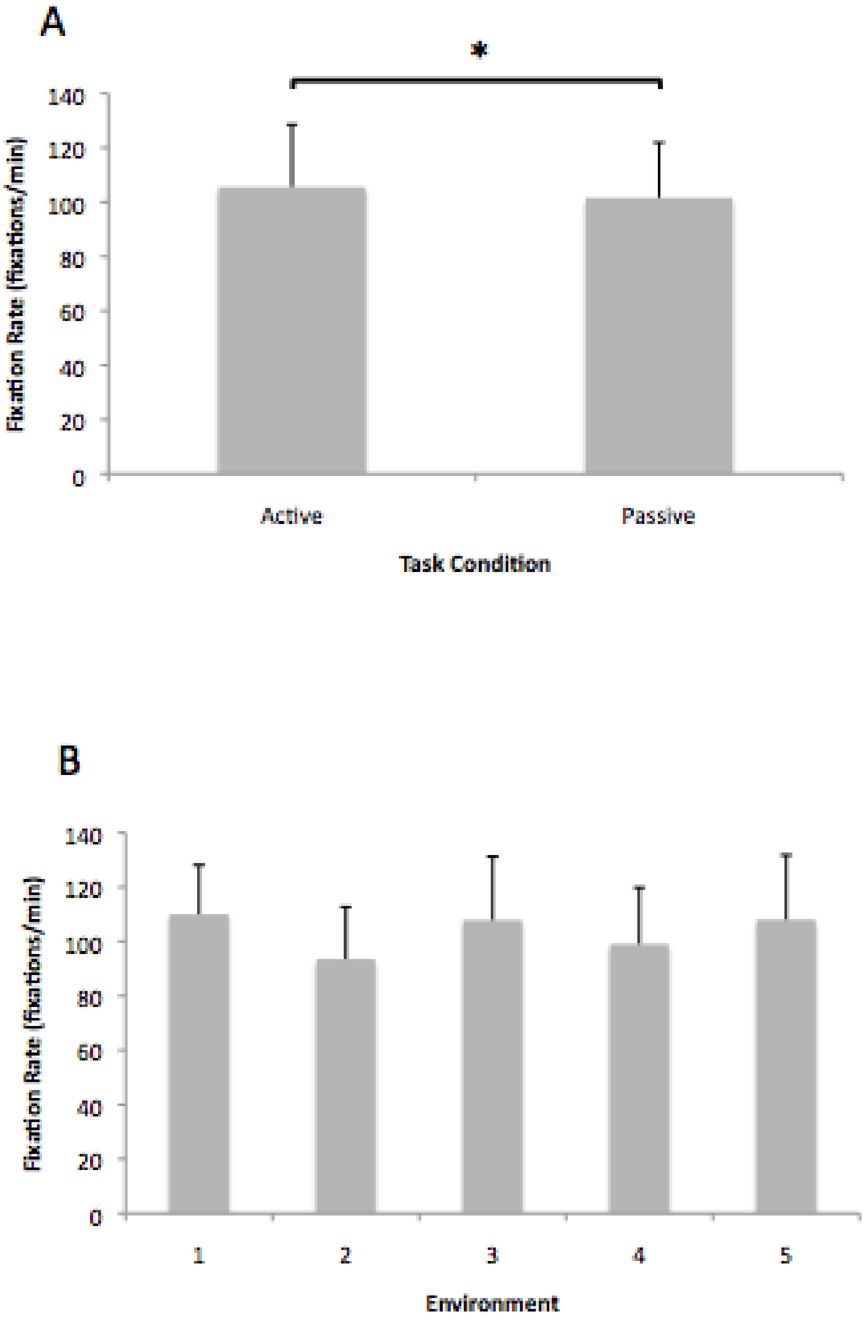

Figure 4.3: Effect of task condition and environment on fixation rate during initial excursion: (A) Mean fixation rates for active and passive task conditions. (B) Mean fixation rates for the 5 environments used; *denotes statistical significance ($p<0.05$).

Return Wayfinding

There was no main effect of task condition (active versus passive) seen on fixation rate on objects within the environment during return wayfinding ($F_{(1,9)}$=3.2, p=0.107). Fixation rates on objects in the environment in active and passive conditions were 95.6±20.1 fixations per minute and 91.9±18.7 fixations per minute respectively (Fig 4.4A). A main effect of environment was seen on fixation rate during return wayfinding ($F_{(4,9)}$=10.2, p<0.0001). A Tukey HSD test determined that environments 2 and 4 were significantly different from environments 1, 3 and 5 (p<0.05). Mean fixation rates for the five different environments shown in Figure 4.4B. No interaction effect was seen between condition and environment ($F_{(4,9)}$=0.99, p=0.43).

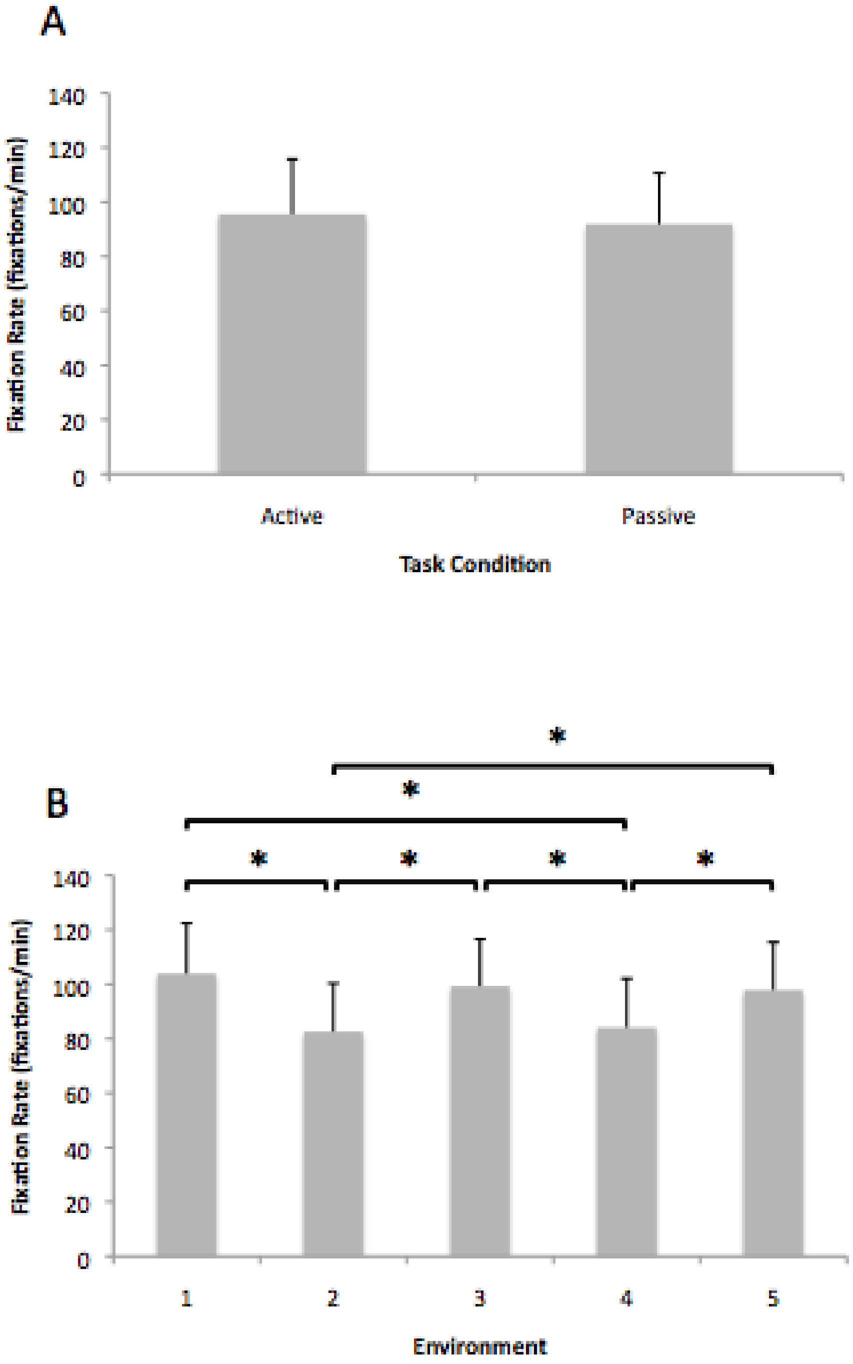

Fig 4.4: Effect of task condition and environment on fixation rate when return wayfinding (A) Mean fixation rates for active and passive task conditions during return wayfinding. (B) Mean fixation rates for the 5 environments used; *denotes statistical significance ($p<0.05$).

4.3.2 Performance - Return Wayfinding Time

There was no main effect of condition (active versus passive) seen on trial time for return wayfinding performance ($F_{(1,9)}$=0.00, p=0.971). Return trial times for active and passive conditions were 110.6±13.5 seconds and 111.98±17.4 seconds respectively (Fig 4.5A). There was a main effect of environment seen on return trial time ($F_{(4,9)}$= 4.8, p=0.0033). Mean wayfinding times for the five different environments is shown in Figure 4.5B, while no statistically significant interatcion effect observed between condition and environment ($F_{(4,9)}$= 0.04, p=0.996).

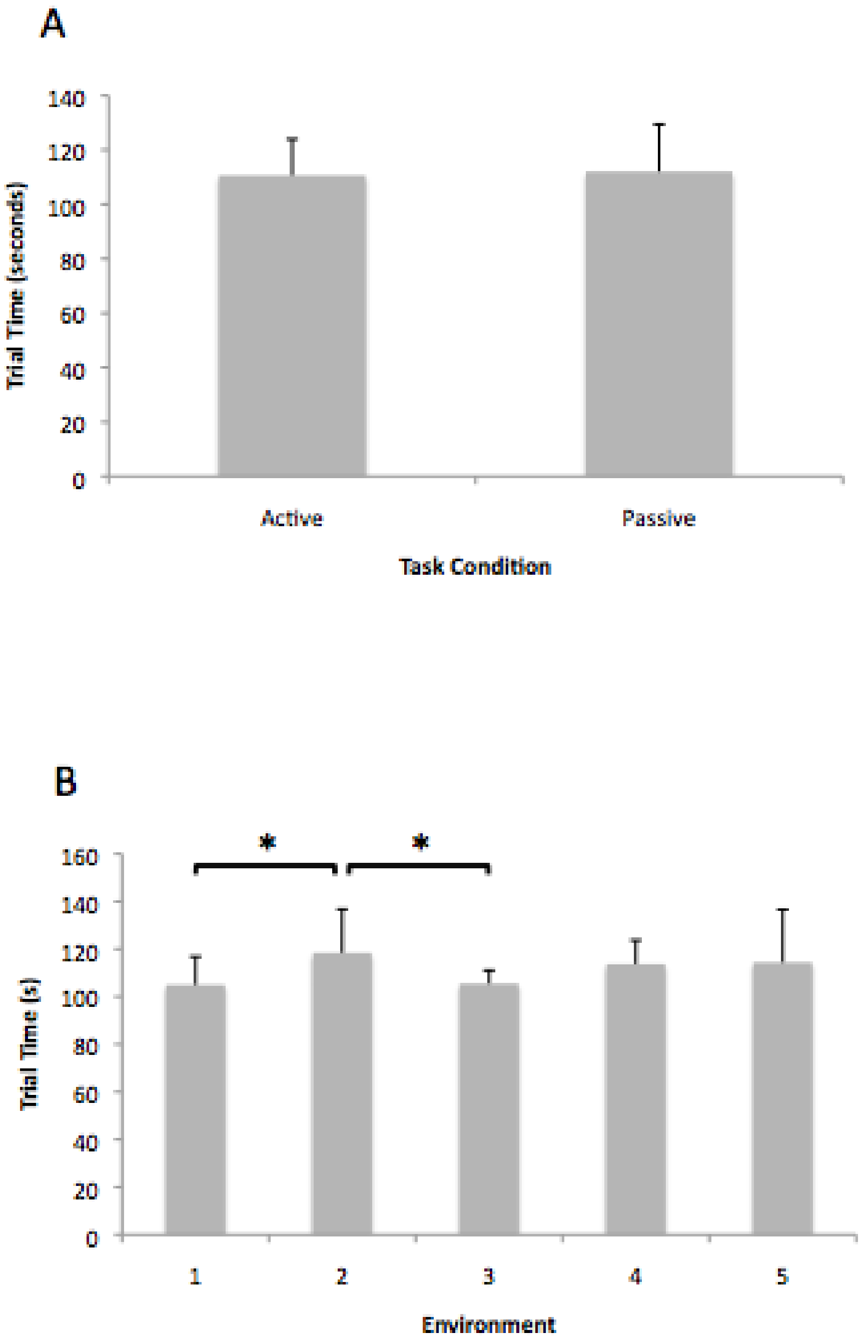

Figure 4.5: Effect of condition and environment on time to complete return wayfinding (A) Mean trial times for return wayfinding in active and passive task conditions. (B) Mean trial times for return wayfinding for the 5 environments; *denotes statistical significance ($p<0.05$).

4.3.3 Performance – Declarative Memory

Overall individuals recognized approximately 7.1 out of 30 objects that were present within the environments, and misidentified (false positives) 3.3 out of 30 objects as being present when they were not in the visual environments shown. Overall there was no significant difference in this success rate or overall error rate comparing between active and passive across the different environments. Specifically there was no effect of condition (active versus passive) seen on the ability to recognize objects within the environment ($F_{(1,9)}$=1.38, p=0.1107), with active trials having 3.0±2.1 objects recognized and passive trials having 4.1±1.2 objects recognized (Fig 4.6A). There was no main effect of environment seen on the ability to recognize objects within the environment ($F_{(4,9)}$=2.03, p=0.1107). Similarly, there was no effect of condition (active versus passive) seen on the ability to recall locations of objects in environments ($F_{(1,9)}$=0.18, p=0.6783), with active trials having 0.6±0.7 objects recalled and passive trials having 0.8±1.0 objects recalled (Fig 4.6B). There was no main effect of environment seen on the ability to recall objects in the environment ($F_{(4,9)}$=0.6 p=0.6617). The overall recall rate of spatial locations was low, averaging 22.53% (among successful recognitions) across all tasks and conditions.

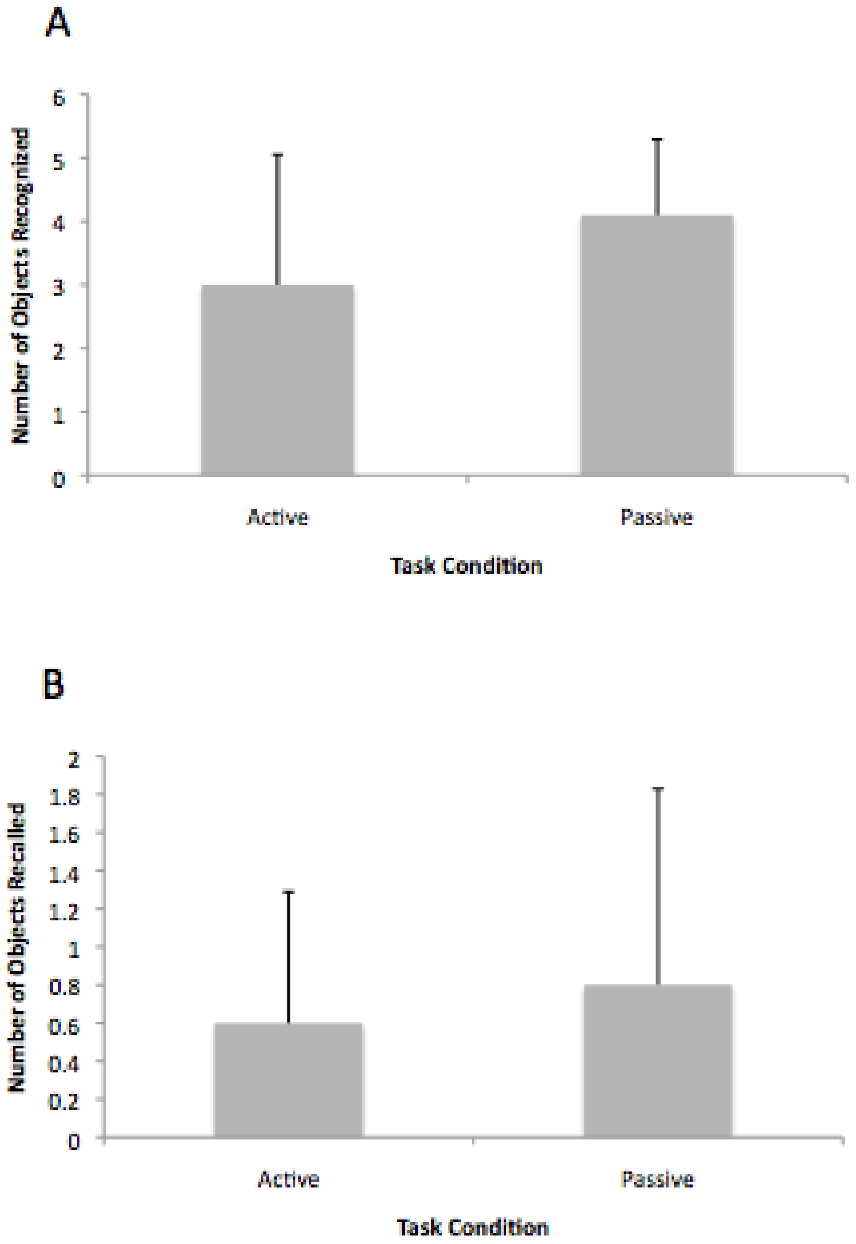

Figure 4.6: Effect of task condition on object recognition and recall (A) Mean number of objects recognized in active and passive trials. (B) Mean number of locations of objects recalled in active and passive trials.

4.3.4 Object Recognition and Fixations

There was a relationship between the number of fixations on and object and whether it was recognized in the declarative memory task (F= 38.2, p=0.0002). Objects that that were recognized in the memory task had a significantly higher number of fixations (12.5±11.8 fixations) than objects that were not recognized (5.1±5.3 fixations) as seen in Figure 4.7A. Similarly, there was a significant correlation between the total number of times an object was recognized across subjects, and the total number of fixations on that object (r=0.5256, p=0.0029) (Fig 4.7B).

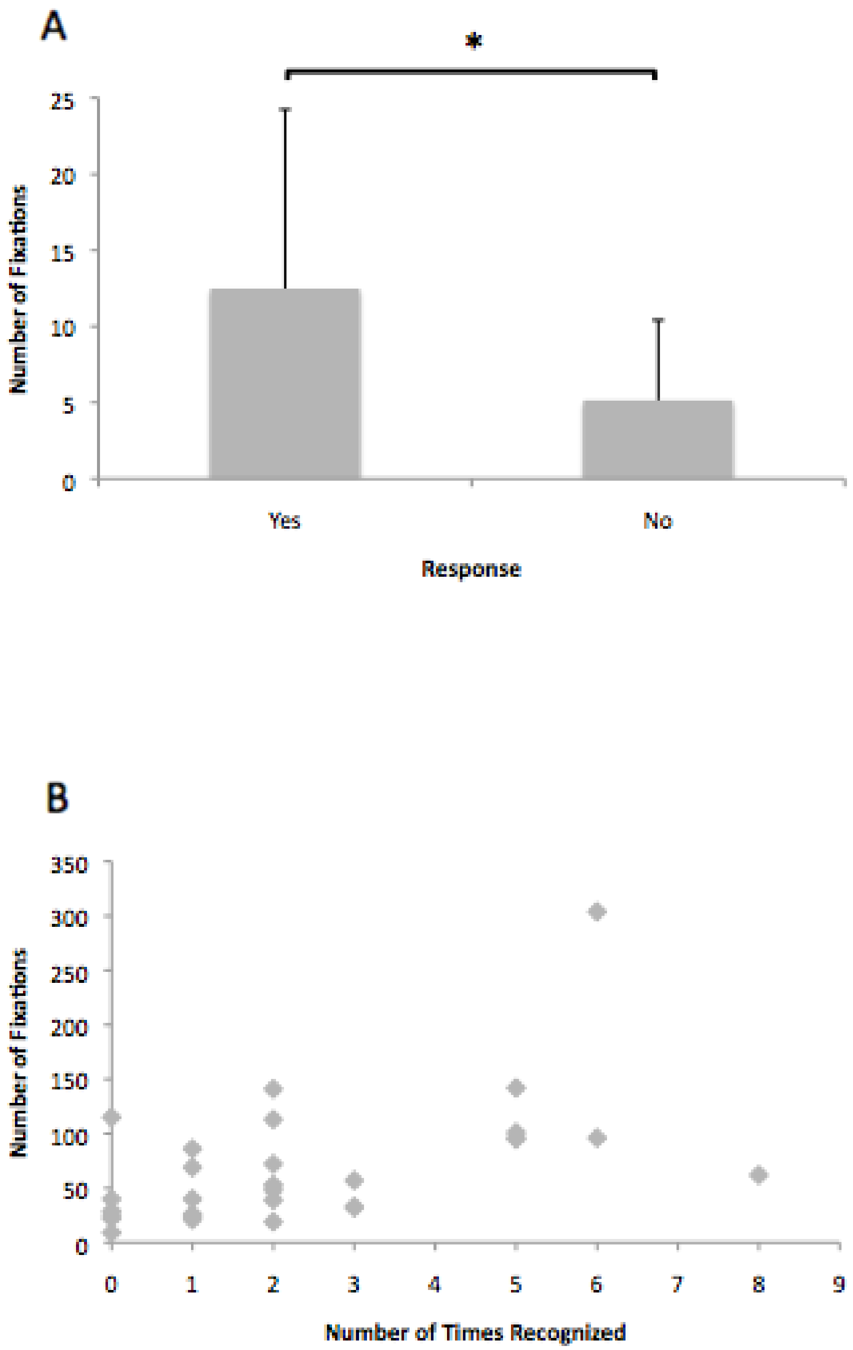

Fig 4.7: (A) Mean number of fixation on objects that were present in the environments that were responded Yes or No to in the recognition task; *denotes statistical significance ($p<0.05$). (B) Relationship between the number of times an object was recognized and the number of fixations on that object across all participants

4.3.5 Corsi-Block Tapping Test and Visual Search Task

The mean block span for the Corsi-block tapping test was 7.5±1.2, which is slightly higher than the normative data for healthy adults provided by Kessels et al (6.2±1.2). The mean total score for the Corsi-block tapping test was 90.5±28.9, which is also higher than the normative data for healthy adults in Kessels et al (55.7±20.3). A correlation was measured between fixation rate and both block span (*r*=-0.651, p=0.0415) and total Corsi score (*r*=0.-689, p=0.0272) during the initial excursion through the environment. There was no statistically significant correlations between block span (*r*=-0.544, p=0.104) or total Corsi score (*r*=-0.503, p=0.139) when performing return wayfinding. No correlation was seen between either the block span (*r*=0.0153, p=0.967) or the total score (*r*=0.136, p=0.708) time to complete on return trials of wayfinding.

The mean response time for the visual search task was 2.5±0.6 seconds. Since this was an in house program there is no normative data to compare to, however no statistically significant correlation was seen between visual search response time and fixation rate on the initial excursion (*r*=0.492. p=0.1487), fixation rate when performing return wayfinding (*r*=0.299, p=0.4) or return wayfinding trial time (*r*=-0.378, p=0.281).

4.4 Discussion

The results of this study support the hypothesis that the fixation rate on landmarks when learning an environment would be higher in active trials versus passive trials. This increase in fixations on objects in the environment is thought to be indicative of an increase in the number of shifts in attention towards objects (Deubel & Schneider, 1996; Henderson, 2003), possibly linked to the active process of storing landmarks. However, there were no associated differences in return wayfinding performance and the ability to recall landmarks in the environment during active versus passive learning. However it is noteworthy that there was an association between the fixations on objects that were recognized versus those that were not recognized suggesting some link between gaze behaviour and a stored representation of the surrounding environment. Collectively the work highlighted differences in specific aspects of gaze behaviour associated with task conditions but not performance measures that may be associated with possible benefits to such changes in gaze behaviour. The text that follows addresses the possible interpretation of these findings.

The hypothesis of a decreased time to complete in actively learned environments was also not confirmed with no difference seen between active and passively learned environments. Seeing a decrease in time to complete would reflect better storage and use of an internal representation as the participant can use this representation in order to more efficiently wayfind, however no difference was seen between the two conditions.

No differences were seen between the ability to recognize or recall objects in the environment, which does not confirm the hypothesis that these measures would be higher in trials where the environment was learned actively. It was believed that the increased fixation rate when learning an environment would lead to better storage of that environment into memory. The increase in fixation rate was seen in actively learned environments, however no difference was seen in the ability to recognize or recall landmarks meaning no benefit to the ability to store an environment into memory.

4.4.1 Differences in Gaze Behaviour: Active versus Passive Learning

In the current study fixation rate was used as a measure of directed attention during the wayfinding task. Previous research has revealed an increase in the fixations on objects in the environment reflects an increase in the number of attentional shifts towards objects in the environment (Deubel & Schneider, 1996; Henderson, 2003), and objects that are attended to are more likely to be stored into memory (Hamid et al., 2010; Loftus, 1972; Smyth & Scholey, 1994). The increase in fixation rate during active trials observed in the present study is therefore thought to reflect an increase in attentional shifts towards these objects. It is presumed that an increase in attention directed towards landmarks is linked to better storage of an environment into memory, which would be represented by a decrease in fixation rate and time to complete in return wayfinding performance and an increase in the ability to recognize and recall objects from the environment.

The link between gaze behaviour and the way that the environment is learned, either actively or passively, has not been investigated in past literature. The expected increase in attentional shifts in active wayfinding was thought to be related to an increased engagement in the task as the participant is required to interact with the environment. Even though the hypothesis was confirmed one can only infer that the differences in gaze were linked to task relevant shifts in attention.

On a related note the difference in fixation rate between active and passive learning was small in comparison to the total number of fixations per minute on objects in the environment (4 out of 101-105). Assuming not all of these fixations (>100 per minute) served the role of storing features for wayfinding it raises the idea that there are likely different reasons for fixations. First it should be noted that previous studies examining free viewing of pictures have shown fixation rates of 3 per second (Buswell, 1935) which corresponds to approximately 180 fixations per minute. The present study showed approximately 101-105 fixations per minute specifically on objects within the environment, but when including all fixations this number is comparable to previous studies.

There are several possible reasons for gaze fixations in such complex scenes and when an individual is moving through the environment: 1) assembling information relevant to mapping the spatial surroundings, 2) for object avoidance associated with active moving, 3) sustained fixations to allow stable gaze for use of peripheral vision for spatial information and/or 4) non-specific exploration of the environment that is either stimulus or centrally evoked.

There has been considerable evidence of the role of gaze fixations for wayfinding regarding obstacle avoidance/clearance or affordances (Patla, 1997). However given that the current task does not actually involve locomotor movements such fixations would be restricted to those associated with moving around/avoiding virtual objects. Evidence also exists demonstrating that peripheral vision is vital for monitoring spatial information about the environment (Fortenbaugh et al., 2007; Turano et al., 2005), and fixations could therefore be used in order to maintain stable gaze for peripheral vision to monitor this spatial information.

Importantly the rate of fixations when return wayfinding reflect some dependence on a stored representation of the environment as increased familiarity with environments require fewer fixations to perform wayfinding (unpublished finding: Phillips, 2014). This indicates that participants rely less on external cues in the environment in order to wayfind as they have a better internal representation of the environment stored into memory. It also provides complementary support that the changes in fixation rates between conditions, even though small in comparison to overall rates, do reflect changes in the frequency of fixations associated with wayfinding as opposed to non-specific exploration or obstacle navigation.

4.4.2 Influence on Return Wayfinding and Memory

In spite of the proposed link between the allocation of attention when learning an environment and the ability to store the environment into memory, no differences were seen between active and passive wayfinding with respect to return wayfinding performance as indicated by time to complete trial or the ability to recognize or recall landmarks. Some previous studies examining the effect of active and passive wayfinding have shown that learning an environment actively leads to increased wayfinding performance (Farrell et al., 2003; Wallet & Sauzéon, 2008; Wallet, Sauzéon, Larrue & N'Kaoua, 2013). However a number of other studies consistent with the present study revealed no benefit to either active or passive wayinding in the ability to recognize or recall spatial locations of objects in the environment (Brooks et al, 1999; Wallet & Sauzéon, 2008; Wilson 1999). It was hypothesized in the current study that fixation rates in the actively learned environments would be lower when compared to passive environments during return wayfinding. Since no difference was seen between the two conditions it may be assumed that participants are referring to the external environment when trying to find their way equally whether the environment was learned actively or passively. The combination of equal reliance on the external environment as reflected by no difference in fixation rate, and no difference in the time taken to complete the return wayfinding between task conditions would indicate that no benefit to the creation and use of an internal representation of the environment is seen between how an environment is learned, either actively or passivley. Alternatively the study design may have impacted the ability to detect changes between actively or passivley learning an environment. For example these might include: 1) task difficulty, 2) instructions given during wayfinding.

One reason for not seeing a benefit to increased attention when learning an environment could be linked to the difficulty of the task. The wayfinding task in the current study involved only one decision point, and by increasing the number of decision points to complete the wayfinding you would increase the memory load to successfully reach the endpoint and could increase the difficulty of the task. This increase in difficulty may help to uncover memory and performance differences between the environments learned actively and those learned passively. Another reason for not seeing the benefit to increased attention when learning an environment actively may be that participants were given instructions on how to reach the end point during the initial excursion. This means that during the active trials participants were not free to find their own way to an end point, and were constrained to follow a path to the end point which may be similar to constraining the passive conditions to a path. This would mean that the only differences between conditions were that in active trials participants were pressing the keyboard, and in passive the keys were pressed by the experimenter. This tight control may not have allowed for active trials to see benefits in learning the environment as participants were constrained to a particular path and instructed on how to reach the end point, making it very similar to the passive trials.

The lack of difference in the ability to recognize and recall objects may be associated with a distinction between increased attention when storing an environment and the ability to store and use an internalized representation. It is possible that the increased fixations when learning trials actively were not related to storage of an environment, but as stated earlier are being used for other purposes such as obstacle avoidance or stabilizing gaze for the use of peripheral vision. However if these changes in attentional shifts are being used in order to help store the surrounding environment, there may be little difference in how the environment is stored. While attention acts to help select which objects will be held in working memory to aid in task completion (Awh & Jonides, 2001; Awh et al., 2006), however working memory is only a short term, temporary store for this information. In order for an internal representation to be built information in visuospatial working memory needs to be consolidated to long-term memory (Baddeley, 1992) where it can then be recalled and used to aid in wayfinding. The lack of a difference in the ability to recognize and recall objects between task conditions in spite of an increase in directed attention when learning the environment may be related to little difference in the conversion of information in visuospatial working memory to long-term memory.

4.4.3 Fixations and Object Recognition

As noted there was a relationship between the number of fixations on an object and the ability to store that object into memory. This relationship has been well documented in previous literature (Hamid et al., 2010; Loftus, 1972; Smyth & Scholey, 1994). This highlights that irrespective of the method of learning (active vs. passive), if an object receives more fixations during navigation it is more likely that object will be recognized. The recognition aspect of the study only probed if the participant recognized an object, and potentially has no reflection of spatial knowledge of the object. The latter is supported by the very low success rate of recalling the spatial location in this study. This dissociation between object recognition and spatial location may reflect the differences in how the CNS stores information. It may indicate that no spatial information was stored about the building as visual and spatial information is stored separately in memory (Della Sala et al., 1999; Hecker & Mapperson, 1997; Tresch et al., 1993).

4.4.4 Effect of Environment on Gaze Behaviour and Trial Time

An effect of environment on the fixation rate during the initial excursion approached significance and an effect was seen on the fixation rate during the return wayfinding performance, and this potential effect of environment reflects the findings of Phillips, (unpublished, 2014). The first study of this thesis revealed that visual complexity of an environment could influence fixation rate, with more visually complex environments having a higher fixation rate. While the environments were all performed in Google Earth and were intended to match as closely as possible, the level of visual complexity, there are no doubt differences between these environments as they all belong to different cities. These small differences in the visual complexity of environments would lead to changes in fixation rates both while performing the initial excursion to learn the environment, and during the return wayfinding performance.

An effect of environment was also seen on the time to complete trial when performing the return wayfinding. This effect could be related to the difficulty of the environment, as it is possible that environments 1 and 3 were slightly less difficult and therefore had faster time to completion. This difference could also be attributed to different environments having different lengths. While every trial was created to be the same length, the geometry of the environment and the spacing of buildings are inherently different in every environment, making it difficult to make every trial the exact same length. This could account for the differences in trial times seen between the five environments.

4.4.5 Corsi-Block Tapping Test and Visual Search

The visual search task and Corsi-block tapping test are used as pre-screening measures in order to better understand individual differences in wayfinding. It has previously been shown that working memory can predict wayfinding ability (Nori et al, 2009), and determining visuo-spatial working memory from the Corsi-block tapping test may give insight into factors that contribute to a participant's wayfinding ability. It has also been show that a decrease in visual scanning during a Morris water maze task results in poorer performance in the trial (Kallai, Makany, Karadi & Jacobs, 2005) indicating that visual search abilities may also predict wayfinding performance.

There was no association between an individual's performance on the two screening tests and task related gaze behaviour or wayfinding performace during return wayfinding. This is not in agreement with previous literature indicating that tests of visuospatial working memory (Nori et al, 2009) and visual search patterns are good predictors of wayfinding ability (Andersen et al., 2012; Kallai et al, 2005). The fact that no relationship was seen in the current study may be related to the difficulty of the task. With only one decision point in each trial the task may not have been difficult enough to see differences in time to complete between participants with respect to visual search and visuospatial working memory abilities. In addition, it is possible that there were little differences in visual abilities within the current group. It is possible that other factors such as experience with video games (West, Stevens, & Pratt, 2008) or sex (Andersen et al., 2012; Mueller et al., 2008) may have a bigger influence on the performance of this task reducing the ability to detect associations with visual processing abilities.

There were moderate correlations seen between the highest level of the Corsi task reached and fixation rate on return wayfinding, as well as the total Corsi score and fixation rate on return wayfinding. This negative correlation would indicate that participants with higher scores on tests of visuospatial working memory use fewer fixations when learning an environment, as it has been shown that visuospatial working memory has an influence on the direction of attention (Fockert, Rees, Frith, & Lavie, 2001; Henderson & Hollingworth, 2003). This reveals that someone with better visuospatial working memory would require fewer fixations on objects, and therefore not rely on the external environment as much when building an internal representation of an environment. This decrease in fixation rate does not however translate to impairment in wayfinding performance, as these participants with higher visuospatial ability that use fewer fixations complete the wayfinding task in the same amount of time.

4.5 Conclusions

This study showed an increase in fixation rate on objects in trials where the environment was learned actively, as well as during return wayfinding performance, where no significant differences were seen for wayfinding performance as indicated by time to complete return wayfinding, or for measures of memory of objects in the environment.

The increased fixation rate when learning the environment indicates an increase in attentional shifts towards objects in the environment and therefore a better chance of these objects being stored into memory, both the object and its spatial information. This potential better storage of information was not reflected in return wayfinding or memory measures, but could be due to the lack of difficulty of the wayfinding task related to the relatively small amount of decision points.

Chapter 5: General Discussion

5.1 Thesis Overview

The results from this thesis help provide insight into how different environmental and modality factors involved with wayfinding can influence cognitive processes such as attention and memory. While previous studies have examined the role of gaze in wayfinding through virtual environments (Andersen et al., 2012; Hamid et al., 2010; Kallai et al., 2005; Livingstone-Lee et al., 2011; Mueller et al., 2008), the first study of this thesis is the first to examine how changing factors of the environment can influence gaze behaviour. Also, while the effect of active and passive wayfinding on memory and wayfinding performance has been investigated (Hahm et al., 2007; Rodrigues & Sauzéon, 2010; Wallet & Sauzéon, 2008; Wallet et al., 2013; Wilson, 1999), study 2 of this thesis examined the role of gaze in this relationship. Study 1 found that changing the visual complexity of an environment, as well as the familiarity of an environment could influence gaze behaviour, which is reflective of changes in the allocation of attention. In more novel or visually complex environments an increase in fixation rate, which reflects an increase in attentional shifts, is seen. In study 2 it was revealed that when learning an environment actively an increase in fixation rate is seen compared to when an environment is learned passively which once again reflects an increase in attentional shifts towards objects in the environment. Despite this there was no benefit seen to the wayfinding performance when an environment was learned actively.

5.2 Potential Implications

Understanding of the processes related to wayfinding using gaze behaviour has implications to several areas of study: 1) provide insight into the role of vision and visual attention in complex everyday tasks (eg driving (Johnson, Sullivan, Hayhoe, & Ballard, 2014)), 2) advance the use of gaze metrics to provide a unique index of learning (decreased fixation rates in better learned environments), 3) advance the development of computer interfaces and artificial intelligence using visual attention and gaze behaviours (Peters & Itti, 2006), 4) develop new approaches to train executive processes associated with video game playing, aging or neurological injury/disease (Hamel et al., 2013). With respect to the latter, such understanding could help to shape and design rehabilitation protocols that might use wayfinding as a method to try and improve cognitive function for populations suffering from cognitive impairments, such as stroke or Alzheimer's.

Importantly, the current work did not reveal any difference in the ability to remember or execute navigation when comparing if an environment was learned actively or passively. This may lead to the possibility that passive wayfinding approaches may serve as a useful training tool making it possible to better prescribe and automate the specific environment to learn and reduce the possible challenges associated with dual-tasking during the learning phase. However, it is important that any study that would adopt a passive training approach should monitor gaze behaviour to ensure active gaze strategies are being adopted reflecting specific approaches to control visual attention. In addition, there was evidence from study 1 that visually complex and novel environments require an increase in the amount of attention directed to the environment. This increase in load on the attentional system means that using this type of environment would provide the most challenge in order to try and improve cognitive function. It may be necessary to train using less visually complex environments during training and progress towards more complex and novel environments.

5.3 Study Limitations

The ability to automate gaze analysis in the studies in this thesis was not possible, due to both the complexity and dynamic nature of the environments. This means that while fixations were automatically determined, it was not possible to automate if these fixations fell on landmarks within the environment. As a result the determination of the spatial location of fixations, and link to environmental characteristics was performed manually working frame by frame. This manual analysis has the potential to introduce some experimenter bias though the largest challenge is the practical limitation in the volume of data (length of trials and complexity of the path) that could be accommodated by this data analysis approach.

Another limitation was the level of task difficulty in study 2 which may have limited the ability to reveal differences between active and passive wayfinding. In the current study a single turn was incorporated in the task (in part to control for differences in route length). If the wayfinding task had involved more decision points, this would increase the memory load to recall the route to return to the starting point and may reveal differences in wayfinding performance between active and passive conditions. As well, the tight controlling of participants routes in active conditions may have prevented some beneficial aspects of active engagement with the task. A limitation of both studies of this thesis are that wayfinding through the environments involved the use of a keyboard/mouse. Performance on the wayfinding task could therefore be influenced by someone’s experience with computer games or other programs that involve the use of a keyboard or mouse for the purposes of movement.

5.4 Future Directions

Future research looking to examine the relationship between how an environment is learned, attention, memory and wayfinding performance should use more difficult wayfinding tasks in order to try and determine if how an environment is learned influences how well it is stored and used as an internal representation. Also reducing the restriction of a route in active wayfinding may help to uncover differences between learning an environment actively or passively.

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Appendices

Appendix A – Verbal instructions for wayfinding task in Study 2.

All sentences in brackets are for reference to the researcher and are not said to the participant.

General Instructions

1) When I tell you to begin, you will turn 90° to the (left/right) and begin walking to the destination. Do your best to refrain from stopping along the way to the destination. After reaching the endpoint, you will return to the building (descriptor).
2) (At ___________) You will now make a (left/right) turn at the next street.
3) (Upon reaching destination) You will now return to the starting point along the same route to the best of your ability.

Johannesburg Route 1 (1)

1) When I tell you to begin, you will turn 90° to the left and begin walking to the destination. Do your best to refrain from stopping along the way to the destination. After reaching the endpoint, you will return to the building with the well mart sign and the cow.
2) (At the blue Tadingo and Retail sign) You will now make a right turn at the next street.
3) (Upon reaching destination) You will now return to the starting point along the same route to the best of your ability.

Johannesburg Route 2 (2)

1) When I tell you to begin, you will turn 90° to the left and begin walking to the destination. Do your best to refrain from stopping along the way to the destination. After reaching the endpoint, you will return to the building with the white Lage Buing sign.
2) (At the yellow mini hotel sign) You will now make a right turn at the next street.
3) (Upon reaching destination) You will now return to the starting point along the same route to the best of your ability.

Mexico City Route 1 (3)

1) When I tell you to begin, you will turn 90° to the left and begin walking to the destination. Do your best to refrain from stopping along the way to the destination. After reaching the endpoint, you will return to the building with the Hainita sign.
2) (At road immediately following the Optima sign) You will now make a right turn at the next street.
3) (Upon reaching destination) You will now return to the starting point along the same route to the best of your ability.

Mexico City Route 2 (4)

1) When I tell you to begin, you will turn 90° to the right and begin walking to the destination. Do your best to refrain from stopping along the way to the destination. After reaching the endpoint, you will return to the building with the red Taqueria Lopez sign.
2) (At road immediately following the green awning on the left) You will now make a right turn at the next street.
3) (Upon reaching destination) You will now return to the starting point along the same route to the best of your ability.

New York Route 1 (5)

1) When I tell you to begin, you will turn 90° to the right and begin walking to the destination. Do your best to refrain from stopping along the way to the destination. After reaching the endpoint, you will return to the building with the Wells Fargo Sign.
2) (At the building with the small blue awning) You will now make a left turn at the next street.
3) (Upon reaching destination) You will now return to the starting point along the same route to the best of your ability.

New York Route 2 (6)

1) When I tell you to begin, you will turn 90° to the left and begin walking to the destination. Do your best to refrain from stopping along the way to the destination. After reaching the endpoint, you will return to the building with 235 on the blue awning.
2) (At the grey buildings with the 2 American flags) You will now make a left turn at the next street.
3) (Upon reaching destination) You will now return to the starting point along the same route to the best of your ability.

Toronto Route 1(7)

1) When I tell you to begin, you will turn 90° to the right and begin walking to the destination. Do your best to refrain from stopping along the way to the destination. After reaching the endpoint, you will return to the building with the Ryerson University sign.
2) (At large brown tower following the blue tower) You will now make a right turn at the next street.
3) (Upon reaching destination) You will now return to the starting point along the same route to the best of your ability.

Toronto Route 2 (8)

1) When I tell you to begin, you will turn 90° to the right and begin walking to the destination. Do your best to refrain from stopping along the way to the destination. After reaching the endpoint, you will return to the green building with the awning.
2) (At the large grey building on the right) You will now make a right turn at the next street.
3) (Upon reaching destination) You will now return to the starting point along the same route to the best of your ability.

NYC Route 1 (9)

1) When I tell you to begin, you will turn 90° to the left and begin walking to the destination. Do your best to refrain from stopping along the way to the destination. After reaching the endpoint, you will return to the building that says 'Anne Fontaine'.
2) (At the large orange/brown building on the left) You will now make a right turn at the next street.
3) (Upon reaching destination) You will now return to the starting point along the same route to the best of your ability.

NYC Route 2 (10)

1) When I tell you to begin, you will turn 90° to the left and begin walking to the destination. Do your best to refrain from stopping along the way to the destination. After reaching the endpoint, you will return to the building with the blue awning that says bar-coastal.
2) (At the series of blue awnings on the left) You will now make a left turn at the next street.
3) (Upon reaching destination) You will now return to the starting point along the same route to the best of your ability.