The influence of landmarks and urban form on cognitive maps using virtual reality

by

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Abstract

Landmarks are universal components of human urbanization. We are a species driven to mark the land with symbolic structures and craft meaning in our built environments. From ancient wonders such as Stonehenge to modern icons like the St. Louis Arch, we have been designing landmarks since the dawn of civilization. Cities, towns, and neighborhoods incorporate landmarks as elements of cultural expression and tools for navigation. Individuals use landmarks as reference points to create an internal cognitive map, permitting more efficient navigation throughout a city and contributing to a heightened sense of place. To aid in research regarding the role of landmarks on cognitive maps and place-identity, we have designed a novel testing paradigm in which subjects wear a virtual reality (VR) head-mounted display (HMD) and traverse a hypothetical urban environment using a gaming controller. The virtual environment (VE) features a gridded street network measuring 5x5 blocks and guides subjects along a fixed route through residential, park, commercial and industrial districts. Along this fixed route, subjects are exposed to ten distinct landmarks. After navigating the VE, subjects are tasked with delineating their perceived route, landmark locations, and district boundaries through map drawing tasks on grid paper as well as a scene recognition task. The most significant finding revealed landmark configuration accuracy to be highly correlated with performance on the route recall and moderately correlated with performance on the scene recognition task. This suggests that, regardless of the landmark type, individuals who more precisely recalled landmark locations also navigated the route and identified scenes more accurately. Landscape and urban planners can leverage these findings to advocate for the strategic inclusion of landmarks throughout an urban fabric, which we term Landmark Configuration Plans (LCP).

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Dedication

I would like to thank my mother and father, Joan and Dave Bruns, for their unconditional love and support and helping me to attain the goal of completing my degree. This has been a challenging yet rewarding journey and I could not have done it without them. Also, I would like to give a shout out to my triplet brothers, Barrett and Derek, for our lifelong friendship. We were tangled in the womb together, and our childhood adventures growing up in the foothills of the Colorado Rockies are what sparked my endless fascination with the landscape.

Preface

This document is structured as a master's thesis, wherein a journal manuscript is contained. As stated in the acknowledgements, there were many individuals involved in this project with varying contributions. As the lead author of this study, I was responsible for the background research and for producing most of the content in this document. Dr. Chamberlain contributed significantly toward the technical writing of the results section and provided valuable skills in computer science to help automate the study procedures. My supervisory committee, Katie Kingery-Page from Landscape Architecture, and Dr. Heather Bailey of Psychology strengthened this work significantly with their substantial knowledge in these research topics . Together Dr. Chamberlain and I developed the analyses to answer the stated hypotheses at the end of Chapter 1. The manuscript, encapsulated in Chapters 1-5, was written with to conform with the aim and standards of the journal of Landscape and Urban Planning, an international peer-reviewed publication "aimed at advancing conceptual, scientific, and applied understandings of landscape in order to promote sustainable solutions for landscape change."

Chapter 1 describes how landmarks and urban form influence place identity, how cognitive maps are formed, and how researchers are utilizing deliberately constrained VEs to study the influence of the landmarks on human spatial cognition. Chapter 2 elaborates on the methods used in our experimental procedures, including: how subjects were recruited, how we structured the VE, and how the recall tasks were administered. Chapter 3 describes the results of the study such as the scores for the Landmark and Route Recall Assessments as well as the Scene Recognition Task. Chapter 4 discusses the theoretical underpinnings of this work and how it relates to our findings. Finally, Chapter 5 concludes the study by underscoring the significance of landmarks in urban environments and suggesting future directions for research.

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Chapter 1 - Introduction

The **broad aim** of this study is to evaluate the extent to which various types of urban landmarks influence an individual's cognitive map. While the following sections discuss how landmarks contribute to a phenomenological sense of place, this specific study does not empirically evaluate social or historic contexts of landmarks. Only the spatial contexts of landmarks are considered. The goal of this research is to understand how landscape and urban planners can employ tactics from the field of environmental psychology to design more memorable places which are inclusive to individuals with a range of navigational expertise.

Subjects were exposed to ten distinct landmarks along a fixed route through a virtual urban environment and were then evaluated on their cognitive map accuracy through map drawing and scene recognition tasks. This understanding of how urban landmarks impact human behavior and cognitive maps will allow landscape and urban planners to devise improved placemaking strategies for cities and communities. The primary research questions are: **1) Do certain types of urban landmarks elicit a heightened spatial memory?;** and **2) Which types of urban landmarks have the highest degree of impact on spatial memory and recall?** Before discussing the methods and results, an introductory chapter describes the theoretical underpinnings of this research and results from previous related studies.

The Role of Landmarks

This study adopts an operational definition of landmark from the field of environmental psychology and applies this definition within broader landscape and urban planning theories. In environmental psychology, landmarks are unique focal points in the built environment which serve as organizing features and navigational aids on an individual's cognitive map (Hirtle, 2008). Landscape and urban planners utilize landmarks as beacons of cultural expression and engines of creative placemaking across the world. From the monolithic monuments at Stonehenge to icons like the St. Louis Arch, humans have been designing them since the dawn of civilization. These landmarks often act as 'spatial magnets' which serve as destinations points for civic activity and commerce (Nijhuis, 2011). While many researchers have explored how landmarks contribute to a phenomenological sense of place (Kwon, 2004; Lalli, 1992; Lengen & Kistemann, 2012; Marichela Sepe, 2010; Schneekloth & Shibley, 1995; Sen & Silverman, 2014; Turner & Turner, 2006), there is much to be learned regarding the cognitive processes involved in forming spatial memory and place identity. The field of environmental psychology is rich with research into cognitive maps and wayfinding behavior (Dolins & Mitchell, 2010; Gallistel, 1990; Golledge, 1999; Golledge & Stimson, 1987; Lloyd, 2013; McNamara, 2017; Montello, 1998; O'Keefe & Nadel, 1978). Yet, relatively few studies have developed systematic deductive methods for evaluating how landmarks and urban form might influence the accuracy of cognitive maps (Evans et al., 1982; Lew, 2011; Presson & Montello, 1988).

Place Identity

A sense of place, or place identity, is an internal construct facilitated by an emotional attachment to location through cultural, historical, and spatial contexts (Williams & Stewart, 1998). However, the notion of placelessness (or non-place) in urban public space, whereby landscapes are devoid of identity is being exacerbated by monotonous development patterns through suburban sprawl and increasing land privatization. These placeless developments are negatively impacting a collective sense of community and land stewardship (Arefi, 2004; Calthorpe, 1993; Scannell & Gifford, 2010). Additionally, car dependence and reliance on GPS navigation aids are diminishing individuals' spatial awareness by drawing attention away from

their surroundings (Ishikawa, Fujiwara, Imai, & Okabe, 2008; Mondschein, Blumenberg, & Taylor, 2010).

Design and planning professionals can help remedy these issues through the process of creative placemaking. Fostering a heightened place-identity in public space is a goal of many landscape and urban planners (Hayden, 1997; Manzo & Perkins, 2006) because it often determines the success of a project from an economic and cultural perspective (Zimring & Reizenstein, 1980). In contrast to monotonous developments, urban settlements that strategically include design elements such as landmarks can capture a person's attention and contribute to a heightened spatial awareness and locational identity. As Whyte (1980) and Jacobs (1969) demonstrated, an urban area with a strong place identity will draw more visitors and drive more economic growth than one that is placeless, drab, and featureless.

The design of the built environment contributes significantly to human psychological development (Proshansky, Fabian, & Kaminoff, 1983), and through various internal associations, people ascribe significance to landmark icons within an urban fabric (Hull, Lam, & Vigo, 1994). Therefore, strategic design considerations should be made about the implementation and preservation of these landmark icons to help nurture a sense of place and belonging within a community (Altman & Low, 2012; Bastéa, 2004; Casakin & Bernardo, 2012). Lynch (1960) helped set the foundation for research into environmental perception in landscape and urban planning with his typology of urban forms. These five types of interrelated urban forms are landmarks, nodes, paths, edges, and districts. Thereafter, much has been written about the influence of the built environment on human spatial cognition, examining how the mind encodes and stores spatial information such as landmarks (Allen, 2004; Collins, Gathercole, Conway, & Morris, 1995; Downs & Stea, 1974; Shettleworth, 2010). The experience of urban spaces is different for every individual. However environmental features such as landmarks can be utilized to foster a heightened sense of place and elicit a more accurate internal representation of the environmental structure.

Spatial Knowledge

The hippocampus and the surrounding medial temporal lobes play prominent roles in human spatial cognition (O'Keefe & Nadel, 1978; Yoder, Clark, & Taube, 2011) . Specialized neurons in these regions of the brain called place cells, grid cells, and head direction cells

coordinate to form distinct types of spatial knowledge which can either be actively acquired through direct/primary sources, or passively through indirect/secondary sources (Burgess, 2006; Lengen & Kistemann, 2012; Moser, Kropff, & Moser, 2008; Pilly & Grossberg, 2012). Direct sources include active exploration through sensorimotor experiences such as walking or biking and are non-symbolic, while indirect sources are symbolic external representations of space such as maps (Montello, 1998; Presson & Montello, 1988). While it may seem obvious, active exploration through cycling or walking has demonstrated improved spatial learning more so than passive strategies such as map-reading or fast-paced transit (B. Appleyard, 2015; Chrastil & Warren, 2015; Mondschein et al., 2010).

Encoding spatial information can occur from both an egocentric perspective and an allocentric perspective. Egocentric spatial encoding occurs when an individual is localizing objects in an environment relating to one's self and is often compared to a "streetview" representation. Allocentric, also called geocentric, spatial encoding occurs when individual orient themselves according to an external frame of reference and is described as a map-like, or aerial perspective (Shettleworth, 2010; Wen, Ishikawa, & Sato, 2013). Allocentric and egocentric spatial encoding combine to form a hierarchy of four distinct types of spatial knowledge: landmark, route, survey (LRS) and graph knowledge (Golledge, Dougherty, & Bell, 1995; Lloyd, 2013; Montello, Waller, Hegarty, & Richardson, 2004). These types of spatial knowledge accumulate to form an internalized cognitive map, permitting a heightened spatial awareness and locational identity (Sarkar, Webster, & Gallacher, 2014).

Declarative landmark knowledge consists of salient visual representation of scenes or objects in an environment, and allows an individual to state with certainty if an object existed within a specific perceptual field (Gale, Golledge, Pellegrino, & Doherty, 1990; Heft, 1979; Parush & Berman, 2004). Route, or procedural, knowledge comprises paths travelled between points as well as the actions (turns) associated with the navigation sequence. Configural survey knowledge is "map-like" and consists of places, landmarks, and their interrelationships including metric distances and directions. Finally, topological graph knowledge is the navigator's internal assumption of the overall environmental structure as a network of paths/nodes, and would allow an individual to distinguish broader spatial relationships such as districts (Chrastil & Warren, 2015; Shettleworth).

Cognitive Mapping

Certain cognitive functions enable mammals to remember their position in space, or their topographical orientation (Gallistel, 1990). These functions are the result of evolutionary adaptations for finding sources of food, escaping predators, and understanding territorial boundaries (Dolins & Mitchell, 2010; Shettleworth, 2010). After conducting spatial learning experiments on lab rats in a maze, Tolman (1948) posited "that mammals form map-like representations of familiar environments," which he first coined as cognitive maps (Lew, 2011). For the next half century, the mechanisms which humans employ in spatial orientation have been studied extensively through the assessment of cognitive maps (D. Appleyard, 1970; Evans et al., 1982; Kara, 2013; Lalli, 1992; Nijhuis, 2011). Cognitive mapping defined as a complex process by which an individual encodes and stores spatial information (Downs & Stea, 1974; Golledge & Stimson, 1987).

Building upon Lynch's typology of urban forms, Golledge (1999) outlines the four geometric components of spatial knowledge acquisition which he describes as points, lines, areas, and surfaces. Individuals are constantly encoding these geometric components, and with over 100 billion neurons in the human brain, a wide spectrum of spatial abilities exist among various demographics (Lloyd, 2013). For instance, Developmental Topographical Disorientation (DTD) is a cognitive disorder which an individual possesses a life-long inability to orient themselves properly in an environment, often getting lost within blocks or even inside their own homes (Iaria & Barton, 2010). Conversely, the most proficient urban navigators are often said to be taxi cab drivers, which have proven to outperform control subjects in route learning tasks (Woollett & Maguire, 2010). Brain scans have also revealed some cab drivers possess larger posterior hippocampal regions compared to non-cab drivers, suggesting that there is a degree of plasticity in the brain with certain occupational demands (Maguire et al., 2000). These studies illuminate the wide range of spatial abilities across human populations and underscore the importance of devising urban design strategies which are more inclusive to this range of navigational expertise. One such strategy is the deliberate inclusion of unique landmark configurations throughout an urban fabric, which increase the environmental affordances for anchor points to be encoded onto an individual's cognitive map (Heft, 1979).

Psychometrics with Controlled Environments

Many studies have measured how the human mind reacts to environmental features in controlled environments, both real and virtual (Darken, 2014; Javadi et al., 2017; Kuliga, Thrash, Dalton, & Hölscher, 2015; Mashhadi Aghajan, 2015; Montello et al., 2004; Richardson, Montello, & Hegarty, 1999). After Tolman's work, the next 70 years of cognitive mapping research has examined the influence of factors such as age (Moffat & Resnick, 2002), gender (Liu, Levy, Barton, & Iaria, 2011), disciplinary training (Uttal et al., 2013), occupational demands (Ekstrom et al., 2005; Maguire et al., 2000; Woollett & Maguire, 2010), head trauma and malformation (Carman & Mactutus, 2002), cognitive disorders (Iaria & Barton, 2010), reliance on GPS wayfinding devices (Ishikawa et al., 2008), mode of transit (B. Appleyard, 2015; Mondschein et al., 2010), and many others. Advancements in VR and other immersive technologies are advancing these theories with continued psychometric research in controlled VEs.

Virtual Reality Studies

Developments in virtual reality (VR) technology over the last two decades have given researchers opportunities to immerse individuals within deliberately constrained VEs in order to study many untested aspects of spatial memory (Allen, 2004; Chrastil & Warren, 2015; Kirsh, Nadeau, & Elvins, 1997; Lukas et al., 2014; Newman et al., 2007; Parsons, Silva, Pair, & Rizzo, 2008; Sévigny, 2009; Turner & Turner, 2006; Turner, Turner, & Burrows, 2013; Waller, 2005; Witmer & Singer, 1998). Recent studies using brain imaging suggest that high-fidelity VEs prompt similar neurological responses in the human brain compared to real-world stimuli (Ekstrom et al., 2005; Mashhadi Aghajan, 2015; Richardson et al., 1999; Waller, Hunt, & Knapp, 1998). This offers a rich testing framework for landscape and urban planners seeking to evaluate the efficacy of their designs before costly investments in construction. Recent studies subjecting individuals to VEs indicate enormous research potential to better understand the degree to which landmarks shape cognitive maps (Barra, Laou, Poline, Lebihan, & Berthoz, 2012; Doeller & Burgess, 2008; Doeller, King, & Burgess, 2008; Nitz, 2015; Parush & Berman, 2004; Richardson et al., 1999; Steck & Mallot, 2000; Zhang, 2012). While the presence of landmarks in VEs has been shown to aid in spatial memory and navigation (Sévigny, 2009; Steck & Mallot,

2000), relatively little research has investigated how types of landmarks and other aspects of urban form influence cognitive mapping abilities (Waller & Lippa, 2007). Based on empirical findings from real-world navigation studies, Vinson (2003) proposes a list of thirteen *Design Guidelines for Landmarks to Support Navigation in Virtual Environments*, listed below, which we have followed for this experiment.

1. *Incorporate several landmarks into the VE*
2. *Include all five types of elements*
    a. *paths, edges, districts, nodes, elements*
3. *Make landmarks distinctive*
    a. *height significance, shape complexity, brightness, scale and visibility, materiality and perceived level of maintenance, surrounded by landscaping, and unique color/texture)*
4. *Use concrete objects, not abstract ones, for landmarks*
5. *Make landmarks visible at all navigable scales*
6. *A landmark should be easy to distinguish from other nearby objects/landmarks*
7. *The sides of a landmark should differ from each other*
8. *Arrays of landmarks will heighten distinctiveness*
9. *Landmarks should carry a common distinguishable element apart from data objects*
10. *Place landmarks on major paths and at path junctions*
11. *Arrange paths and edges to form a grid*
12. *Align the landmarks' main axes with the path/edge grid's main axis*
13. *Align each landmark's main axes with those of other landmarks*

Hypotheses

To assess subjects' recollection of the VE, the Map Drawing and Scene Recognition Tasks are used to evaluate landmark, route, and survey (LRS) knowledge. As an exploratory measure, we also assessed graph knowledge by asking subjects to delineate the four districts from the VE: residential, park, urban, and industrial. Route, graph, and survey knowledge are extracted from subjects' Map Drawing Tasks, while landmark knowledge is assessed through the Scene Recognition Task. The two hypotheses below correspond with literature regarding LRS knowledge types.

Hypothesis 1: Landmark Knowledge - According to the Gestalt laws of proximity and similarity, landmarks with high visual contrast when compared to their contextual backgrounds are

expected to be most memorable (Ellis, 1938; Vinson, 2003). This also corresponds with Lynch's concept of imageability which describes the phenomenon of a scene becoming iconic or highly memorable. The configuration of landmarks included in the VE has been selected to include several categories common to urban environments, including elements such as expressive sculptures, infrastructure, signage, and monuments. These landmarks conform with Vinson's (2003) design guidelines with varying sizes and degrees of visual contrast. Our first hypothesis is that the largest landmarks with high visual contrast will be more accurately matched with the correct scene, because they may trigger heightened emotional and cognitive responses. Conversely, smaller landmarks which seem subtler are expected to not be as accurately recalled. This cognitive response, or lack thereof is referred to as an affective episode, or a 'moment' (Varey Carol & Kahneman Daniel, 2006) and has been used in experiments to quantify cognitive responses to dynamic environmental features such as forest harvesting patterns along highways (Chamberlain & Meitner, 2012).

Hypothesis 2: Route and Survey Knowledge - Route and survey knowledge are assessed through two map drawing tasks called the Landmark and Route Recall Assessments. Landmark recall performance is measured by calculating the average estimation error (Euclidean distance) between subjects stated landmark locations versus the actual coordinate location. We term this the subjects' Landmark Configuration Accuracy, following the configural landmark scores of Gardony, Taylor, & Brunyé (2016). The same is done for the end point of the route, determining Route Accuracy. The corresponding hypothesis that performance on the Route Recall Assessment will increase as a function of performance on the Landmark Recall Assessment, validating the findings of Heft, (1979) indicating environmental features play a significant role in route learning.

Chapter 2 - Methods

The structure of the study comprises two major parts administered in a controlled laboratory environment. Part 1 (Appendix A) consists of a series of six questionnaires and cognitive tests administered through a touchscreen tablet web browser. These questionnaires were selected to test for variation in individual visuospatial executive function and to determine potential correlation between our own recall tests and those previously identified in the literature. In Part 2 subjects were administered several map drawing and scene recognition tasks following a VR walk-through of a novel VE (Appendix B) . The VE has been deliberately constrained to control for spatial parameters and test relationships between environmental features such as landmarks, districts, and other contextual elements. Performance on the questionnaires and cognitive tests was assessed in conjunction with performance on the map drawing tasks to determine which landmarks may be considered most memorable, what about the environment triggers memory of landmarks, and if any individual variations exists which may explain how well someone remembers the environment. As described in Chapter 1, landmarks are dependent upon social, historical, and spatial contexts. This study only evaluates the spatial contexts of landmarks in a novel VE, and not the historical or cultural contexts. Further details from Part 1 and Part 2 of the study are explained in subsequent sections.

Participant Recruitment

Subjects were recruited from the university campus community through mass emails, posters placed throughout campus buildings, university announcements, and via a web sign-up survey (Appendix C). The web sign-up survey listed the preconditions of involvement in the study, which were: 1) Being above 18 years of age, 2) Not having any significant visual impairments after using corrective lenses, and 3) The ability to use both hands simultaneously to operate the left and right thumb sticks while holding a gaming controller. Subjects were randomly selected from a larger pool of participants (*n = 320*) that took part in other related studies. The only knowledge these individuals had about the study was they were to participate in the "Spatial Memory Test" in VR that would take between 45 and 60 minutes. Each participant received a $10 gift card incentive upon completion. To comply with the university's internal review board's policies regarding the collection of sensitive information on human subjects, anonymity was preserved by randomly assigning a unique five-digit participant identification number (PID #) to each person. The PID # was written on a small index card (Appendix D) and was given to each person upon entering the lab.

Experimental Design

Part 1: Questionnaires and Cognitive Tests

In Part 1 of the study, participants reported basic demographic information and were administered a series of six questionnaires in randomized order via a tablet web browser. We included these to ascertain whether the environment is influencing recall scores or if the results are guided primarily by individual characteristics in visuospatial abilities. Then, several common psychological tests were administered to help measure subjects' visuospatial abilities. We anticipated using these tests to conduct a correlation analysis with our Landmark/Route Recall and Scene Recognition tests to identify if individual variation of abilities predicts recall accuracy.

Ishihara's (1972) *Tests for Colour-Blindness* is used to isolate whether certain individuals had a bias towards certain environmental features due to their color awareness. Witmer & Singer's (1998) *Immersive Tendencies Questionnaire* (ITQ) evaluates a person's capacity to be

immersed into a VE. This is useful, because those who have low ITQ scores may not have been as readily immersed into the VE and were unable to encode spatial information, potentially limiting the accuracy of psychometric analysis. Lawton's (1994) *Wayfinding Strategy Scale* (WSS) is designed to assess gender differences in route-learning or orientation strategies, while the *Spatial Anxiety Scale* (SAS) evaluates levels of anxiety about environmental navigation. Schmitz' (1999) *Configurational Competence Scale* (CCS) assesses one's ability to leverage configurational, or 'global', knowledge using a Euclidean reference system. Blazhenkova & Kozhevnikov's (2009) *Object-Spatial Imagery and Verbal Questionnaire* (OSIVQ) helps differentiate an individual's object imagery, spatial imagery and verbal cognitive styles. After completing the questionnaires, subjects underwent a series of pre-programmed cognitive tests. The *Corsi Block-Tapping Test* (Corsi, 1972) is the spatial version of the Digit Span Test. Both are used to evaluate executive function and memory, but Corsi block aims to evaluate visuospatial cognition which is more relevant for our study. Trail Making Test Parts A and B (Armitage, 1945) are widely used studies that also aim to evaluate visuospatial executive function (Sargent et al., 2013). Part 1 of the study concluded following completion of these cognitive tests and took roughly 20-30 minutes to complete. Table 2.1 on the following page lists each of these questionnaires, how they were scored, and the corresponding literature.

Table 2.1 *Questionnaires and Cognitive Tests: These were administered in Part 1 of the study to test for correlations with the Landmark and Route Recall Assessment scores.*

Title	Description	Scoring	Source
Demographics	Self-reported information.	See Chapter 3	(See Table 3 in Chapter 3)
Tests for Color-Blindness	Series of 24 colored "plates" (images) designed to isolate color vision deficiencies.	Composite Score out of 24	Ishihara (1972)
Immersive Tendencies Questionnaire (ITQ)	Capacity to be immersed into a VE through categories of Focus, Involvement, Emotions, and Game. Reported on a Likert-type scale from 1-7.	Composite score per sub-category, as well as total score out of 126	Witmer and Singer (1998)
Wayfinding Strategy Scale (WSS)	Determines an individual's inclination to use either a Route Strategy or Orientation Strategy for wayfinding. Reported on a Likert-type scale from 1-5.	Composite scores out of 45 for Orientation Strategy. Score out of 25 for Route Strategy	Lawton (1994)
Spatial Anxiety Scale (SAS)	Degree of anxiety during environmental navigation. Reported on a Likert-type scale from 1-5.	Composite score out of 40	Lawton (1994)
Configurational Competence Scale (CCS)	Three questions assessing configurational, or global knowledge. Reported on a Likert-type scale from 1-4.	Composite score out of 12.	Schmitz (1999)
Object-Spatial Imagery and Verbal Questionnaire (OSIVQ)	A four-part test that distinguishes the use of a specific visual-verbal cognitive style. Reported on a Likert-type scale from 1-5.	Calculated Mean Score from all 41 questions.	Blazhenkova and Kozhevnikov (2009)
Corsi Block-Tapping Test	Measures Visuospatial Executive Function (EF) through a series of consecutive block-tapping tests which get progressively more difficult.	Scored as a sequence. Participants who scored < 0-2 were removed from data.	Corsi (1972)
Trail Making Tests A & B	Trail A & B Tests help measure visuospatial Executive Function (EF) by time (in seconds)	TMT Scores determined by calculating (B-A)/A.	Armitage (1945)
Self-Reported Reliance on GPS Aids	Reported on a 1-3 Likert-type scale.	Individual Scores out of 3	Bruns and Chamberlain (2018)

Part 2: Virtual Environment Navigation and Recall Tests

In Part 2 of the study, subjects were transferred to a quiet, separate room with several gaming PCs and Oculus Rift VR headsets. Wearing the VR headset, subjects navigated a novel VE through a first-person perspective and were then administered several map drawing and scene recognition tasks. Participants began Part 2 by first walking through a small demonstration virtual environment (DemoVE) to get accustomed to gaming controls and visual cues prior to entering the study virtual environment (StudyVE). Functionality of the Xbox gaming controller was deliberately limited to use the left thumb stick for single-speed forward motion and the right thumb stick for adjusting head angle/viewing direction. This limited functionality helped standardize the gaming controls for varying degrees of gaming experience among participants.

The DemoVE introduced subjects to visual cues such as blue guide arrows that automatically appeared at specific intersections to prompt motion along a fixed route. Additionally, movement was constrained along the route using invisible walls that bordered the streets. This ensured subjects did not wander away from the fixed route. Subjects were also told to move through the VE at an appropriate pace and were informed of the constraints with the invisible walls. There were no moving avatars or objects in the VE, only static 3D objects. Subjects were not tested over their knowledge of the DemoVE, and only the StudyVE was used for the later Route and Landmark Recall Assessments. After successfully navigating the StudyVE, subjects were prompted to remove the VR headset and were then administered several follow-up tasks on a computer monitor. Following Gale, Golledge, Pellegrino, & Doherty (1990) these tasks included: Landmark Recall, Route Recall, and Scene Recognition. Throughout all parts of the study, data was being transmitted to an on-site server to minimize error and ensure subjects experienced a standard process with limited interaction with the study moderators. Part 2 took approximately 20-30 minutes to complete, and further details are delivered in the subsequent sections.

Virtual Environment and Interface

The use of a 3D gaming engines for this type of research provides many benefits. First, it allowed for the control of spatial parameters and design features within the VE, permitting analysis of individual variables. Additionally, with the expertise of student research assistants in computer science, Unity was used to program eight of the ten landmarks to appear in randomized

locations. Because of this randomization of locations, every person who went through the experiment witnessed a different landmark configuration, with the exception of the Bakersfield (#2) arch and the church structure(#6). This experimental procedure helped eliminate context and order bias. Figure 2.1 illustrates the ten landmark locations, with the fixed landmarks bolded.

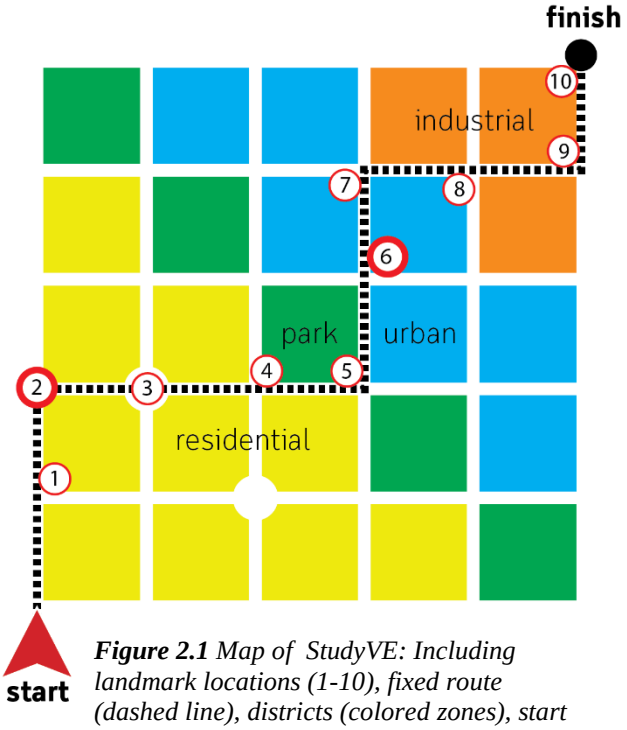

Figure 2.1 *Map of StudyVE: Including landmark locations (1-10), fixed route (dashed line), districts (colored zones), start point (red arrow), and finish points (black dot).*

The StudyVE was designed to enhance overall usability and immersive experience. It comprises a gridded street network measuring 5x5 blocks with a mix of residential, park, urban and industrial districts. Ten distinct landmark locations have been predetermined, which are numbered 1-10. Subjects navigate the VE using a Xbox 360 gaming controller to move along a fixed route (shown as dotted line in Figure 2.1). The general character and 3D assets placed within each of these districts typifies what might be seen in a real-world setting, and conforms with basic patterns of development along an urban-rural gradient (Weng, 2007).

Example scenes from each of the four districts within the VE are featured in Figure 2.2 (on page 15). The residential district contains a variety of single family home structures complete with driveways, garages, mailboxes, trash cans, and landscaping. The park districts comprise a fenced-in green space with mature trees, signage at major entry points, and a landmark feature. The urban district contains commercial structures, largely concrete and glass, with signage for businesses and other urban elements like fire hydrants, raised planters, spot lights, and various paving materials on the sidewalks. The industrial district contains warehouse structures made of metal and brick, without obvious indications of commercial activity such as signage or urban amenities. The modular grid structure permits easy alteration and repetition of environmental features, as well as standardized units for adjusting spatial parameters.

Figure 2.2 *Example Scenes from StudyVE: Including residential (top left), park (top right), commercial (bottom left), and industrial districts (bottom right).*

To achieve an optimized frame rate for gameplay (see Oculus Rift User Guide for recommendations), the number of triangles, vertices, and texture sizes within the 3D assets were all minimized to the greatest extent allowable. Frame rates varied between 55-65 frames per second. The sky and atmospheric lighting simulates dusk and was selected to provide sufficient ambient lighting to visualize textures and materials within the VE. The grid design of 5x5 street blocks allows for a relatively complex fixed route through the VE and is realistic in it's complexity to relate to an everyday navigation task.

The VE for this study has been augmented to comply with Vinson's (2003) *Design Guidelines for Landmarks to Support Navigation in Virtual Environments* (listed in Chapter 1) . Ten landmark types common to urban environments which fit within these guidelines have been selected for inclusion in this study (Figure 2.3, on page 16). These landmarks include a neighborhood archway, a bus stop, a church structure, a water tower, a monument marker, a colorful billboard, an abstract sculpture, stone statues, a neighborhood sign, and a tiered fountain. The Bakersfield arch is a tall and wide neighborhood gateway with two towers connected with a large sign which reads "Bakersfield." The bus stop is a small shelter structure with a map image displayed inside the glass. The church structure is a standard chapel with religious symbol and a

bell tower. The water tower a is tall cylindrical structure supported by metal trusses. The monument marker is a typical concrete obelisk denoting a location of significance. The colorful billboard is tall and illuminated, displaying an image of umbrellas floating in the sky. The fountain is circular in shape and has multiple tiers of cascading water that was not animated. These landmarks have been selected to include a diverse range of categories and scales including infrastructure, expressive urban art, and signage. Other than the church structure and Bakersfield arch, all the landmarks conform to a similar footprint. An important note is that each of these landmarks, except for the stone statues (Easter Island heads), had any real-world cultural or historical associations. Lastly, the church structure was the only landmark that contained a habitable building space.

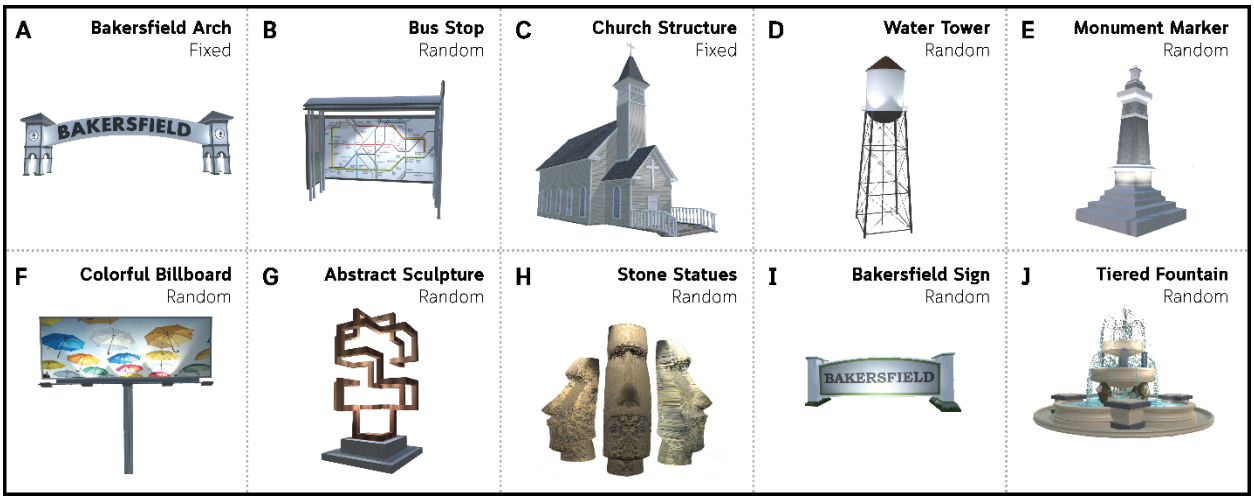

Figure 2.3 *Landmark Key: Identified by letters (A-J) and descriptor. Random or Fixed indicates if the landmarks was located randomly or not for each participant.*

To test which of these ten landmarks elicited the highest recall accuracy, eight of the ten landmarks were programmed to appear in one of eight randomized locations. This method eliminated context and order bias, permitting a more accurate analysis of individual features. Those eight locations are shown in Figure 2.1 as numbers 1, 3-5, 7-10. The Bakersfield arch was always positioned in location 2 and the church structure was always located in position 6. These static elements were necessary because they are substantially different in size and form than the other randomized landmarks. The randomized location ensured that each subject experienced a unique landmark configuration along the fixed route.

As subjects moved along the route, they were guided using translucent blue arrows hovering just above street level. The arrows were displayed at regular intervals as the subject approached an intersection and at turning points along the fixed route. A system of invisible walls was developed to restrict movement to within the street. Backtracking along the route was also restricted. All subjects were informed that they may halt the experiment at any point if they experience any degree of discomfort, nausea, or dizziness (simulation sickness).

Map Drawing Tasks

Map drawing, or sketch mapping, is an intuitive way for individuals to express the configuration of environmental features. Since Lynch's (1960) work, sketch maps have been used extensively in psychological experiments and proven reliable measures for assessing spatial memory and predicting wayfinding performance (Blajenkova, Motes, & Kozhevnikov, 2005; Gale et al., 1990; Ishikawa et al., 2008; Lukas et al., 2014). Historically, sketch map analysis has consisted of a lengthy and often unstandardized process of qualitative analysis through carefully designed scoring rubrics, affecting data objectivity with reviewer bias. As a remedy to this, new software tools are being devised for quantitative sketch map analysis to objectively assess cognitive map accuracy (Gardony et al., 2016). This study employs a custom software package to analyze spatial knowledge from sketch maps in an automated computer program purpose-built for this study. Subjects' hand-drawn sketch maps are scanned and digitized in vector format, and the custom-built parsing software extracts variables from the Landmark and Route Recall Assessments. In the following subsections, the procedures used for the recall tasks are explained, followed by a description of the coding and analysis processes used for the map drawings.

Assessment Procedures

After navigation in the StudyVE, subjects removed the VR goggles and were administered the Route and Landmark Recall Assessments on a 24" full-color computer monitor at 1080p resolution. Each subject was given the option to select which recall test they preferred to start with. Among the study sample (n=39), the choice distribution between the two tests was relatively even, with 21 subjects (54%) choosing to start the Route Recall Assessment first and 18 subjects (46%) preferring to begin with the Landmark Recall Assessment.

The map drawing tasks were administered on square 11x11 inch sheets of blank grid paper containing a red arrow indicating the start point of the fixed route. A grid was chosen for the map drawing tasks because it is reflective of the Jeffersonian-like grid of the StudyVE, which is situated on a 5x5 orthogonal street block structure (see Figure 2.1 on page 16). Before starting the map drawing tasks, subjects were informed that each bolder grid increment was the equivalent distance of one street block segment. This was the only unit of reference given throughout the recall tests (Figure 2.4). Each of the bold grid cells were subdivided into half block units with lighter lines, giving subjects more precision when placing landmarks. The full grid page features 14x14 grid cell units and was deliberately oversized to generate variation, but control for scale. In other words, the 14x14 unit grid was selected rather than a 5x5 unit grid page because it intentionally captures subjects' navigation errors. The starting point at the red arrow was situated in the middle of the grid page to ensure subjects did not develop assumptions about their route or landmark locations (e.g. turning left or right first).

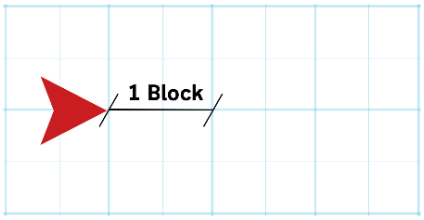

Figure 2.4 *Block Unit Reference: Given to subjects prior to the Map Drawing Tasks. 1 bold grid increment = 1 street block from the StudyVE.*

Each subject was given two grid pages, one for Route Recall and another Landmark Recall. For each of the Map Drawing Tasks, subjects were asked to position the grid page according to the orientation they felt most comfortable. They were given three options with the red start arrow situated either on the left, the front middle, or on the right (Figure 2.5). This orientation choice may help determine subjects' preference for an egocentric "streetview" perspective, or an allocentric "map-like" perspective. Subjects were never shown a map or any type of secondary source of the VE at any point throughout the experiment. The only spatial information presented was their own unique first-person navigational experience in VR.

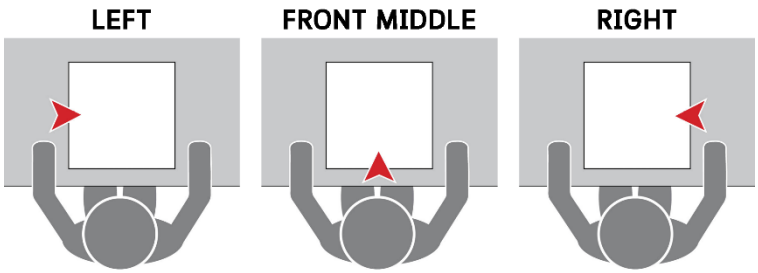

Figure 2.5 *Page Orientation Choices: Given to subjects prior to the Map Drawing Tasks*

Route Recall Assessment

The Route Recall Assessment tasked subjects with delineating their perceived route through the StudyVE on a blank grid page, which was provided in an enclosed folder. Subjects began drawing the line of their route starting at the red arrow and continuing until they reached the end of their route, which they indicated with a bold circular dot (Figure 2.6) Several variables were extracted from subject's route map drawings to assess accuracy, including: end point location, total route length, direction travelled per route segment, total number of turns, and the sequence of turn directions. After subjects completed this recall test, they then placed the paper in a folder on the desk and proceeded to the next task, which was automated depending on their initial choice.

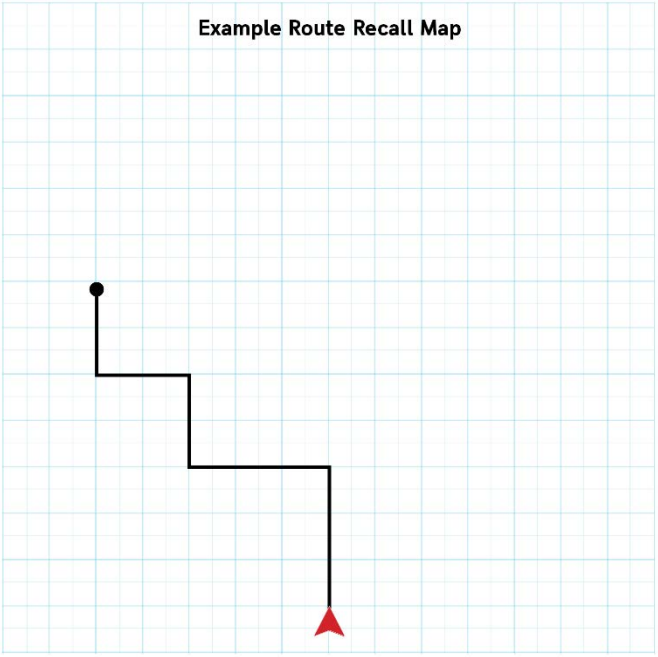

Figure 2.6 *Example Route Recall Map: Displayed to subjects to give them clear directions about how to draw their perceived route using the grid page and pencil provided. Dark line=route; Circular dot=end point.*

Landmark Recall Assessment

Both survey and graph knowledge were assessed through a singular map drawing exercise, however these two forms of spatial knowledge were evaluated independently of one another. Following (Gale et al., 1990) participants were asked to identify the locations of all ten landmarks on a blank grid page, which was identical to the one used in the Route Knowledge Assessment. They were presented with a landmark key (see Figure 2.3, on page 16), whereby each of the ten landmarks were pictured with a corresponding letter (A-J). Subjects were given clear instructions to write only the capital letter for the corresponding landmark on the grid page where they believed its' location to be. Subjects were asked to control the size of their lettering to give a more precise indication of the perceived landmark locations (Figure 2.7).

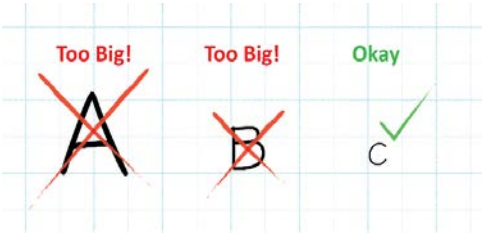

Figure 2.7 *Landmark Letter Sizes: This graphic helped control the size of lettering to give a more precise indication of landmark locations.*

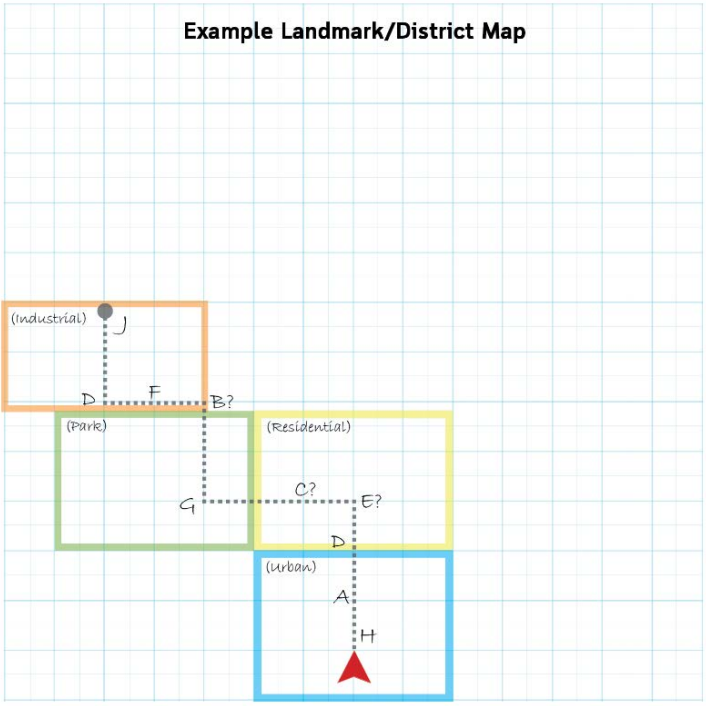

Figure 2.8 *Example Landmark Recall Map: Displayed to subjects to give them clear directions about how to draw their perceived landmarks and districts with the grid page and drawing utensils. Red Arrow=start point; Letters A-J=Landmark Locations; Colors=Districts.*

Once landmarks were located on the grid page, participants were evaluated for their memory of districts (graph knowledge) as a supplemental exploratory measure. To complete this task, participants used colored markers to illustrate each of the four district boundaries (residential, park, urban, industrial). No specific data was extracted from the district drawings, as it was primarily used as a pilot test for further research. A visual overlay (see Figure 4.2, on page 33) was created to examine whether participants were able to ascertain the basic layout of the districts and the findings are discussed in Chapter 4. An example of what the finished Landmark Recall map should look like was shown to participants

to elicit more consistency among subjects (Figure 2.8). They were informed that this example map was not indicative of any of the environmental features, and that they should only reference it for instructions on how to conduct their Landmark Recall Assessment.

While we scored Landmark Configuration Accuracy at a continuous level, we aggregated the data to the one-half block to account for variation in handwriting size (when participants indicated the location of landmarks), variation in the projection of maps, and variation of the translation to the XY values in vector format. We believe the ½ block provides a more intuitive measure rather than reporting on the pixel variation (default in Adobe Illustrator) or projection to feet from the Unity gaming engine. For the final part of our analysis, we determined which landmarks were most accurately recalled, and whether landmark configuration accuracy was correlated with route accuracy to answer the key research questions listed on page 1. Table 2.2 provides the variables which were extracted from the map drawing tasks.

Table 2.2 *Recall Test Metrics: Landmark and Route Recall Assessments and the variables extracted from each of the map drawing tasks.*

Recall Test	Metric	Description
Landmark	Configuration Accuracy	Spatial variance from stated to actual location of landmark
Route	End-Point	Spatial variance from stated end point (last point of sketched route) and actual end point
Route	Total Distance	Total distance walked (blocks)
Route	Total # Turns	Total number of turns taken
Route	Correct Sequence	Correct sequence of turns (stopped counting at 5)

Digitizing and Analyzing Map Drawings

The Route and Landmark Recall Tasks (map drawings) were collected by moderators after each subject successfully completed the experiment. Upon collection, the pages were oriented consistently to ensure uniformity when scanning into digital image format. The pages were scanned in color at a resolution of 300 dpi and saved in a single PDF document, then transferred to a PC hard drive. The PDF pages were then cropped to be exactly 11 x 11 inches, and each page was exported as an individual PNG image. Once the PNG images were exported, they were each renamed according to the participant ID number. Each of these was then manually converted to vector format using Adobe Illustrator. For each participant, the districts, routes, and landmarks were recreated in separate layers. After every map drawing was converted into vector format, the file was saved as an Scalable Vector Graphics (SVG) format. This file, which represents an XML variant, was then decoded by custom parsing software written using

the Java DOM (Document Object Model). The parsing software then extracted the Cartesian coordinate locations of each landmark, as well as, details about the route. For each landmark the distance between the subjects' identified location and the actual location was measured (in blocks), determining the Landmark Configuration Accuracy.

Scene Recognition Task

Testing the distinction between contextual scenes and landmark objects is an important facet of acquiring route and survey knowledge (Hollingworth & Henderson, 2002). That is, after navigation can people accurately recall whether a certain landmark was or was not present in a given scene. The Scene Recognition Task assesses subjects' declarative landmark knowledge by asking them to match one of the ten landmarks with a corresponding scene, absent the landmark. This allows us to deduce which of the environmental scenes elicited the highest memorability, irrespective of its location. A series of ten screenshots of scenes from the VE, each without their corresponding landmarks, were presented to participants following the map drawing tasks (Figure 2.9, above). Subjects were scored on a 1-10 scale, with one point given per correctly matched landmark and scene. We refer to this evaluation as the Scene-Matching Score.

Figure 2.9 *Scene Recognition Task: One out of the ten scene matching questions described above. Subjects were presented with a drop-down menu of the landmark letters (A-J) and were prompted to recall which one they remembered in the given scene to the best of their abilities.*

Chapter 3 - Results

The key research questions for this study were: **1) Do certain types of urban landmarks elicit a heightened spatial memory?;** and **2) Which types of urban landmarks have the highest degree of impact on spatial memory and recall?** To help answer this, we conducted analyses to determine if there were any factors that may have influenced scores. Further, we investigated if there are any correlations between the standardized questionnaires and cognitive tests identified in Chapter 2 . We then conducted an Analysis of Variance (ANOVA) to determine if there were any factors that may be influencing differences in recall performance. Landmark Configuration Accuracy is used as the dependent variable for reporting and ANOVA because this measure was found to be significantly correlated with several other recall scores.

Subjects

A total of 39 adults (mean age= 21.0, SD= 2.2) with varying years of post-secondary education (mean=2.8, SD= 2.1) participated. This group comprised 17 females and 21 males, 1 gender non-conforming individual. There were 32 undergraduate students, 5 graduate students, 1 PhD student, and 1 non-student represented in the entire study group. Six colleges were represented in the majority student sample (38 total students): Engineering (13), Agriculture (2), Arts and Sciences (9), Architecture, Planning and Design (6), Human Ecology (3), and Business Administration (5). Colleges and majors were then categorized according to three disciplines: visual arts (e.g. architecture related disciplines and arts), humanities (e.g. business, sociology) and science (e.g. engineering, biology) following Blazhenkova & Kozhevnikov, (2009). Subjects also optionally self-reported any psychiatric or learning disabilities, and 5 individuals indicated some type of attention disorder (e.g. ADD, ADHD). Following Parush and Berman (2001), we asked subjects to rate their experience playing first or third person 3D video games on a 1 to 5 scale with 1 denoting no experience and 5 denoting very experienced. The mean rating of gaming experience was 3.2 (SD= 1.6), indicating a general competency among the study group for playing 3D videogames. After navigating the VE, subjects also reported their level of comfort in the VE on a 1 to 5 scale with 1 denoting extreme discomfort and 5 denoting extreme comfort. The mean comfort level was 3.4 (SD= 1.2), indicating a moderate degree of ease in the VE, with 2 individuals reporting extreme discomfort. Table 3.1 on the following page describes this break down further.

Table 3.1 *Subject Demographics and Self-Reported Information: Variables collected in Part 1 of the study.*

Variable	Categories and Measures	Totals
Gender	Male Female Other/Non-conforming	21 17 1
Age	Range = 18 to 27	Mean = 21.0, SD = 2.2
Dominant Hand	Right Left	35 4
Postsecondary Education (Years)	Range = 0 to 9	Mean = 2.8, SD = 2.1
Type of Student vs Non-Student	Undergraduate Graduate PhD Non-Student	32 5 1 1
Associated College	Engineering Arts and Sciences Architecture, Planning and Design Business Administration Human Ecology Agriculture	13 9 6 5 3 2
Discipline	Visual Arts Science Humanities	9 20 9
Environment Growing Up	Rural Suburban Urban	9 19 11
Environment Now	Rural Suburban Urban	6 26 7
Gaming Experience	Scaled from 1 (No experience) to 5 (Very experienced)	Mean = 3.2, SD = 1.6
Sense of Direction	Scale from 1 (low) to 4 (high)	Mean = 3.4, SD = 1.2

Predicting Recall Performance

Analysis of variance showed a very small effect of gender on the landmark configuration accuracy, $F(1, 378) = 5.203$, $p = .023$, $\eta_p^2 = 0.014$. Tukey's HSD indicates males outperform females on Landmark Configuration Accuracy with an average estimation error of one block closer than females. This validates existing literature regarding gender differences on spatial navigation and landmark placement tasks (Liu et al., 2011). However, consideration should be given to other contributing factors such as implicit cultural bias. Graduate students were also found to perform better than undergraduate students $F(1, 357) = 5.933$, $p = .015$, $\eta_p^2 = 0.016$ with just over a block more accurate. We also tested whether subjects' college, discipline, handedness, environmental context, and gaming experience had any predictive effects and discovered no statistically significant correlations. While there was a positive correlation with

self-reported sense of direction, the relationship with landmark configuration accuracy was inconclusive due to a small sample size within each quartile.

We further analyzed the extent to which various questionnaires and tests might predict landmark configuration accuracy. No correlations were found between results from the questionnaires and cognitive tests from Part 1 and the Landmark and Route Recall Assessments. All the questionnaires and tests are scored as scalar data with a diverse range of upper and lower limits. Therefore, we developed an analysis using quartiles of each of these different scores to determine if there may be predictive properties based on the quartile of score individuals fell into. The analysis of variance using quartiles showed mixed results. The Immersive Tendencies Questionnaire (ITQ) total score results in statistical significance but the results are inconclusive because the sample size for the statistically different quartile was only two individuals. We discovered an effect with Spatial Anxiety Scale $F(2,387) = 3.751$, $p = .024$, $\eta_p^2 = 0.019$ with a Tukey HSD indicating a difference between participants with a lower level of anxiety (1) and higher level of anxiety (3, $p = .014$). Ironically, those indicating a higher level of anxiety showed better accuracy by over one block. Scores from the Wayfinding Strategy Scale also showed a statistically-significant difference. Those that tended toward a route strategy $F(2,383) = 4.59$, $p = .011$, $\eta_p^2 = 0.023$) performed more accurately on Landmark Recall Assessment. Likewise, those that tended toward an orientation strategy $F(2,383) = 3.81$, $p = .023$, $\eta_p^2 = 0.02$) performed more accurately on the Landmark Recall Assessment. This validates previous findings of Hund & Minarik (2006), who discovered that navigation efficiency increases as a function of increased reliance on orientation strategies.

A comparison of the Route and Landmark Recall Assessments was conducted to ascertain the strength of correlations between variables. Table 3.2 shows Pearson's correlations between each of the recall assessment variables. The Scene Matching Score test had no correlation with the

Table 3.2 *Pearson Correlations of Recall Assessments*

		Landmark Configuration Accuracy	**Route**			
			End Point	**Total Distance**	**Total # Turns**	**Correct Sequence**
Scene-matching		**-.325***	-0.179	-0.010	0.188	0.312
Landmark Configuration Accuracy			**.732****	**.503****	0.173	**-.332***
Route	**End Point**			**.712****	0.288	**-.433****
	Total Distance				0.273	-0.088
	Total # Turns					**.420****

Correlation (2-tailed); * Significant at the 0.05 level. ** Significant at the 0.01 level; All tests *n*=39

route tests and a moderate negative correlation with Landmark Configuration. The negative correlation exists because zero represents the best configuration recall, while higher scene matching indicates better recall. The landmark configuration test correlations indicate a high correlation with the end location and the number of blocks walked, as well as, a moderate correlation with the number of turns in sequence. The Route Recall Assessments only correlated with themselves, except route end point was highly correlated with landmark configuration accuracy. The implications of this finding are discussed in Chapter 4.

Landmark Configuration Accuracy

The key question of the study focused on identifying which landmarks elicit the highest recall scores. We determined this through the Landmark Recall Assessment (described in Chapter 2) and calculated the average estimation error of the stated versus the true locations for each landmark. This average estimation error for each landmark was measured in street block units. A One-sample t-test was ran to determine statistical differences between each landmark's average estimation error (listed in Table 3.3).

Table 3.3 *Landmark Configuration Accuracy: Individual landmark scores (in street-block units) which reflect the average estimation error across all subjects (n=39) stated versus true landmark locations.*

Landmarks (A-J)	**Average Estimation Error** *(measured in blocks)*
Bakersfield Arch (A)	1.37
Bus Stop (B)	3.46
Church Structure (C)	2.78
Water Tower (D)	3.72
Monument Marker (E)	5.41
Colorful Billboard (F)	4.44
Abstract Sculpture (G)	4.40
Stone Statues (H)	3.90
Bakersfield Sign (I)	3.36
Tiered Fountain (J)	4.03

First, we identified the average distance from stated versus true location for all landmarks (M = 3.68 blocks from true; used as the t-test value). The t-test indicated that participants were much better at identifying the location of the Bakersfield Arch (M = 1.37, SD = 1.15), $t(38) = -12.53$, $p < .000$, $d = -2.01$ and location of the church structure (M = 2.78, SD = 2.66), $t(38) = -2.12$, $p < .041$, $d = -0.34$, but were not able to identify the location of the monument marker as well as the average (M = 5.41, SD = 4.36), $t(38) = 2.47$, $p < .018$, $d = -0.40$. Figure 3.1 provides a chart of the confidence intervals for each landmark's configuration accuracy. The chart labels 0 as the Mean error from stated versus true location of landmarks (3.68 blocks away). So, the Bakersfield Arch was identified roughly two blocks more

accurately (negative values) than the average landmark. In contrast, the monument marker was identified less accurately than the average landmark. In general, it appears that the range of landmarks falls within the average error.

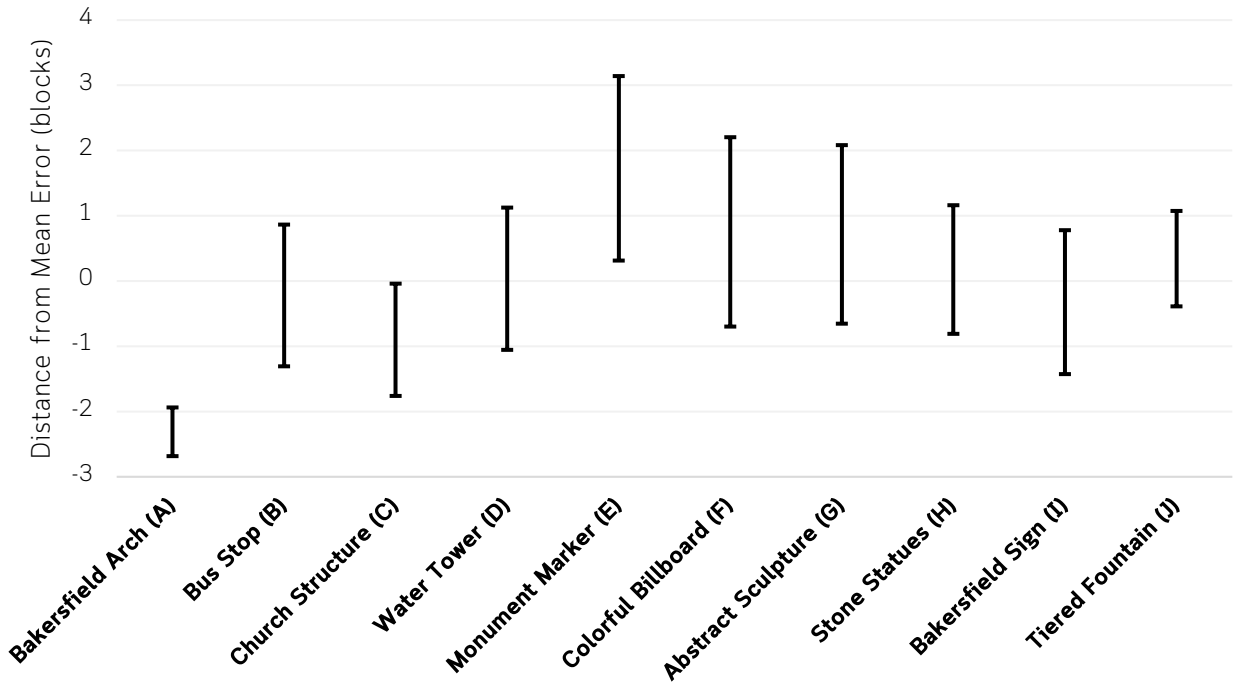

Figure 3.1 *Landmark Configuration Accuracy Confidence Intervals: Each landmark from the VE as measured by the Mean error from the stated versus true landmark locations (0 = 3.68 blocks away, -2 = 1.68 block away, 2 = 5.68 blocks away).*

Scene Matching Score

The Scene Recognition Assessment allowed us to determine scene matching scores. to discover the degree to which landmarks were recognizable in their context as each participant would have experienced the scene. The ten landmark locations are shown in Figure 2.1. The number of times each landmark was correctly identified in each of the ten locations is listed, beginning with location one and ending with location ten: 10, 31, 38, 11, 9, 6, 10, 14, 16, 20. For instance, the second location was correctly identified 31 times. This location happened to be the Bakersfield Arch, which was one of the two landmark objects which remained in a fixed location. Landmarks in the third location were correctly identified 38 times; this location

happens to be the only round-about in the StudyVE. Objects in the final location were correctly identified 20 times.

Table 3.4 reveals how many times each landmark was correctly identified regardless of the location. The Bakersfield arch (at fixed-location 2 in Figure 2.3) was correctly identified 31 times. The monument marker was recognized only 11 times. This aligns with the findings for Landmark Configuration Accuracy. However, the church structure was correctly identified only six times. In general, there is an association between the landmark location accuracy for each landmark and the correct number of times it was identified in the Scene Recognition Assessment. This is further supported by the moderate correlation of the Landmark Configuration Accuracy and Scene Matching Score shown in Table 3.2 on page 26. ANOVA was conducted to identify if any demographic variables predicted Scene Matching Score, and no variables were found to be predictive.

Table 3.4 *Scene Matching Scores: Number of instances each landmark was correctly identified on the Scene Recognition Task*

Landmarks	Instances Correctly Identified
Bakersfield Arch (A)	31
Bus Stop (B)	14
Church Structure (C)	6
Water Tower (D)	17
Monument Marker (E)	11
Colorful Billboard (F)	18
Abstract Sculpture (G)	18
Stone Statues (H)	19
Bakersfield Sign (I)	14
Tiered Fountain (J)	17

Chapter 4 - Discussion

The goal of this research is to devise enhanced placemaking strategies through the strategic inclusion of landmark configurations in an urban fabric. We did this by drawing upon research methods in environmental psychology and using a deliberately constrained three-dimensional VR environment. We reflect upon the origins of cognitive map theory (Tolman, 1948), seminal work into the realm of environmental perception and urban form (Lynch, 1960), as well as, Whyte's (1980) instrumental work linking many aspects of design to the success and identity of a place. The discussion broadly focuses on the types of spatial knowledge which were assessed following the hypothesis in Chapter 1 . The most significant finding of the study reveals that Landmark Configuration Accuracy is highly correlated with performance on the Route Recall Assessment and Scene Recognition Tasks, illustrated in Figure 4.1. This finding suggests that, regardless of the landmark type, individuals who more accurately recall landmark locations will also identify routes and scenes more accurately. Landscape and urban planners can leverage these findings to advocate for the inclusion of new and unique landmark configurations throughout an urban fabric, as well as for the preservation of existing and historic landmarks.

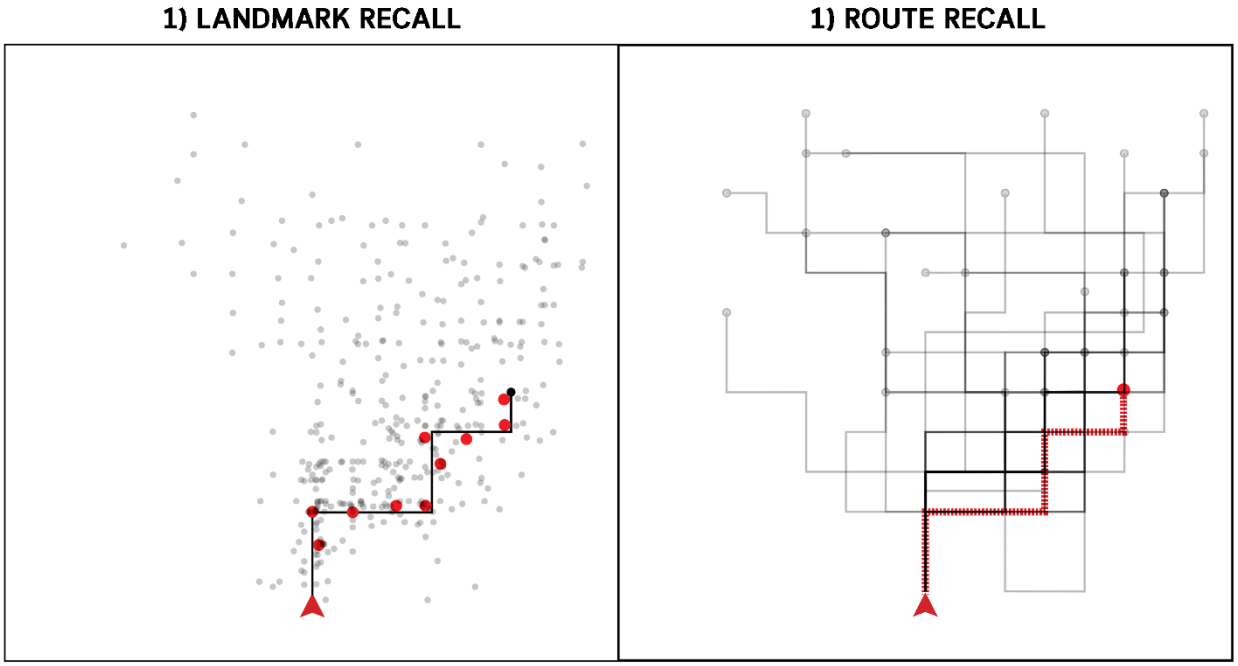

Figure 4.1 *Landmark VS Route Recall: A map overlay of each of the recall assessments across all subjects (n=39).*

Landmark, Route, and Survey Knowledge

The first hypothesis identified in the introduction was that larger landmarks with the highest degree of visual contrast would be more accurately recalled, and thus more memorable. Our findings support this hypothesis partially, but also suggest that there are more nuanced reasons why certain landmarks were more accurately identified on the map drawing tasks. The landmarks reported to have the highest locational accuracy were the Bakersfield Arch and the church structure, which were among the largest in scale throughout the VE, and the only two that remained stationary. However, the water tower and billboard, which are the two tallest landmarks, were statistically not any different than the average of all landmarks, suggesting that sheer height is not predictive of landmark accuracy. While would have preferred to have implemented a random location for the Bakersfield Arch and the church structure, we believe that these findings are aligned with literature regarding Gestalt theory.

Landmark knowledge depends on how well the viewer paid attention to their environment but could also be due to a specific landmark's capacity to be encoded as an anchor point on an individual's cognitive map. As indicated in the results, those with higher spatial anxiety scores slightly outperformed those with lower spatial anxiety. This is most likely attributed to the subject's attentional allocation (Lee & Kim, 2008) or focus within the VE. An individual may choose to focus more on certain environmental features, and may thus recall them more accurately, for many reasons. For instance, Hull et al. (1994) previously identified that places of worship were an important element in place identity and thus well recognized. Within the cultural context of our participant pool, the church structure would represent a prominent place of worship, bringing a strong cultural association to that specific landmark. The Bakersfield arch represents a gateway feature that is often placed at town entrances, but in this context may have been out of character with the residential environment providing a stronger visual contrast with the surrounding features. Considering Lynch's (1960) typology, the Bakersfield arch could have been cognitively interpreted as an edge delineation, prompting a better transcription of this location onto one's cognitive map.

The same cannot be said for the church structure, which elicited higher locational accuracy on the Landmark Recall Assessment but scored lowest in the Scene Recognition Assessment. The church structure was positioned in a fixed location (#6 in Figure 2.1) near the middle of the route, so if subjects were not very precise with their recall, they could still maintain

accuracy as a group if they located the church structure somewhere near the middle of their landmarks. However, with scene-matching, subjects may have been confused by the removal of the church structure in the context of the urban-park transition zone. With the church structure removed from the scene, the empty space revealed greater amount of vegetation with the urban area as the background. It is likely participants did not recognize this scene because the structure obscured the trees in the StudyVE, and therefore were unable to remember the matching scene.

The range of accuracy scores for each of the landmark types may also be related to how individuals encoded them as a hierarchy of proximal and distal cues within the VE. Proximal cues, also called beacons, are typically encoded as more prominent anchor points on an individual's cognitive map. Beacons are also more typically associated with reaching a destination point, which could explain the increase in Scene Recognition and Landmark Configuration scores at the end point of the VE. Distal cues, or smaller and less prominent landmark arrays, often fall as secondary anchor points, which could explain why landmarks such as the tiered fountain, Bakersfield sign, and monument marker were recalled less accurately (Waller & Lippa, 2007).

Supplemental Findings

As a supplemental measure for this study, graph knowledge was also assessed through delineations of perceived district on the Landmark Recall map drawing task. No specific data was extracted from individuals district drawings, however, the visuals below (Figure 4.2) demonstrate a wide variation in where subjects thought each of the districts were located. Each of the colored zones is representative of one specific district, with all 39 district drawings separated into transparent layers. In general, it appears that subjects were able to understand the procedural order of the districts but did not understand the scale. These findings harken back to Lynch's (1960) concept of edges, which are valuable tools in urban design. If a strong edge is delineated for a particular district, one would expect these colored zones to increase in accuracy.

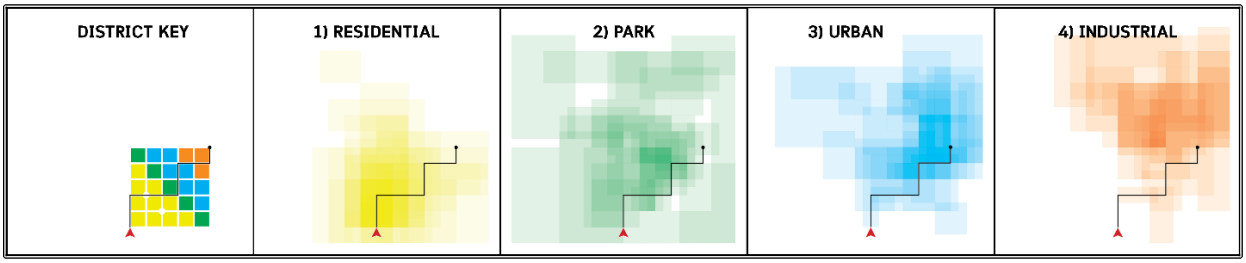

Figure 4.2 *District Delineations: An overlay of all subjects' perceived district boundaries at 10% opacity per participant. From the left, the Key shows the actual locations of the districts. (n=39)*

Limitations of Virtual Reality Environment

One of the major hurdles for this research was using a VR HMD as an immersion tool. While technology has advanced tremendously over the past several years, there are still some major bottlenecks that could be improved in the future. For instance, smoothness and ease of gameplay is a major influencing factor for subject's perceptions of VEs. This is affected by many variables, including polygon count (richness of detail), playback frame rate (smoothness), and the use of gaming controllers and joysticks for motoric controls. The frame rate we achieved for this study averaged between 55-65 fps, falling short of the recommendation from Oculus Rift of 90 fps. This may be due to limited expertise and equipment, but more likely because our environment was highly detailed and quite large with limited occlusion (occlusion is often used in videogames, so graphics cards do not need to render distant objects). Future studies should

strive to reach target frame rates which match the industry recommendations for specific VR hardware.

Simulation sickness is another major consideration when designing VEs, particularly when using VR headsets. This has been proven to be significantly and negatively correlated with the successful acquisition of spatial information (Witmer & Singer, 1998). Following Parush & Berman (2004), we tested for this by asking subjects of their comfort level after navigating the VE on a 1 to 5 scale with 1 denoting extreme discomfort and 5 denoting extreme comfort. The mean comfort level was 3.4 (SD= 1.2), indicating a moderate degree of ease in the VE, with 2 individuals reporting extreme discomfort. However, no correlation was found between subjects' self-reported comfort level and performance on the Recall or Scene Recognition Tasks. We recommend that further studies employ Witmer and Singer's (1998) full Simulation Sickness Questionnaire to validate this hypothesis.

Future Research

Landscape and urban planners are increasingly harnessing vast amounts of publicly available geospatial data. They are using this data to create compelling 3D visualizations of design proposals for clients seeking heightened levels of immersion and realism in graphic communications. To this end, design professionals can lend their skills in constructing high-fidelity 3D environments to aid in psychometric research in analytical behavioral geography (Golledge & Stimson, 1987). Having greater knowledge about how the built environment influences human behavior will allow urban designers to create better places which amplify a more positive human experience. As stated in Chapter 1, this study only evaluates landmarks based upon their spatial contexts, and not their social or historic aspects. Other psychometric studies in VR could bring in these cultural and historic components to help understand the degree to which these constructs influence an individual's memory.

Chapter 5 - Conclusion

Landmarks are an integral part of the built environment and are universal elements of human urbanization. However, there are no coherent policies in place for designing strategic landmark *configurations* throughout an urban fabric. While some cities have landmark preservation ordinances, no consistent framework acknowledges the vital role of landmark configurations in forming place-identity and increasing spatial awareness. Our finding that Landmark Configuration Accuracy is highly correlated with Route Recall and Scene Recognition provides powerful evidence for landscape and urban planners to holistically consider spatial layouts of landmarks within urban design frameworks. These findings can be used to inform city zoning policies which recognize the critical role of landmark configurations in fostering both place identity and spatial awareness. The findings from this study support the development of a new planning framework which guides the design, implementation, and preservation of landmarks, which we have termed Landmark Configuration Plans (LCP). As the world continues to urbanize, LCPs would give planners and policymakers a valuable tool to advocate for new and existing landmark configurations and the many benefits they provide.

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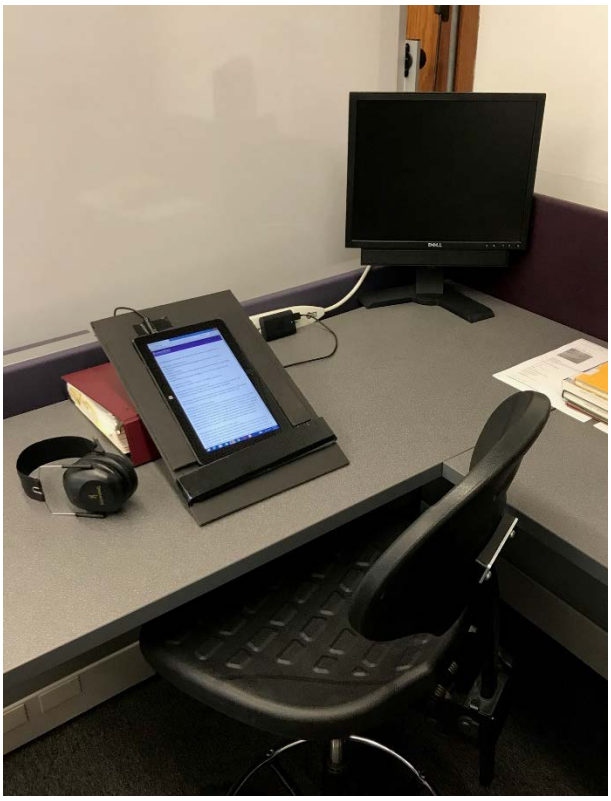
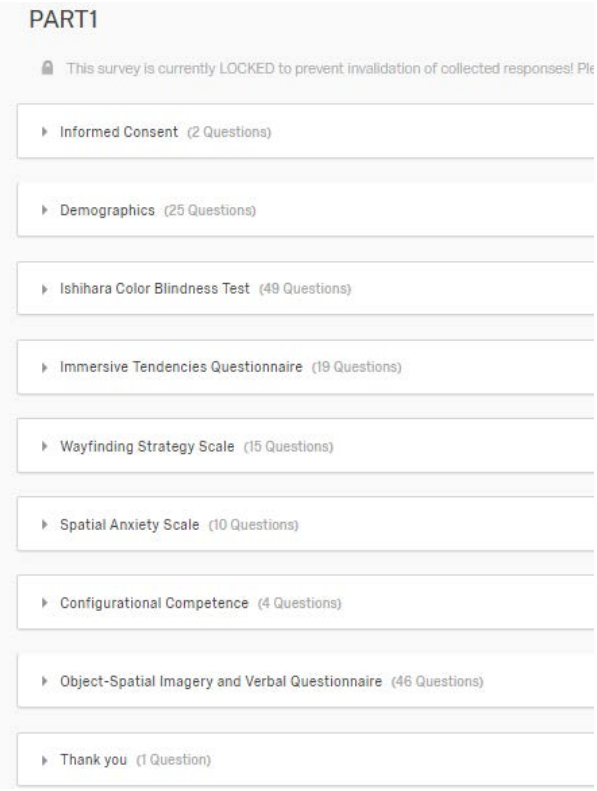
Appendix A - Part 1: Qualtrics Questionnaires

NOTE: The following Appendix has been extracted from a PDF document which contained the pages of questionnaires administered in Part 1 of the study procedures via an online Qualtrics survey. Any questions regarding these should be directed to the authors of this study, Bruns and Chamberlain (2018), who hold access to the raw data. Part 1 was administered on a Dell Venue 11 Pro (model no. T06G001) touchscreen PC tablet running Windows 8.1. The web browser used to launch the online Qualtrics survey. The image below shows one of the three tablet workstations we had set up to run participants through the experiment. Noise cancelling headphones were provided, and the tablets were secured with a custom-built workstation stand, which angled the screen towards the user at approximately 45 degrees.





IC.
Investigating the Influence of Wayfinding Interventions on Spatial Memory

PRINCIPAL INVESTIGATOR:
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Landscape Architecture and Regional & Community Planning, Kansas State University
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CO-INVESTIGATORS:
Conner Bruns, Graduate Student, Landscape Architecture

IRB CHAIR CONTACT INFORMATION:
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Cheryl Doerr, Associate Vice President for Research Compliance, 203 Fairchild Hall, Kansas State University, Manhattan, KS 66506, (785) 532-3224

PURPOSE OF THIS RESEARCH:
The purpose of this research study is to investigate an individual's ability to recall his or her route and survey knowledge of a novel virtual environment. This includes understanding the influence of different levels of immersion (e.g. monitor vs VR headset) and the influence of navigational aids. The information collected will help us better understand the role that navigational aids play in forming our spatial memory of a place. This is important because if we understand the triggers that may increase one's spatial memory, we can consider how to augment the aids to support a better understanding of unaided navigation.

PROCEDURES OR METHODS TO BE USED:
You will be randomly assigned to one of three different immersion technologies (computer monitor, large panoramic immersion screen or VR headset). You may then be connected to non-invasive biometric equipment (e.g. to observe heart rate) and will begin completion of a short survey. Following the survey you will be asked to complete a few spatial memory tests. Upon completion of tests, you will then be directed to begin walking through a virtual environment using your assigned immersive technology. The environment is of part of a hypothetical city and you will be directed along a path by our own built-in navigational aid (e.g. GPS). After the virtual walk, you will then be asked to complete a final spatial memory test of the environment you just experienced.

RISKS OR DISCOMFORTS ANTICIPATED:
The virtual environment was created using a gaming engine. If you are prone to motion sickness from video games you may experience some discomfort (more likely if you are randomly assigned the VR headset). If you do consider yourself very highly susceptible to motion sickness, please notify the moderator and you may be assigned a lower level of immersion technology. However, please note that you can walk through the environment at your own pace, or choose to end the experience at any time without loss of compensation for your time.

LENGTH OF STUDY: The study will require roughly an hour to complete. Depending upon the tests conducted and the speed of completion, this time may increase or decrease by up to 20 minutes.

COMPENSATION:
You will be offered a $10 stipend for your participation.

BENEFITS ANTICIPATED:
Your randomly assigned participant ID number and website are located on the notecard given to you at the beginning of the experiment. You will be able to request access to your test scores by entering your participant ID number via the researcher's website. For your data to remain anonymous, we will not have any link to your personal information and participant ID number – so if you wish to access your scores in the future, do not lose the notecard. Your data will be made available once all analysis has been completed.

Outcomes of this research may include publication and presentations. By understanding how spatial memory is influenced by various cues and immersive wayfinding technologies, the intent is to inform better methods for supporting improved spatial memory compared with existing wayfinding devices.

EXTENT OF CONFIDENTIALITY:
All data collected will remain anonymous. Any data collected will be shared anonymously with assurance that no personally-identifiable information will be provided such that you could be recognized. The digital information collected will be saved on computers in the lab using secure cloud-based storage. All written analog information will be stored in the PI's office in a locked cabinet.

IS COMPENSATION OR MEDICAL TREATMENT AVAILABLE IF INJURY OCCURS:
No compensation or medical treatment will be provided in the instance of injury.

Q172.
TERMS OF PARTICIPATION:
Your participation in this research study is voluntary, refusal to participate will involve no penalty or loss of benefits to which the subject is otherwise entitled, and the subject may discontinue participation at any time without penalty or loss of benefits, to which the subject is otherwise entitled.

I verify that entering my participant ID number below indicates that I have read and understood this consent form, and willingly agree to participate in this study under the terms described.

Please enter your participant ID.

This ID is only intended to be used so we can match accurate data across all completed tests and experiments in this study.

001 lc

D1. We are delighted to have your participation!

This is Part 1 of your survey which will include a number of demographic questions, memory tests, and cognitive questionnaires. We expect this part to take roughly around 20 minutes. You will see a progress bar above Kansas State logo that shows you your progress.

As a reminder, please know that the information collected in this survey will remain **anonymous** and is only intended to be used for aggregate statistical analyses.

No personally identifiable information will be shared.

D2. What is your gender (or the gender you most identify with)?

- Male
- (•) Female
- Other/Nonbinary

D3. What gender do you identify with?

This question was not displayed to the respondent.

D1. Age

21

D8. Are you proficient in English?

- (•) Yes
- No

D9. Which is your dominant hand?

Entirely Left-Handed Entirely Right-Handed

Q170. Do you have any significant visual impairments?

- ○ Yes
- ◉ No

Q171. What visual impairment do you have?

This question was not displayed to the respondent.

Q172. Are you wearing your corrective lenses?

This question was not displayed to the respondent.

D22. Please indicate any psychiatric or learning disabilities:

N/A

D10. Years of post secondary education completed (# of years after high school):

4

D11. Are you currently a student?

- ◉ Yes
- ○ No

Q171. What were your major(s) while enrolled?

This question was not displayed to the respondent.

D12. I am a/an ____ student:

- ◉ Undergraduate Student
- ○ Graduate Student
- ○ PhD Student
- ○ Non Degree

D13. What is your major and college(s) that you are associated with? (If more than one, please select all that apply by pressing the Ctrl button on the keyboard and clicking on the appropriate majors)

D14. If you also have a minor, choose from the options below.

Q179. You have now completed the basic demographics questions. In this next (extended) section we are going to be asking you to complete a number of different questionnaires. Please pay close attention to the questions, and as always, if you have questions ask your moderator.

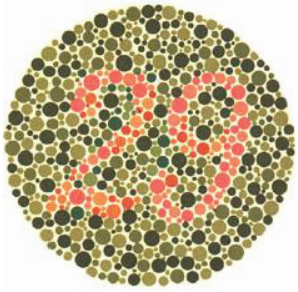
CB1. You will now complete a color vision test. For each of the following plates, you have to either enter the number visible to you or you have to choose the number of lines you can see. If you don't see anything or what you see is not completely clear, just leave the input field empty.

CB3. Type the number you see in the space below. Remember, if you do not see anything or the number is not completely clear and in the middle of the circle, leave the input field empty.

12

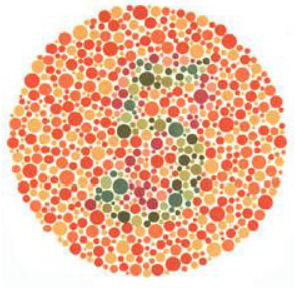
CB5. Type the number you see in the space below. Remember, if you do not see anything or the number is not completely clear and in the middle of the circle, leave the input field empty.

8



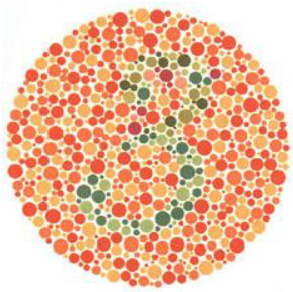
CB7. Type the number you see in the space below. Remember, if you do not see anything or the number is not completely clear and in the middle of the circle, leave the input field empty.

29



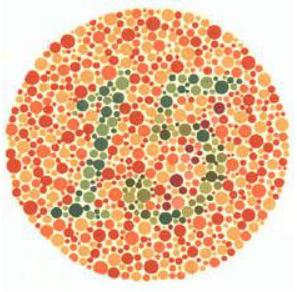
CB9. Type the number you see in the space below. Remember, if you do not see anything or the number is not completely clear and in the middle of the circle, leave the input field empty.

5



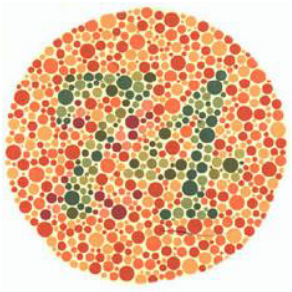
CB11. Type the number you see in the space below. Remember, if you do not see anything or the number is not completely clear and in the middle of the circle, leave the input field empty.

3



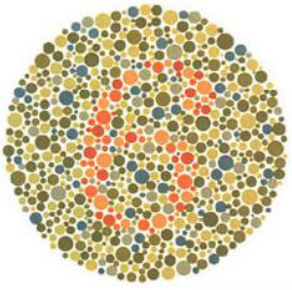
CB13. Type the number you see in the space below. Remember, if you do not see anything or the number is not completely clear and in the middle of the circle, leave the input field empty.

15



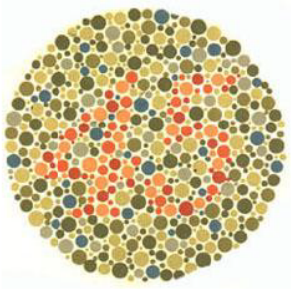
CB15. Type the number you see in the space below. Remember, if you do not see anything or the number is not completely clear and in the middle of the circle, leave the input field empty.

74



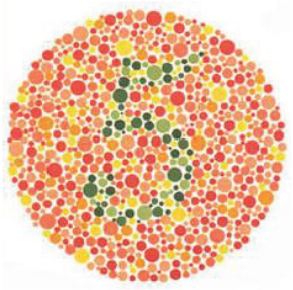
CB17. Type the number you see in the space below. Remember, if you do not see anything or the number is not completely clear and in the middle of the circle, leave the input field empty.

6



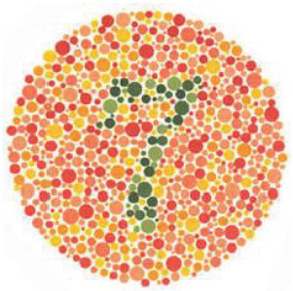
CB19. Type the number you see in the space below. Remember, if you do not see anything or the number is not completely clear and in the middle of the circle, leave the input field empty.

45



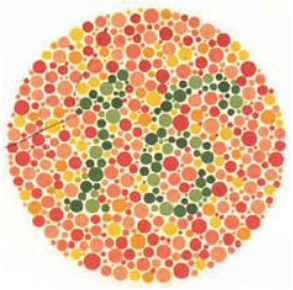
CB21. Type the number you see in the space below. Remember, if you do not see anything or the number is not completely clear and in the middle of the circle, leave the input field empty.

5



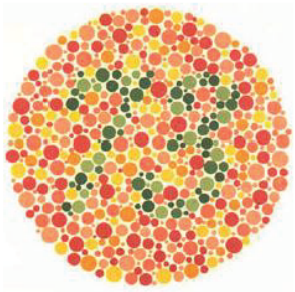
CB23. Type the number you see in the space below. Remember, if you do not see anything or the number is not completely clear and in the middle of the circle, leave the input field empty.

7



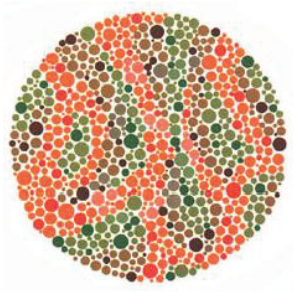
CB25. Type the number you see in the space below. Remember, if you do not see anything or the number is not completely clear and in the middle of the circle, leave the input field empty.

16



CB27. Type the number you see in the space below. Remember, if you do not see anything or the number is not completely clear and in the middle of the circle, leave the input field empty.

73



CB29. Type the number you see in the space below. Remember, if you do not see anything or the number is not completely clear and in the middle of the circle, leave the input field empty.

CB31. Type the number you see in the space below. Remember, if you do not see anything or the number is not completely clear and in the middle of the circle, leave the input field empty.

4

CB33. Type the number you see in the space below. Remember, if you do not see anything or the number is not completely clear and in the middle of the circle, leave the input field empty.

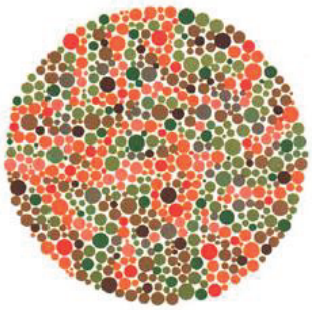
26

CB35. Type the number you see in the space below. Remember, if you do not see anything or the number is not completely clear and in the middle of the circle, leave the input field empty.

42

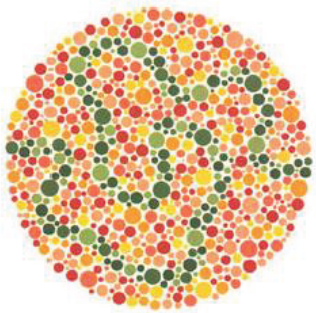
CB37. Indicate how many lines you see. If you don't see any clear and cohesive lines, choose 0.

- ○ 0
- ○ 1
- ◉ 2



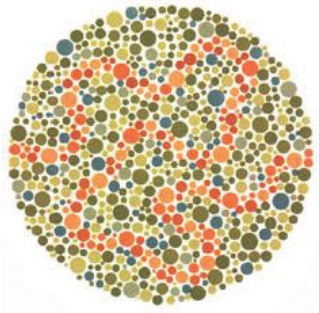
CB39. Indicate how many lines you see. If you don't see any clear and cohesive lines, choose 0.

- (•) 0
- ( ) 1
- ( ) 2



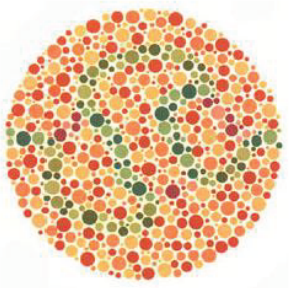
CB41. Indicate how many lines you see. If you don't see any clear and cohesive lines, choose 0.

- ( ) 0
- (•) 1
- ( ) 2



CB43. Indicate how many lines you see. If you don't see any clear and cohesive lines, choose 0.

- ( ) 0
- (•) 1
- ( ) 2

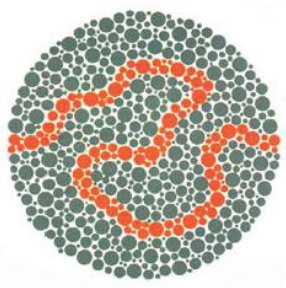


CB45. Indicate how many lines you see. If you don't see any clear and cohesive lines, choose 0.

- ○ 0
- ◉ 1
- ○ 2

CB47. Indicate how many lines you see. If you don't see any clear and cohesive lines, choose 0.

- ○ 0
- ◉ 1
- ○ 2



CB49. Indicate how many lines you see. If you don't see any clear and cohesive lines, choose 0.

- ○ 0
- ◉ 1
- ○ 2

ITQ1.
Indicate your preferred answer by marking the appropriate circle of the seven point scale. Please consider the full range of the scale when making your responses.

ITQ2.

	Never			Occasionally			Often
Do you easily become deeply involved in movies or tv dramas?	○	○	○	○	○	○	◉

ITQ3.

	Never			Occasionally			Often
Do you ever become so involved in a television program or book that people have problems getting your attention?	○	○	○	○	◉	○	○

ITQ4.

	Not Alert			Moderately			Fully Alert
How mentally alert do you feel at the present time?	○	○	○	○	○	○	◉

ITQ5.

	Never			Occasionally			Often
Do you ever become so involved in a movie that you are not fully aware of things happening around you?	○	○	○	○	○	◉	○

ITQ6.

	Never			Occasionally			Often
How frequently do you find yourself closely identifying with the characters in a story line?	○	○	○	○	◉	○	○

ITQ7.

	Never			Occasionally			Often
Do you ever become so involved in a video game that it is as if you are inside the game rather than moving a joystick and watching the screen?	○	○	◉	○	○	○	○

ITQ8.

	Not Fit			Moderately Fit			Extremely Fit
How physically fit do you feel today?	○	○	○	○	◉	○	○

ITQ9.

	Not Very Good			Somewhat Good			Very Good
How good are you at blocking out external distractions when you are involved in something?	○	○	○	○	◉	○	○

ITQ10.

	Never			Occasionally			Often

When watching sports, do you ever become so involved in the game that you react as if you were one of the players?	○	○	○	○	◉	○	○

ITQ11.

	Never			Occasionally			Often
Do you ever become so involved in a daydream that you are not fully aware of things happening around you?	○	○	○	○	○	○	◉

ITQ12.

	Never			Occasionally			Often
Do you ever have dreams that are so real that you feel disoriented when you awake?	○	○	○	○	○	◉	○

ITQ13.

	Never			Occasionally			Often
When playing sports, do you become so involved in the game that you lose track of time?	○	○	◉	○	○	○	○

ITQ14.

	Not At All			Moderately Well			Very Well
How well do you concentrate on enjoyable activities?	○	○	○	○	○	○	◉

ITQ15.

	Never			Occasionally			Often
How often do you play arcade or video games? (Often should be taken to mean everyday or every two days, on average.)	○	○	◉	○	○	○	○

ITQ16.

	Never			Occasionally			Often
Have you ever gotten excited during a chase or fight scene on TV or in the movies?	○	○	○	○	○	◉	○

ITQ17.

	Never			Occasionally			Often
Have you ever gotten scared by something happening on a TV show or in a movie?	○	○	○	○	○	○	◉

ITQ18.

	Never			Occasionally			Often
Have you ever remained apprehensive or fearful long after watching a scary movie?	○	○	○	○	○	◉	○

ITQ19.

	Never			Occasionally			Often
Do you ever become so involved in doing something that you lose all track of time?	○	○	◉	○	○	○	○

W1. In the following items, rate how typical it is for you to use the following strategies in situations in the past when you have gone from one location to another in a city or town that was somewhat familiar.

W2.

	Not at all typical of me				Extremely typical of me
I kept track of the direction (north, south, east or west) in which I was going.	○	◉	○	○	○

W3.

	Not at all typical of me				Extremely typical of me
Before starting, I asked for directions telling me whether to go east, west, north or south at particular streets or landmarks.	○	○	◉	○	○

W4.

	Not at all typical of me				Extremely typical of me
I kept track of where I was in relationship to the sun (or moon) in the sky as I went.	◉	○	○	○	○

W5.

	Not at all typical of me				Extremely typical of me
I kept track of the relationship between where I was and the center of town.	○	◉	○	○	○

W6.

	Not at all typical of me				Extremely typical of me
As I drove, I made a mental note of the mileage I traveled on different roads.	◉	○	○	○	○

W7.

	Not at all typical of me				Extremely typical of me
Before starting, I asked for directions telling me how far to go in terms of mileage.	○	○	◉	○	○

W8.

	Not at all typical of me				Extremely typical of me
I kept track of the relationship between where I was and the next place where I had to change direction.	○	○	◉	○	○

W9.

	Not at all typical of me				Extremely typical of me
I visualized a map or layout of the area in my mind as I drove.	○	○	○	◉	○

W10.

	Not at all typical of me				Extremely typical of me
I referred to a published road map.	○	○	○	○	◉

W11.

	Not at all typical of me				Extremely typical of me
Before starting, I asked for directions telling me whether to turn right or left at particular streets or landmarks.	○	○	○	○	◉

W12.

	Not at all typical of me				Extremely typical of me
Before starting, I asked for directions telling me how many streets to pass before making each turn.	○	○	○	◉	○

W13.

	Not at all typical of me				Extremely typical of me
As I drove, I made a mental note of the number of streets I passed before making each turn.	○	○	○	○	◉

W14.

	Not at all typical of me				Extremely typical of me
Before starting, I asked for a hand-drawn map of the area.	◉	○	○	○	○

W15.

	Not at all typical of me				Extremely typical of me
I made a mental note of landmarks, such as buildings or natural features, that I passed along the way.	○	○	○	○	◉

S1. Rate the level of anxiety you would expect to experience in the situations below.

S2.

	No anxiety				Very much
Leaving a store that you have been to for the first time and deciding which way to turn to get to a destination.	○	○	◉	○	○

S3.

	No anxiety				Very much
Finding your way out of a complex arrangement of offices that you have visited for the first time.	○	◉	○	○	○

S4.

	No anxiety				Very much
Pointing in the direction of a place outside that someone wants to get to and has asked you for directions, when you are in a windowless room.	○	○	○	◉	○

S5.

	No anxiety				Very much
Locating your car in a very large parking lot or parking garage.	○	○	○	◉	○

S6.

	No anxiety				Very much
Trying a new route that you think will be a shortcut without the benefit of a map or GPS (e.g. smartphone, in-car navigation, etc.).	○	◉	○	○	○

S7.

	No anxiety				Very much
Finding your way back to a familiar area after realizing you have made a wrong turn and become lost while driving without the benefit of a map or GPS (e.g. smartphone, in-car navigation, etc.).	○	◉	○	○	○

S8.

	No anxiety				Very much
Finding your way around in an unfamiliar mall.	◉	○	○	○	○

S9.

	No anxiety				Very much
Finding your way to an appointment in an area of a city or town with which you are not familiar without the benefit of a map or GPS (e.g. smartphone, in-car navigation, etc.).	○	○	○	◉	○

Q173. How reliant are you on your GPS (e.g. smartphone, in-car navigation, etc.) when navigating from one location to another in an unfamiliar place?

- ◉ Extremely reliant (almost always looking/listening to the device for directions)
- ○ Somewhat Reliant (sometimes looking/listening to the device for directions)
- ○ Not reliant at all (not looking/listening to the device for directions)

C1. Rate the following items below to the best of your ability.

C2.

	Nearly Never			Nearly Always
I am good at estimating distances.	○	◉	○	○

C3.

	Nearly Never			Nearly Always
I have problems in estimating distances between two places.	○	○	◉	○

C4.

	Nearly Never			Nearly Always
I am bad at reading maps.	◉	○	○	○

O1. Please, read the following statements and indicate the extent to which you agree how true each is for you.

O2.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I was very good in 3-D geometry as a student.	○	○	○	◉	○

O3.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I have difficulty expressing myself in writing.	○	◉	○	○	○

O4.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
If I were asked to choose between engineering professions and visual arts, I would prefer engineering.	○	○	○	○	◉

O5.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
My verbal abilities would make a career in language arts relatively easy for me.	○	○	◉	○	○

O6.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
Architecture interests me more than painting.	○	○	○	◉	○

O7.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
My mental images are very colorful and bright.	○	○	○	◉	○

O8.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I prefer schematic diagrams and sketches when reading a textbook instead of colorful and pictorial illustrations.	○	◉	○	○	○

O9.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I tell jokes and stories better than most people.	○	○	○	◉	○

O10.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
Essay writing is difficult for me and I do not enjoy doing it at all.	○	◉	○	○	○

O11.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
My images are more like schematic representations of things and events rather than detailed pictures.	○	○	○	○	◉

O12.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
When reading fiction, I usually form a clear and detailed mental picture of a scene or room that has been described.	○	○	○	◉	○

O13.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
If I were asked to choose among engineering professions, or visual arts, I would choose visual arts.	◉	○	○	○	○

O14.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I have a photographic memory.	○	○	○	◉	○

O15.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I can easily imagine and mentally rotate three-dimensional geometric figures.	○	○	◉	○	○

O16.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I enjoy pictures with bright colors and unusual shapes like the ones in modern art.	○	○	○	○	◉

O17.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
My verbal skills are excellent.	○	○	○	○	◉

O18.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
When thinking about an abstract concept (or building), I imagine an abstract schematic building in my mind or its blueprint rather than a specific concrete building.	○	◉	○	○	○

O19.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
When entering a familiar store to get a specific item, I can easily picture the exact location of the target item, the shelf it stands on, how it is arranged and the surrounding articles.	○	○	○	○	◉

O20.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
Putting together furniture kits (e.g. a TV stand or a chair) it is much easier for me when I have detailed verbal instructions than when I only have a diagram or picture.	○	○	◉	○	○

O21.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
My images are very vivid and photographic.	○	○	○	◉	○

O22.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
When explaining something, I would rather give verbal explanations than make drawings or sketches.	○	○	○	○	◉

O23.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
If someone were to give me two-digit numbers to add (e.g. 43 and 32) I would simply do the adding without visualizing the numbers.	○	◉	○	○	○

O24.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
My mental images of different objects very much resemble the size, shape and color of actual objects that I have seen.	○	○	○	◉	○

O25.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I usually do not try to visualize or sketch diagrams when reading a textbook.	○	○	○	◉	○

O26.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I normally do not experience many spontaneous vivid images; I use my mental imagery mostly when attempting to solve some problems like the ones in mathematics.	○	○	○	◉	○

O27.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
When I imagine the face of a friend, I have a perfectly clear and bright image.	○	○	○	○	◉

O28.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I have excellent abilities in technical graphics.	○	○	◉	○	○

O29.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
When remembering a scene, I use verbal descriptions rather than mental pictures.	○	○	○	○	◉

O30.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I can easily remember a great deal of visual details that someone else might never notice. For example, I would just automatically take some things in, like what color is a shirt someone wears or what color are his/her shoes.	○	○	○	○	◉

O31.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I can easily sketch a blueprint for a building that I am familiar with.	○	◉	○	○	○

O32.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
In school, I had no problems with geometry.	○	○	○	○	◉

O33.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I am good at playing spatial games involving constructing from blocks and paper (e.g. Lego, Tetris, Origami).	○	○	○	○	◉

O34.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
Sometimes my images are so vivid and persistent that it is difficult to ignore them.	○	◉	○	○	○

O35.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I can close my eyes and easily picture a scene that I have experienced.	○	○	○	○	◉

O36.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I have better than average fluency in using words	○	○	○	◉	○

O37.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I would rather have a verbal description of an object or person than a picture.	○	○	◉	○	○

O38.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I am always aware of sentence structure.	◉	○	○	○	○

O39.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
My images are more schematic than colorful and pictorial.	○	○	◉	○	○

O40.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I enjoy being able to rephrase my thoughts in many ways for variety's sake in both writing and speaking.	○	○	○	◉	○

O41.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I remember everything visually. I can recount what people wore to a dinner and I can talk about the way they sat and the way they looked probably in more detail than I could discuss what they said.	○	○	○	◉	○

O42.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I sometimes have a problem expressing exactly what I want to say.	○	◉	○	○	○

O43.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
I find it difficult to imagine how a three-dimensional geometric figure would exactly look like when rotated.	○	○	○	◉	○

O44.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
My visual images are in my head all the time. They are just right there.	○	◉	○	○	○

O45.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
My graphic abilities would make a career in architecture relatively easy for me.	○	◉	○	○	○

O46.

	Totally Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Totally Agree
When I hear a radio announcer or a DJ I've never actually seen, I usually find myself picturing what he or she might look like.	○	○	○	○	◉

Q169. Thank you for completing the spatial memory and color vision tests. You will now complete a number of tasks before experiencing the virtual environment.

END OF APPENDIX A

Appendix B - Part 2: Map-Drawing Tasks & Debriefing

NOTE: The following Appendix has been extracted from a PDF document which contained the pages instructions administered in Part 2 of the study procedures via an online Qualtrics survey. Any questions regarding these should be directed to the authors of this study, Bruns and Chamberlain (2018), who hold access to the raw data. Part 2 was administered on a 24” full-color computer monitor at 1080p resolution via an automated web survey created in Qualtrics. Certain questions were pre-programmed to only appear given a previous condition, meaning that not all subjects experienced the exact same survey. All of the content is listed, however certain questions may be grayed out indicating this specific subject from which this PDF document was taken, did not see those questions.

Q8. Now that you are done navigating the virtual environment, there are three follow up tasks to evaluate what you remember:

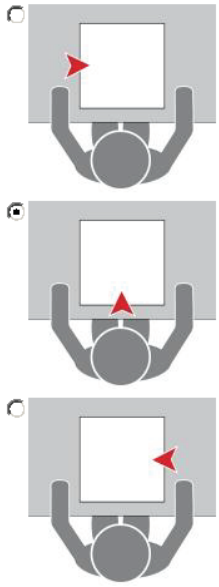
- Landmark Recall: Identify memory of landmarks and structural elements of the environment.
- Route Recall: Delineate the route taken.
- Scene Matching: Match a landmark with the correct scene.

Before you begin the task, please open the **red folder** lying on the desk and take out one of the grid pages with the red arrow. Then, orient the grid in front of you so that the arrow is in the direction you are most comfortable with.

Please enter your Participant ID number below when finished:

00612

Q10. Select one of the following page orientations you feel most comfortable with.



Q28. Now, write your Participant ID in the top right corner of the paper. Verify that you have completed this by clicking below. Then click Next to proceed.

(•) I have written my Participant ID on the top right corner

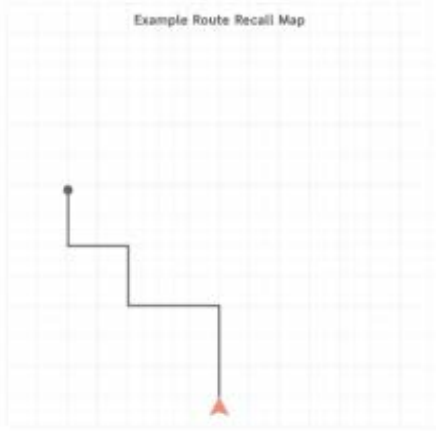
Q9. Now, please select which of the recall tests you would like to start with.

( ) Route
(•) Landmark

Q11. You have chosen to complete the **Route Recall Test** first.

Paper Grid Structure:
On the page, **the red arrow indicates your start location**.
Each of the bold square units on the grid represents one street block.
The lighter grid units are simply for visual reference. *(see below)*

Task:
Draw the route taken (using a pencil) from the start point to where you think the end point is located.
When the route is complete, indicate you have reached the end point by boldly drawing a circular dot.
Ensure that your pencil stroke is dark and legible.



If these instructions are unclear, signal your moderator to clarify.
Once you are ready to begin this task, click Next.

This question was not displayed to the respondent.

Q13. Timing

This question was not displayed to the respondent.

Q14. Route Recall Test in progress.
Only click next after finishing the task.
After you have indicated the end of your route with a bold circular dot, click the button below.

This question was not displayed to the respondent.

Q31. Now that you are done with route recall, please place your grid into the **blue folder**. Please ***do not reference this grid at any point for the next task.***

Prior to completing the next task, please open the **red folder** lying on the desk and take out the second grid page with the red arrow.
Then, orient the grid in front of you so that the arrow is in the direction you are most comfortable with.

This question was not displayed to the respondent.

Q24. Select one of the following page orientations you feel most comfortable with.

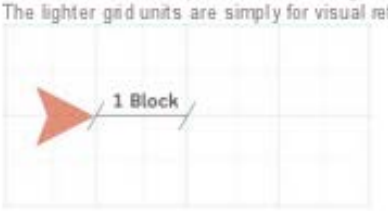
This question was not displayed to the respondent.

Q29. Now, write your Participant ID in the top right corner of the paper. Verify that you have completed this by clicking below. Then click Next to proceed.

This question was not displayed to the respondent.

Q17. You will now complete the **Landmark Recall Test**.
For this test, you will identify where ten different landmarks are located in the virtual environment.
These landmarks will be displayed on the following screen, with each assigned a letter from A to J.

Paper Grid Structure:
On the page, **the red arrow indicates your start location**.
Each of the bolder square units on the grid represents one street block.
The lighter grid units are simply for visual reference. *(see below)*



Task:
Indicate on the paper grid (in pencil) where you think each landmark (A-J) was located.
To do this, write the capital letter in the precise location where you remember the landmark being.
Use a consistent letter size smaller than a dime *(see below)*.
You may redraw your route if it helps you identify the landmark locations.
However, ***DO NOT look back at your previous grid drawing.***

Ensure your pencil stroke is dark and legible.

If these instructions are unclear, signal your moderator to clarify.
Once you are ready to begin this task, click Next.

This question was not displayed to the respondent.

Q18. Timing

This question was not displayed to the respondent.

Q19.

- Please assign each letter to a corresponding location on the grid page.
- If you have no memory of the landmark in the virtual environment, place it in the area you believe it was located, then, follow the letter with a question mark.
  - For example, if you do not remember the Bus Stop, write "**B?**" in the place you believe it was located.

Landmark Recall Test in progress.
Only click next after assigning each landmark (A-J) to a specific location.
Once you are finished, click the button below.

This question was not displayed to the respondent.

Q37. Landmark objects2

This question was not displayed to the respondent.

Q40. Timing

This question was not displayed to the respondent.

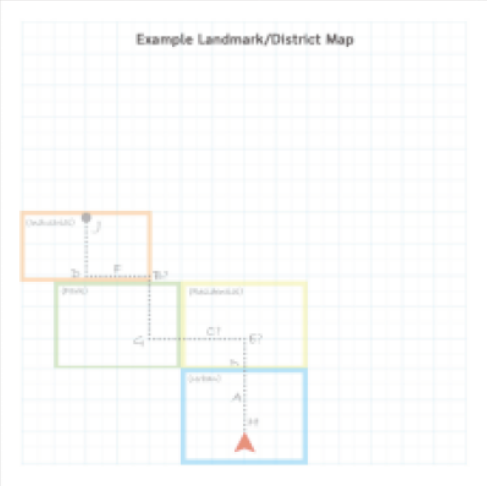
Q39. Now that you have finished identifying the landmark locations, we want to know your recollection of the various districts within the environment.

TASK:
On the ***same grid page*** in front of you, using the highlighter markers, please draw an outline for the following districts:

- Industrial (orange)
- Park (green)
- Residential (yellow)
- Urban (blue)

To do this, draw an outline on your grid indicating what you believe is the widest extent of each of the four districts. Then, write the name of the district you have drawn so we can determine which district you have identified. You may redraw your route if it helps you identify where the landmarks were.
Ensure that your pencil stroke is dark and legible.

See the example map below (do not reference this for your drawing, as it is not accurate).



If these instructions are unclear, signal your moderator to clarify.
Only click Next once you are finished completing the task.

This question was not displayed to the respondent.

Q12. You have chosen to complete the **Landmark Recall Test** first.
For this test, you will identify where ten various landmarks are located in the virtual environment.
These landmarks will be displayed on the following screen, with each assigned a letter from A to J.

Paper Grid Structure:
On the page, **the red arrow indicates your start location.**
Each of the bold square units on the grid represents one street block.
The lighter grid units are simply for visual reference. *(see below)*

Task:
You will need to indicate on the paper grid in (in pencil), where you think each landmark (A-J) was located.
To do this, write the capital letter in the precise location where you remember the landmark being.
Use a consistent letter size smaller than a dime *(see below)*.
You may redraw your route if it helps you identify the landmark locations.
However, ***DO NOT look back at your previous grid drawing***.

Ensure that your pencil stroke is dark and legible.

If these instructions are unclear, signal your moderator to clarify.
Once you are ready to begin this task, click Next.

Q16. Timing

First Click: 0
Last Click: 0
Page Submit: 479.365
Click Count: 0

Q15.

- Please assign each letter to a corresponding location on the grid page.
- If you have no memory of the landmark in the virtual environment, place it in the area you believe it was located, then, follow the letter with a question mark.
  - For example, if you do not remember the Bus Stop, write "B?" in the place you believe it was located.

Landmark Recall Test in progress.
Only click next after assigning each landmark (A-J) to a specific location.
Once you are finished, click the button below.

Q42. Timing

First Click: 0
Last Click: 0
Page Submit: 250.711
Click Count: 0

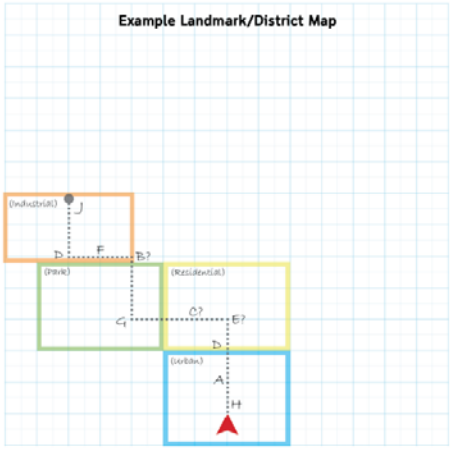
Q41. Now that you have finished identifying the landmark locations, we want to know your recollection of the various districts within the environment.

TASK:
On the ***same grid page*** in front of you, using the highlighter markers, please draw an outline for the following districts:

- Industrial (orange)
- Park (green)
- Residential (yellow)
- Urban (blue)

To do this, draw an outline on your grid indicating what you believe is the widest extent of each of the four districts. Then, write the name of the district you have drawn so we can determine which district you have identified. You may redraw your route if it helps you identify where the landmarks were.
Ensure that your pencil stroke is dark and legible.

See the example map below (do not reference this for your drawing, as it is not accurate).



If these instructions are unclear, signal your moderator to clarify.
Only click Next once you are finished completing the task.

Q32. Now that you are done with landmark recall, please place your grid into the **blue folder**. Please do not reference this grid at any point for the next task.

Prior to completing the next task, please open the **red folder** lying on the desk and take out the second grid page with the red arrow. Then, orient the grid in front of you so that the arrow is in the direction you are most comfortable with.

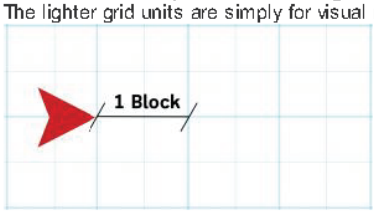
Q27. Select one of the following page orientations you feel most comfortable with.

Q30. Now, write your Participant ID in the top right corner of the paper. Verify that you have completed this by clicking below. Then click the arrow to proceed.

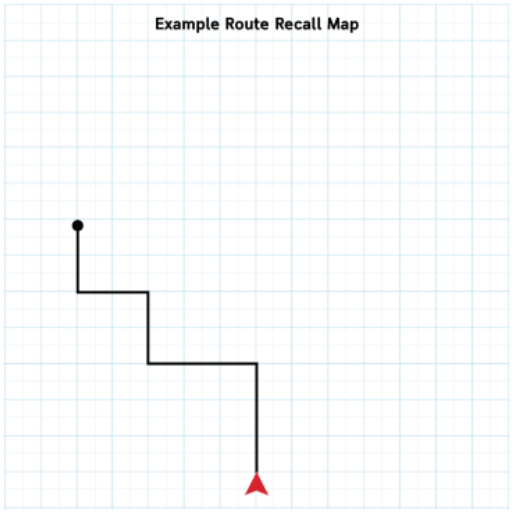
◉ I have written my Participant ID on the top right corner

Q20. You will now complete the **Route Recall Test**.

Paper Grid Structure:
On the page, **the red arrow indicates your start location.**
Each of the bold square units on the grid represents one street block.
The lighter grid units are simply for visual reference. *(see below)*



Task:
Draw the route taken (using a pencil) from the start point to where you think the end point is located.
When the route is complete, indicate you have reached the end point by boldly drawing a circular dot.
Ensure that your pencil stroke is dark and legible.

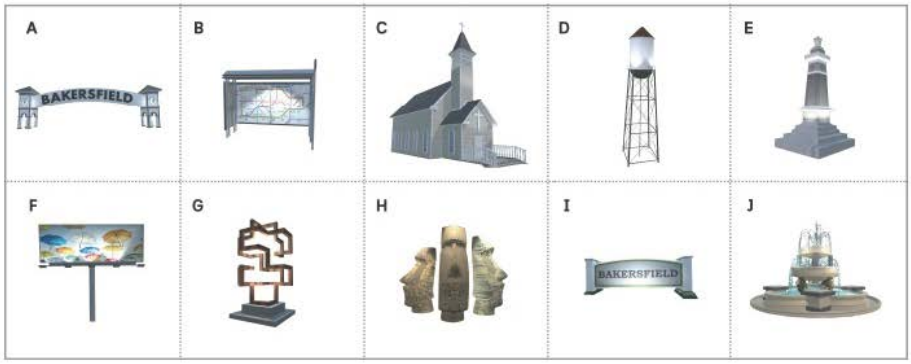


If these instructions are unclear, signal your moderator to clarify.
Once you are ready to begin this task, click Next.

Q21. Timing

First Click: 0
Last Click: 0
Page Submit: 6.063
Click Count: 0

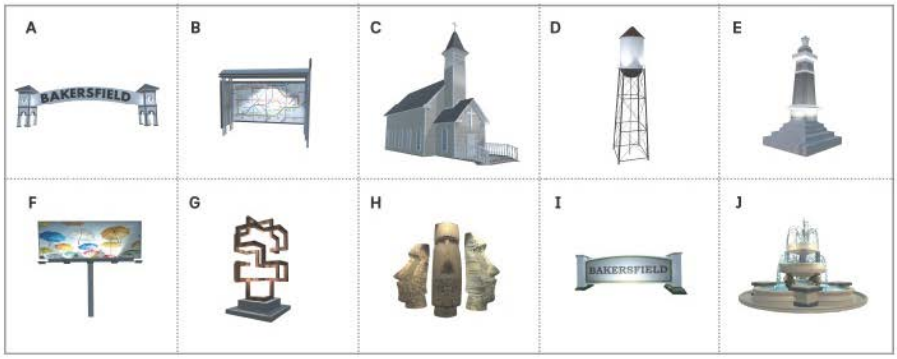
Q22. **Route Recall Test** in progress.
Only click next after finishing the task.
After you have indicated the end of your route with a bold circular dot, click the button below.



Q46.

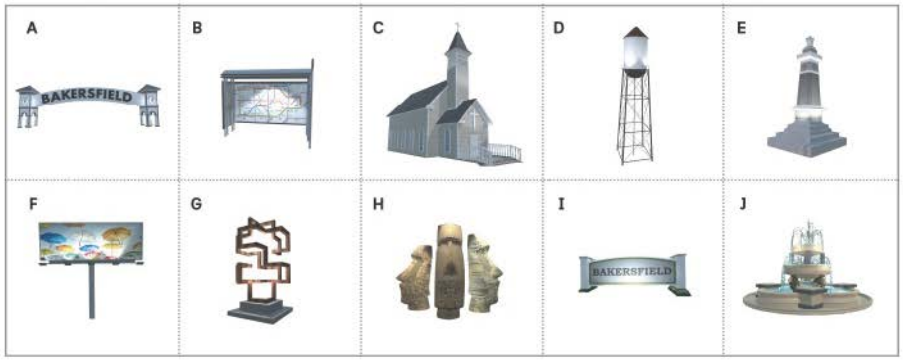
The above scene has a missing landmark. Indicate which landmark object you recall seeing in this location by selecting the corresponding letter from the drop-down menu. If you are uncertain, make your best guess.

E



Q65.

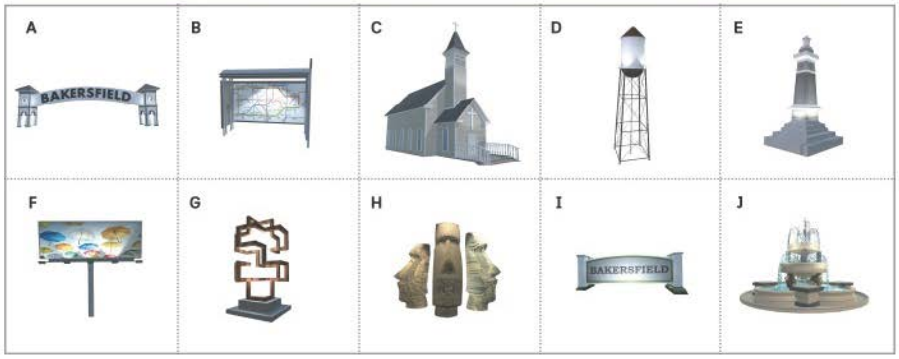
The above scene has a missing landmark. Indicate which landmark object you recall seeing in this location by selecting the corresponding letter from the drop-down menu. If you are uncertain, make your best guess, and use each letter only once.



Q58.

The above scene has a missing landmark. Indicate which landmark object you recall seeing in this location by selecting the corresponding letter from the drop-down menu. If you are uncertain, make your best guess, and use each letter only once.

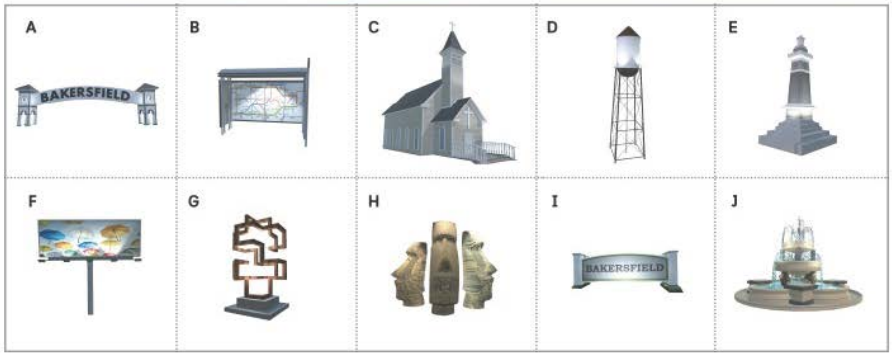
J



Q57.

The above scene has a missing landmark. Indicate which landmark object you recall seeing in this location by selecting the corresponding letter from the drop-down menu. If you are uncertain, make your best guess, and use each letter only once.

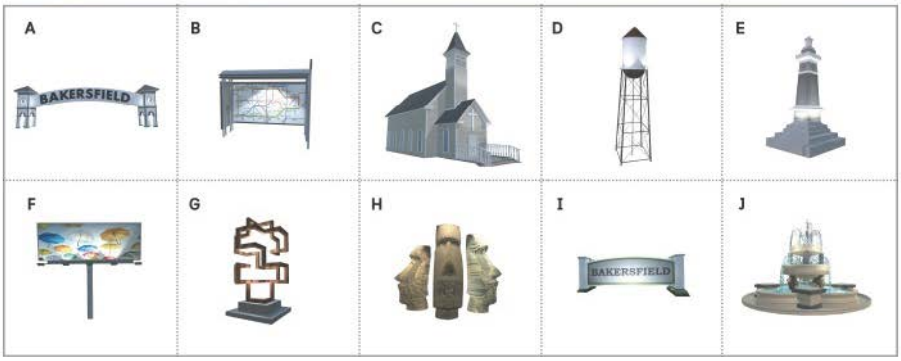
B



Q50.

Thee above scene has a missing landmark. Indicate which landmark object you recall seeing in this location by selecting the corresponding letter from the drop-down menu. If you are uncertain, make your best guess, and use each letter only once.

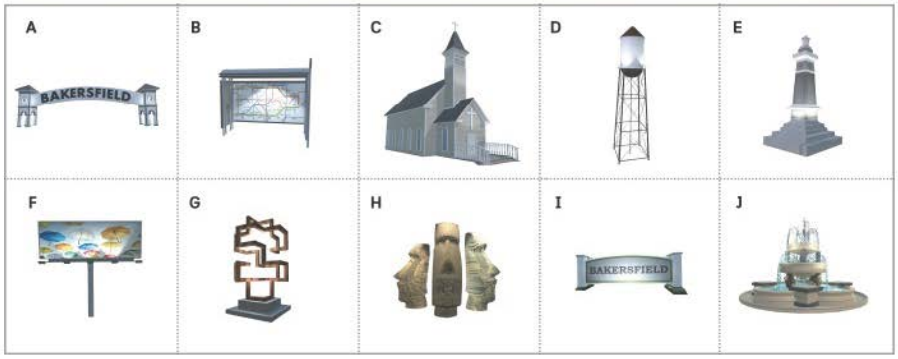
H



Q61.

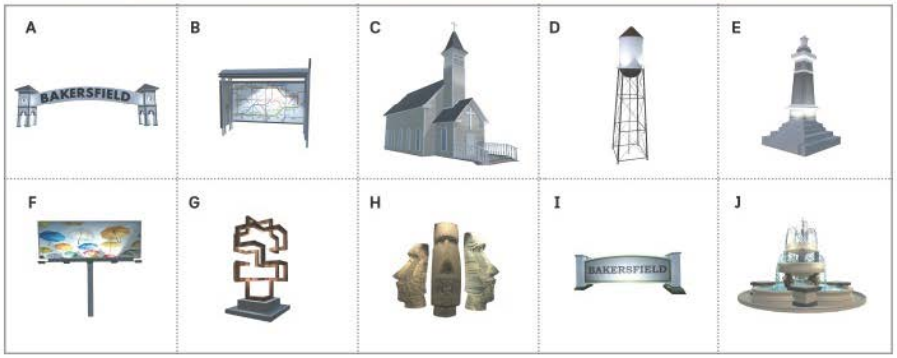
The above scene has a missing landmark. Indicate which landmark object you recall seeing in this location by selecting the corresponding letter from the drop-down menu. If you are uncertain, make your best guess, and use each letter only once.

F



Q53.

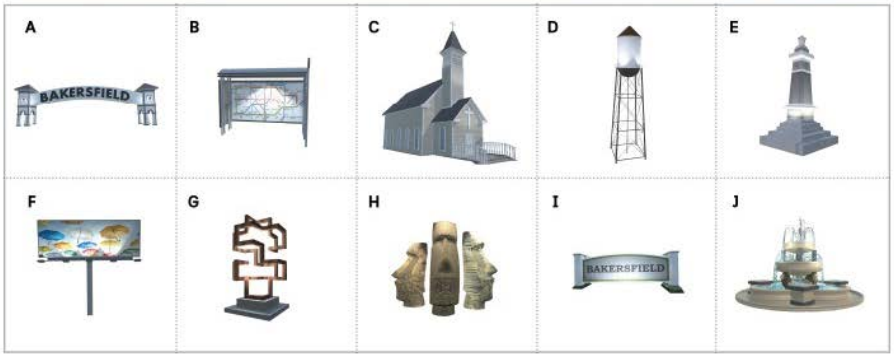
The above scene has a missing landmark. Indicate which landmark object you recall seeing in this location by selecting the corresponding letter from the drop-down menu. If you are uncertain, make your best guess, and use each letter only once.



Q55.

The above scene has a missing landmark. Indicate which landmark object you recall seeing in this location by selecting the corresponding letter from the drop-down menu. If you are uncertain, make your best guess, and use each letter only once.

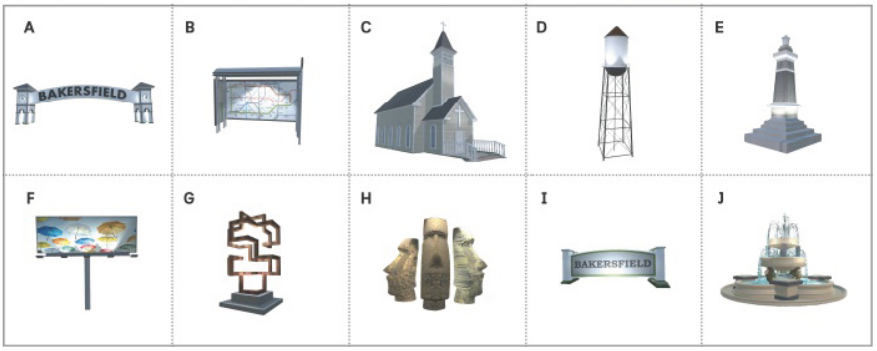
C



Q63.

The above scene has a missing landmark. Indicate which landmark object you recall seeing in this location by selecting the corresponding letter from the drop-down menu. If you are uncertain, make your best guess, and use each letter only once.

A



Q48.

The above scene has a missing landmark. Indicate which landmark object you recall seeing in this location by selecting the corresponding letter from the drop-down menu. If you are uncertain, make your best guess.

G

DB1.
The ALIVE! Lab thanks you for your participation in this study.

The purpose of this study is to investigate an individual's ability to recall his or her route and survey knowledge of a novel virtual environment. This includes: understanding the influence of different levels of immersion (e.g. monitor vs a virtual reality headset) and the influence of navigational aids. This information will help us better understand the role that navigational aids play in forming our spatial memory of a place. This is important because if we understand triggers that may increase one's spatial memory, we can consider how to augment the aids to support a better understanding how to support unaided navigation.

It is our hope that outcomes of this research may include publication, presentations and public dissemination (e.g. website). By understanding how spatial memory is influenced by various cues and immersive wayfinding technologies, the intent is to inform better methods for supporting improved spatial memory compared with existing wayfinding devices.

Now that you have completed the study, take your Participant ID card with you. This number can be used to access your individual test scores by entering your randomly assigned ID into the website on the back of your note-card. When the study is completed and analyses confirmed, we will post this information on the website for you to obtain your scores. Please be patient with us as we conduct the analyses (you may want to check back in March). In the meantime please ***keep hold of your note-card or save the ID somewhere*** – otherwise you will not be able to access your results.

Finally, you will be asked a few follow-up questions regarding your experience in the virtual environment.
Click Next to proceed.

DB2. Please answer the following questions concerning your experience in the virtual environment.

Q31. Between or during the tests, did you reorient the grid in any way to help you better complete the tasks?

- (•) Yes
- ( ) No

Q32. Please explain why you reoriented the grid in the space below:

i was walking forward, so it is easier for me to think in a "forward" direction

Q7. Did you use the virtual reality headset? (Oculus Head-Mounted Display)

- (•) Yes
- ( ) No

DB3. How comfortable did you feel in the environment?

- ( ) Extremely comfortable
- ( ) Somewhat comfortable
- ( ) Neither comfortable nor uncomfortable
- ( ) Somewhat uncomfortable
- (•) Extremely uncomfortable

DB4. Did you have any strategies to help you remember the route or landmarks during the recall tests? If no strategies were used, also state that below.

I remembered seeing the first few, but had completely forgotten how many streets were between each one etc. I thought I was trying to remember where I was, how many turns I had made, etc, but the headset was very disorienting to me.

DB5. We would like to thank you again for your participation and are hoping to obtain the results of this experiment in the first few months of 2018. All data collected will remain anonymous and no personally-identifiable information will be shared.

This study will continue into the new year, and we are still actively seeking a diversity of participants. Please encourage your friends/colleagues to participate and earn the $10 reward!
They can sign up at *survey.ksualive.com* , come knock on our door, or email *alive@ksu.edu*

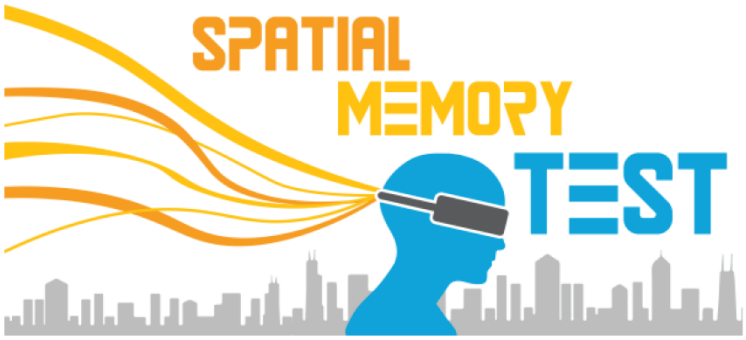
Please *DO NOT share any information* with others about the study procedures.
This will ensure we gain reliable data and accurate results.

Once again, please **keep your Participant ID card with your unique number** on it as it will guarantee that you are able to access your scores when they are published on the website. If you would like to receive an email reminder when your results are finalized, please type ***your email*** in the box below.

END OF APPENDIX B

Appendix C - Participant Sign-Up Survey

NOTE: The following Appendix has been extracted from a PDF document containing the web sign-up survey administered via Qualtrics. Any questions regarding these should be directed to the authors of this study, Bruns and Chamberlain (2018), who hold access to the raw data. The Participant Sign-Up Survey was widely circulated across campus through a marketing campaign using flyers and digital displays (see image below).



Q1.

Thank you for your interest in the Spatial Memory Test!

We are taking registrations to schedule participants until March 2018. In order to be considered for this study, we ask you to provide a few pieces of information (below). None of your personal contact information will be shared.

Note: The nature of study requires participants be above 18 years of age and not significantly visually impaired. Further, this study requires using an Xbox controller to navigate a virtual environment, which necessitates the use of both left and right hands. If you have significant visual impairments or are unable to use both of your hands, but would still like to participate in this study, please contact the ALIVE! Lab (email listed below) so that special accommodations may be made.

We will contact you once you are selected to participate. Please check your email for updates as we are scheduling participants for the majority of the semester. **We do take walk-in participants**, but cannot guarantee you will be able to run through the experiment, as we have limited equipment and personnel.

Upon your participation, you will automatically qualify for a **$10 Union Gift card reward**. Please be on the lookout for an email to schedule a time. Send any inquiries to alive@ksu.edu, or stop by the lab, (directions below.)

Directions to ALIVE! Lab

LOCATION:
- 1153 Seaton Hall

DIRECTIONS:
- If you are unfamiliar with the location, we recommend entering Seaton Hall (the building just north of the Student Union) using the middle doors just off of Bosco Plaza.
- Turn right upon entering, and the ALIVE! Lab is the first door on your right-hand side.

LOST?
- If you still can't find your way, feel free to call Jody Hodges at (785) 532-5961 or send an email to alive@ksu.edu and indicate you are looking for the location of the Spatial Memory Test.

IRB Approval #8812

Brent Chamberlain, Ph.D.
Assistant Professor
Principle Investigator of the study

Director, Advanced Landscape and Immersive Visualization Environment
http://ksualive.com

Q2. Full Name:

[redacted]

Q3. Email:

[redacted]

Q4. Select the college you are in or associated with.

Architecture, Planning and Design

Q5. I have significant visual impairments which may inhibit me from navigating a virtual environment.

- ○ True
- ◉ False

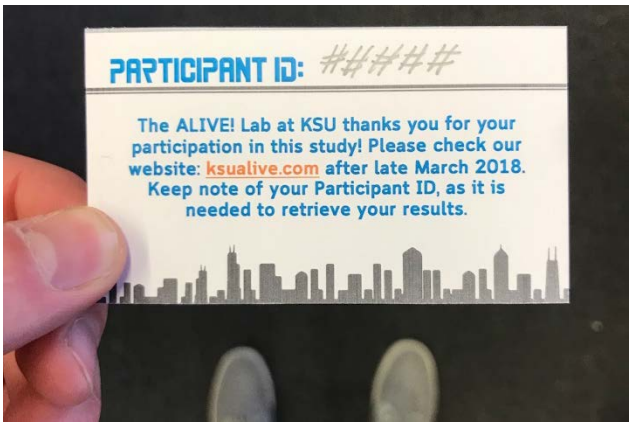
Q6. I certify I am above 18 years of age, do not have any significant visual impairments, and agree to be emailed for a time to schedule participation in the study.

- ◉ Yes, I am above 18 and I agree.
- ○ No, I am under 18 or am not eligible for the study.

END OF APPENDIX C

Appendix D - Participant ID Card

NOTE: The following Appendix demonstrates the process by which we preserved participant anonymity. To comply with the university's internal review board's policies regarding the collection of sensitive information on human subjects, participant anonymity was preserved by randomly assigning a unique five-digit participant identification number (PID #) to each person. The PID # was written on a small index card (see images below) and was given to each person upon entering the lab. For the exact files used to print these cards, contact the authors of the study (Bruns and Chamberlain, 2018).



END OF APPENDIX D