Recall differences in the reconstitution of a tour through a virtual environment

Sara Cameron

A Thesis
in
The Department
of
Geography, Planning and Environment

Presented in Partial Fulfillment of the Requirements for the Degree of
Master of Science (Geography, Urban and Environmental Studies) at
Concordia University
Montreal, Quebec, Canada

July 2008

Your file Votre référence
ISBN: 978-0-494-67223-5
Our file Notre référence
ISBN: 978-0-494-67223-5

CONCORDIA UNIVERSITY

School of Graduate Studies

This is to certify that the thesis prepared

By: Sara Cameron

Entitled: Recall differences in the reconstitution of a tour through a virtual environment

and submitted in partial fulfillment of the requirements for the degree of

Master of Science (Geography, Urban and Environmental Studies)

Complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the final examining committee:

________________________________ Chair

________________________________ Examiner

________________________________ Examiner

________________________________ Supervisor

Approved by: ________________________________

Chair of Department or Graduate Program Director

____________ 20_____ ________________________________

Dean of Faculty

Abstract

Recall differences in the reconstitution of a tour through a virtual environment
Sara Cameron

A rapidly expanding area of human geography is the study of spatial knowledge. This growth can be partly attributed to the recent emergence of user-friendly and affordable technology that allows more researchers (notably students) to design, build and use virtual environments in spatial knowledge research.

The purpose of this thesis project is to explore recall differences in the reconstitution of spatial knowledge acquired by means of a tour through a virtual environment. The motivation behind this area of inquiry is the apparent assumption that the order of spatial knowledge tasks may have some effect on acquisition or recall, which is evidenced in some current research methodologies.

The results show that there is no significant difference between two groups of participants with respect to the order of recall tasks; however, one group of participants performed better in almost every task, suggesting that the first recall task appears to be influencing the succeeding recall task. This study contributes to the ongoing debate regarding the recall of spatial knowledge and introduces issues of concern regarding methodological design.

Acknowledgements

This thesis project would not have been possible without the help of many people. First, I would like to thank Dr. John Zacharias, whose advice, patience, time and hard-work during the past two years are greatly appreciated. Also, thank you to Dr. Hélène Bélanger for her kindness, positive energy, generosity of spirit, and intellect, and to Dr. Pierre Gauthier for his sense of humour, encouragement and support. Thank you to Dr. Eric Weiss-Altaner for his thorough reading and insightful feedback.

Thank you to Dr. Alan Nash, for teaching me how to ask the right questions and for helping me to realize the nonsense of it all. Thanks to Dr. Pierre Deslauriers for giving me a chance and opening the door. Thank you to Dr. Pascale Biron for keeping it all moving forward. And thank you to Joy St. John for possessing the rare and underappreciated qualities of forthrightness and reliability- there are many days our brief conversations restored me to sanity.

Thank you to my fellow students, most especially Donny Seto for his inspiration at every level and for putting up with me in general. Also, thanks to "the Ryans" who helped keep it all in perspective.

Thank you to Marc Léger for his unique proofreading skills- it all reads much better now.

Finally, thank you to Christiane, quite literally, for everything.

Dedication

To EC, who was there at the beginning;

To CR, who'll be there until the end;

And to the munchkin waiting in the wings.

Table of Contents

List of Figures

List of Tables

1-Introduction

The study of spatial knowledge is a rapidly expanding area of human geography. This expansion can be attributed, in part, to the development of new technologies— notably the accessibility of virtual environments used to test the ways in which humans understand built space. The availability and accessibility of new technology has meant that many of the assumptions regarding the acquisition, coding, recall and reconstitution of spatial knowledge have started to be re-examined using virtual environments. Researchers from diverse fields— such as geography, psychology, architecture, engineering, urban planning, urban design and computer technology— have added to the many spatial knowledge debates.

The goal of this project was to explore the effect of the order of recall tasks on the reconstitution of spatial knowledge. This project was motivated by a lack of consistency in experimental methods, specifically methodological differences with respect to the way spatial knowledge is being tested. There appear to be underlying assumptions that recall task order may have an effect, yet not all researchers account for this in their methods and analysis.

The first chapter of this thesis project proceeds with a review of current literature on spatial knowledge and the use of virtual environments as research tools in this field. It is followed by the methodology chapter, which details the design and procedure of the experiment. Next, the analysis and results chapter shows how the data were analysed, including calculations. The following chapter is a discussion of the results, which expands on some ideas introduced in the analysis and results section. Finally, the conclusion chapter summarises the results, discusses the contribution of this research project to the field of spatial knowledge as a whole, makes recommendations to improve the current project, and ends with a brief discussion of the implications of this work.

2-Literature Review

2.1-Spatial Knowledge

The acquisition, coding, storage, recall and reconstitution of spatial knowledge are complex and vigorously debated topics in current research. Research in this area typically addresses questions related to the types of spatial knowledge, the organization, storage and acquisition of spatial knowledge, and the way in which spatial knowledge is used. In this section, I will present: the types of spatial knowledge; the organization of spatial knowledge; spatial knowledge in memory and recall; the acquisition of spatial knowledge (through navigation and wayfinding); environmental cues (for example, landmarks) and their role in spatial knowledge acquisition; and finally, cognitive maps and cognitive mapping.

2.1.1-Types of spatial knowledge: landmark, route, and survey knowledge

There are three commonly accepted types of spatial knowledge: landmark knowledge, route (or procedural) knowledge and survey (or configurational) knowledge.

Landmark knowledge consists of static information about the visual details of a specific location (Darken & Sibert, 1996, p.142). When the navigator knows the sequence of actions required to follow a route (i.e., when encountering a landmark, the navigator knows what procedure to follow to continue along the correct path), he or she possesses route knowledge (Darken & Sibert, 1996, p.142). Allen (1999) defines route knowledge as “unidirectional information about the temporal spatial sequence of environmental features” (Allen, 1999, p.71). Golledge (1999b) holds that route knowledge expands by means of an overlay process, whereby routes are integrated over time (by re-experiencing the environment by means of routes taken), eventually overlaying the districts through which the routes pass. “Some theorists have proposed that route knowledge is a primitive form of cognitive map that precedes configuration knowledge”…while “[o]thers have proposed that route knowledge and cognitive maps involve different types of learning mediated by different neural structures” (Allen, 1999, p.71). Golledge (1999b) believes the former, arguing that “segment by segment information learned by route following can be parlayed into a network” (Golledge, 1999b, p.10).

Survey knowledge— also known as map knowledge, configurational knowledge, vector knowledge and a cognitive map (Allen, 1999)— is “multidimensional information about the spatial relationships among environmental features” (Allen, 1999, p.71). With survey knowledge, the navigator can conceive of the environment as a whole. “Object locations and inter-object distances are encoded in terms of a geo-centric, fixed, frame of reference” (Darken & Sibert, 1996, p.142). One possesses survey knowledge when distances can be calculated between landmarks and destinations, directions to destinations can be accurately indicated, and shortcuts can be taken (Witmer et al., 2002). In addition, some researchers believe that survey knowledge is hierarchical in nature, where distinct places or locations are “encoded with subnetworks of smaller, more specific places…being defined within each” (Darken & Sibert, 1996, p.142) instead of being coded according to absolute positions and directions.

2.1.2-The organization of spatial knowledge

Many researchers have investigated the theory that individuals must possess specific types of spatial knowledge in order to successfully navigate or understand an environment. Researchers have sought to support this theory by looking at the coding of landmarks or by examining the acquisition of route knowledge in an attempt to understand how people travel from one place to another, for example (Anooshian, 1996, p.472). Many studies have been done with the assumption that people learn or understand space in a particular way.

There is an ongoing debate about the way in which types of spatial knowledge are related. Some theories have suggested a hierarchical relationship between the types of spatial knowledge, whereas other theories have proposed that the relationship is much more complex.

A long accepted theory of the relationship between types of spatial knowledge is the Landmark-Route-Survey (LRS) Model (Siegel & White, 1975). This model represents a hierarchical progression from one type of spatial knowledge to another, where spatial knowledge is learned in sequence: landmark knowledge leads to (and is a pre-requisite for) route knowledge and route knowledge leads to (and is a pre-requisite for) survey knowledge. This model requires *both* landmark and route knowledge to be acquired before it is possible to acquire survey knowledge. Thus, different types of knowledge about the same environment are related (Lathrop & Kaiser, 2005).

According to this model, landmarks (i.e., distinct environmental features that help the navigator to distinguish locations) are the first visual cues that navigators learn to recognize. Moreover, landmarks that appear at locations of possible direction changes are learned faster and remembered better (Lathrop & Kaiser, 2005). Next, route knowledge is acquired (i.e., how to get from one location/landmark to another). This requires recognition of landmarks in addition to remembering what actions to take at, and between, each landmark in order to reach a destination (Lathrop & Kaiser, 2005). "These actions are mediated by knowledge of landmark order, direction, and distance" (Lathrop & Kaiser, 2005, p.250). In addition, route learning can be affected by the complexity of the route— for example, the number of changes in direction, the number of available direction changes at choice points, and the length of the route. Once sufficient experience has allowed for the formation of landmark and route knowledge, survey knowledge can be acquired as the final step in the hierarchy. Survey knowledge can encompass both the configuration of the environment as well as position and orientation within that configuration. Survey representations thus "consist of knowledge about environment locations with respect to egocentric and exocentric frames of reference" (Lathrop & Kaiser, 2005, p.250).

The theory of a hierarchical relationship between types of spatial knowledge has been challenged over the last decade with the theory that "[r]oute knowledge, defined as knowledge of navigational procedures (e.g., which way to turn at specific places), does not presuppose place knowledge (e.g., being able to recall places); nor does it necessarily promote configurational knowledge" (Anooshian, 1996, p.474). Research has shown that route knowledge may not be part of the hierarchy as Siegel & White (1975) theorized, as it may not serve as an intermediary stage between landmark and survey knowledge (Stankiewicz & Kalia., 2007, p.379).

Gärling et al. (1981) found that the order of landmarks was probably learned before the metric relations were learned, and thus routes were learned before the *location* of landmarks (i.e., ordinal knowledge was learned before metric knowledge with respect to landmarks). Thus, if a navigator cannot perceive a landmark from a current location, information about the path that connects them must be remembered (i.e., route knowledge). However, Gärling et al. (1981) do not believe that this route knowledge is stored in long-term memory, with the exception of habitually traversed paths.

Many current spatial knowledge acquisition theories support the critical role of route knowledge in coming to know environments. These theories of spatial knowledge can be placed into two broad categories: place/landmark theories which describe route knowledge as "the encoding of places along a temporal sequence" and procedural theories, which describe route knowledge as "decisions about what to do at or between places" (Anooshian, 1996, p.474)— thus, there is little "place-by-place correspondence" (Anooshian, 1996, p.475). In this case, the navigator may have excellent route knowledge yet little knowledge about place or configuration (Anooshian, 1996).

Not surprisingly, new theories continue to be put forward to challenge or add to place/landmark theories and procedural theories. For example, *the anchor-point theory*

(Couclelis et al., 1987) hypothesizes that *regions* of space are anchored by salient cues, thus creating an organized, hierarchical map. More recently, Mallot & Gilner (2000), have presented the *view-graph approach,* supporting the hypothesis that spatial representations are made up of a series of views, and each view is associated with an action- thus, successful navigation does not require survey-level knowledge of the environment at all (Stankiewicz & Kalia, 2007). Finally, Kuipers (1982) criticizes place/landmark theories because they fail to recognize that spatial knowledge can consist of "disconnected components with little or no relation between the components" (Anooshian, 1996, p.475).

2.1.3-Spatial knowledge in memory and recall

We constantly call on spatial knowledge to accomplish everyday tasks, and most often we are calling on knowledge of environments that we do not currently perceive (Brockmole & Wang, 2002). This requires a balance between the storage and the computation of environmental representations. This may be mediated by a representational system that breaks down the environment into smaller representations, allowing for recall of the relevant local aspects of the environment.

"Past research has suggested that environments are encoded by a series of independent representations that are organized in memory" (Brockmole & Wang, 2002, p.295). More recently, however, an organizational structure linking mental representations of environments in a *hierarchical* relationship has become the dominant view (Brockmole

& Wang, 2002). According to this theory, environments are grouped and memorized; larger regions are divided into smaller ones, smaller regions are remembered relative to larger ones, and landmarks are often remembered in relation to the region encompassing them. "This is a hierarchy based on containment or part-whole relations" (Taylor & Tversky, 1992, p.484) which may contribute to distortions in reconstituted internal spatial representations. This hierarchical relationship has been inferred from the observation of retrieval patterns of spatial knowledge recall or spatial judgments about environmental layouts (Brockmole & Wang, 2002).

The theory of a hierarchical relationship in spatial memory and recall has been challenged and "[r]ecent research findings have increasingly questioned the extent of hierarchical organization in spatial memory" (Anooshian, 1996, p.490). Anooshian (1996) argues that there may be dissociation among types of spatial knowledge due to observed stochastic independence of different types of memory. Essentially, implicit (i.e., one is *not* conscious of the act of remembering) and explicit (i.e., one *is* conscious of the act of remembering) memory measures are unrelated, such that good configurational knowledge does not imply good procedural knowledge, and vice-versa. "In the case of spatial cognition, procedural measures (e.g., whether someone turns correctly at a particular place) appear more tied to implicit remembering whereas place measures (e.g., recalling salient landmarks) are typically derived from explicit remembering" (Anooshian, 1996, p.476). Thus, remembering place measures and remembering procedural measures may be much more complex than a simple hierarchical relationship if they are in fact two distinct types of remembering.

Interestingly, *how* people remember may also be influenced by *why* they remember. Task expectations or constraints, as well as the environmental characteristics, may influence how and what individuals remember and are later able to recall (Taylor & Tversky, 1992). "Learners may form a mental image of a map when expecting to draw a map and may attempt to form an implicit description of the map when expected to describe it" (Taylor & Tversky, 1992, p.484).

2.1.4-Acquiring spatial knowledge: navigation and wayfinding

The best way for one to learn about an environment is to explore it in some way. This can be done by walking down the street, hearing about a place from another person, or studying a map. However, the most common way for people to learn a new environment is by navigation. "[N]avigating an environment is the best way to obtain knowledge of routes and landmarks" (Witmer et al., 2002, p.2). Indeed, survey knowledge gained from navigation has been shown to exceed survey knowledge gained from maps (Witmer et al., 2002).

Darken et al. (1999) define navigation as the aggregate task of motion (or physical translation through space) and wayfinding (defined as the cognitive element of navigation which involves mental representations, distance and direction estimations, and route planning). Navigation strategies are defined in terms of how the navigator uses spatial updating cues to maintain spatial orientation (Riecke et al., 2002).

> Successful spatial orientation and navigation involve a number of different processes, including sensing the environment, building up a mental spatial representation, and using it (such as, to plan the next steps). During navigation, one needs to update one's mental representation of the current position and orientation in the environment (spatial updating).
>
> Riecke et al., 2002, p.443

If position is used as a spatial cue, Riecke et al. (2002) define this as position (or recognition-based) navigation (also called *piloting*). If velocity and acceleration are used as spatial cues, they define this as *path-integration* or *dead-reckoning*.

Piloting uses exteroceptive information (visible, audible or "perceivable reference points," or "distinct, stationary, and salient objects or cues" (Riecke et al., 2002, p.443)) to determine position and orientation. "Only piloting allows for correction of errors in perceived position and orientation through reference points...and is thus more suited for large-scale navigation" (Riecke et al., 2002, p.444).

Path integration/dead-reckoning is complementary to piloting as it is based on means other than landmarks for spatial updating cues. For example, path integration/dead-reckoning allows the navigator to determine current position and orientation by integrating the perceived velocity or acceleration over time with respect to a starting point. It is, however, "susceptible to accumulation errors due to the integration process. It is well suited for small-scale navigation and connecting neighboring landmarks, but uncertainty and error increase exponentially with traveled distance" (Riecke et al., 2002, p.444).

Foo et al. (2005) classify navigation strategies according to the demands the strategies place on memory storage and cognitive processing— in other words., "…a hierarchical classification from weak to progressively stronger spatial structure" (Foo et al., 2005, pp.195-196). These navigation strategies are (in order from weak to strong spatial structure): *locomotor guidance* (traveling toward or away from something in view, such as a building or mountain range), *landmark navigation* (navigation with respect to a known landmark/location held in memory), *path integration/dead-reckoning* (constantly updated direction and distance traveled with respect to a starting point), *route-based navigation* (remembering sequences of positions— landmarks, for example— and the actions taken at these positions) and *map-based navigation* (traveling with survey knowledge, where one has a strong knowledge of the spatial structure of the elements in the environment and their relationships to one another).

Finally, Darken & Sibert (1996) have determined three primary categories of wayfinding tasks: *naïve search* (no prior knowledge of the environment, therefore an exhaustive search is required), *primed search* (navigator knows the location of the target; therefore a non-exhaustive search is required), and *exploration* (the navigator has no target and is free to wander) (Darken & Sibert, 1996, p.143).

2.1.5-Environmental cues and their role in spatial knowledge acquisition

"Humans acquire spatial knowledge of a new environmental space...by travelling through this environment" (Jansen-Osmann & Weidenbauer, 2004, p.347). Whether spatial knowledge is associative, dissociative or hierarchical, landmarks have been shown to affect spatial representations and the acquisition of route and configurational knowledge (Jansen-Osmann & Weidenbauer, 2004, p.348).

Landmarks are remembered not only so they can be recalled or recognized as significant objects, points or places, but because they can act as reference points (or spatial cues) that help to encode spatial information and aid navigation (Anooshian, 1996; Jansen-Osmann & Weidenbauer, 2004; Stankiewicz & Kalia, 2007). They serve as signalling sites, as aids in locating other landmarks and as visual confirmation of the route being taken (as correct or incorrect) (Jansen-Osmann & Weidenbauer, 2004). Lynch (1960) defined four types of landmarks: nodes, paths, boundaries and districts. Stankiewicz & Kalia (2007) place landmarks into two groups: structural landmarks (geometric features of the layout) and object landmarks (non-structural features of the environment).

In order for landmarks to be useful, they should be persistent (not move), perceptually salient (detectable and identifiable) and informative (provide information about position or action) (Stankiewicz & Kalia, 2007). If landmarks are too abstract, they do not aid navigation. In terms of providing spatial coordinate information, Stankiewicz and Kalia (2007) argue that object landmarks are more successful than structural landmarks.

Some research has addressed the influence of landmarks— specifically as directional cues and/or spatial differentiation— as elements that give a space or an environment a distinct identity. Predominantly, the research has focused on wayfinding ability. For example, Arthur and Passini (1992) argued that distinctiveness of spaces may affect wayfinding, O'Neill (1991b) showed that building complexity had a stronger influence on wayfinding ability than other factors, Passini (1984) determined that some individuals rely on signage while others rely on the clarity of the building layout when wayfinding, and Best (1970) concluded that signage at decision points improves wayfinding. Baskaya et al. (2004) studied the layout, signage and spatial differentiation of two environments with respect to wayfinding and they concluded that "...both the graphic [directional cues] and spatial representations as landmarks should be complementary" (Baskaya et al., 2004, p.865).

2.1.6-Cognitive maps and cognitive mapping

Humans have a fundamental need to know the world around them, and this knowledge structures our spatial behaviour and our sense of place. Research on cognitive maps is concerned with how people make sense of the world around them and how they use spatial knowledge to make spatial decisions and choices (Kitchin et al., 1997, p.227).

The term *cognitive map* was first coined by Tolman (1948) to describe the internal representation of large-scale space. A cognitive map is defined as "a representation of a set of connected places which are systematically related to each other by a group of spatial transformation rules" (O'Keefe & Nadel, 1978, p.86). The term is also used "to specify the internal representation of spatial information" (Golledge, 1999b, p.15). In *Human Wayfinding and Cognitive Maps*, Golledge (1999b) lists questions that the reconstitution of cognitive maps are designed to answer: Where am I? Where are the phenomena for which am searching? How do I know when I'm lost? (Golledge, 1999b, pp.21-22).

Cognitive maps allow for the representation of a great deal of information "in a flexible format with an economy of effort" (Allen, 1999, p.72). They have alternately been found to incorporate representations at different spatial scales, to be organized in a hierarchy and to contain errors and distortions (Foo et al., 2005, p.196). It is commonly agreed that cognitive maps are made up of points, lines, areas and surfaces (Golledge, 1999b, p15). Lynch (1960) considered cognitive maps to be the end result of *experiencing* a novel environment where the experience is context dependent and multi-sensory.

Cognitive map knowledge consists of information and knowledge structures. Information is made up of attributive (encoding info about the characteristics of the location) and locational (encoding where phenomenon are sited) data. Knowledge structures are used in storing and processing information (Kitchin et al., 1997). Downs & Stea (1973b) define the whole *process*— whereby "an individual acquires, codes, stores, recalls, and decodes information about their relative locations and attributes of phenomena in his [*sic*] everyday spatial environment" (Downs & Stea, 1973b, p.9)— as *cognitive mapping*.

Whatever method and cues we use to acquire spatial knowledge of an environment, this knowledge is ultimately used to create a cognitive map. To develop a cognitive map, individuals must experience the environment in some way. The more experience one has with the environment, the more accurate the cognitive map will become (Jacobson et al., 2001).

2.1.7-Reconstitution of cognitive maps

Tuan (1975) believes that cognitive maps serve five functions:

1) Cognitive maps make it possible to give directions to a stranger.
If we are asked for directions, we must first recall the image we have of the environment and relay this information. We are successful if we are able to transmit our cognitive map into the mind of the stranger, who will then have his or her own cognitive map to help find the way.

2) Cognitive maps make it possible to rehearse spatial behaviour in the mind.
If we are certain we know where we are going, we do not need a cognitive map— we will probably travel by instinct or habit. If we are lost, we need a real map to find our way as we have no reference point to use our cognitive map. If, however, we think we know

where we are and have a sense of where to go, we use our cognitive map to rehearse in advance what path we will take, how we will behave and to fill in the gaps in order to find our way.

3) Cognitive maps are a mnemonic device.

When we need to memorize events, people or places, it helps to know locations and use this mental representation as a reference point. If we meet a group of people for the first time, it is helpful to memorize the names of everyone around a table, for example, and recall this arrangement even after the people have moved. Tuan (1975) notes that this method has been used since ancient times to help orators tell long stories and make speeches.

4) Cognitive maps, like real images, can be used as a means to structure and store knowledge.

However, not everyone uses cognitive maps to structure and store knowledge.

5) Cognitive maps are imaginary worlds.

Cognitive maps are used to "tempt people out of their habitual rounds" (Tuan, 1975, p.211), and encourage people to migrate: "Quintessential human migration occurs when people deliberately abandon one home in favor of a distant and unseen goal" (Tuan, 1975, pp.210-211). In addition, cognitive maps also allow individuals to take shortcuts—we can imagine an alternate route as part of the network of routes we are familiar with (Foo et al., 2005).

2.1.7.1-Reconstitution of cognitive maps: an example of sketch maps

Although cognitive maps are constantly being used and updated, they cannot be seen by the researcher. If they cannot be seen, how can we know what they consist of? How can we gain access to internal representations?

> Until neurological evidence confirms that humans have specific "place cells" that define where spatial information is stored in the brain…and identifies the means by which place cell information is integrated and used, internal representations must be inferred from one or more external symbolic representations (e.g., sketch maps of a city) or from some other forms of observable behaviour (e.g., search behaviour to find a specific location).
>
> Golledge, 1999b, p.8

Externalizing internal representations can be done through a variety of means: verbal descriptions or estimations, reproduction, modeling or sketching techniques (Downs & Stea, 1973a, pp.79-86). Lynch (1960) believed that sketch maps were a useful tool to reveal which elements are perceived as important in the environment and to see how people structure urban environments (from Saarinen, 1973). Saarinen (1973) argues that other methods are not as useful to obtain this type of information.

Previous studies on (or studies conducted using) sketch maps have shown that "subjects decompose environments into landmarks, nodes, districts, paths, and boundaries, and tie them together topologically and geometrically to summarize personal and group knowledge structures into cognitive maps" (Golledge et al., 1995, p.135). Appleyard

(1969) showed that sketch maps can be drawn either sequentially (with roads and rivers as organising principles) or spatially (with buildings and districts as organising principles). Hart & Moore (1973) found that the majority of individuals exposed to a new environment reconstituted the environment with sequential maps. If individuals acquire spatial knowledge differently, sketch maps allow for them to reconstitute their cognitive maps without bias towards one style of representation or another— they essentially have a blank page to reconstitute the environment as they wish.

Sketch maps, one of the early tools used to study spatial knowledge, continue to be used in current studies (Aginsky et al., 1997; Baskaya et al., 2004; Golledge et al., 1995; Kim & Penn, 2004; Nohara & Mori, 2002; Péruch et al., 1995). Allen (1999) notes that "[t]he chief means of assessing spatial knowledge has been the verification of inferences and the accuracy of sketch maps" (Allen, 1999, p.72).

Orleans (1973) argues that the ability to draw maps is based on the ability to draw and the familiarity one has with maps in general: "[I]t appears that a mapped imagery is not necessarily consonant with knowledge of the environment elicited in verbal form" (Orleans, 1973, p.129)[1] (footnotes are to be found on p.86). Of more concern here is his belief that "...a blank sheet of paper as a stimulus for obtaining a mapped image of the city is more of a liability than an asset..." (Orleans, 1973, p.129) since individuals may have more information than they are capable of putting down on paper. He suggests giving cues to aid in the reconstitution of cognitive maps.

Passini stresses that "[s]ketch maps are not to be equated with cognitive maps" (Passini 1984, p.49) as they are simply one form of representation of a cognitive map, complete with a loss and/or transformation of information when this knowledge is expressed (Passini, 1984, p. 49). "Any internal model of an environment is still only a model, no matter how precise, and is subject to errors..." (Chown, 1999, p.352). Golledge (1999b) also believes that any "spatial products" may not reflect stored knowledge accurately, or that the mode chosen to express spatial information may increase the propensity for error (Golledge, 1999b, pp. 14-15). "Given that errors can occur when encoding, internally manipulating, decoding, and representing information, it is no wonder that cognitive maps are usually assumed to be fragmented and incomplete" (Golledge, 1999b, p.23).

2.1.8-Error in cognitive maps

> It cannot be assumed that people walk about with pictures in the head, or that people's spatial behaviour is guided by picture-like images and mental maps that are like real maps...Geographers run the risk of seeing maps in people's heads...
>
> Tuan, 1975, p.213

Cognitive maps can be prone to error due to "[d]ifficulities experienced in mentally integrating routes and their associated features into networked structures" (Golledge, 1999b, p.6). Cognitive maps can also change over time: accretion (minor changes whereby the route is learned by traveling somewhere and then returning— an accumulation), diminution (small changes in a cognitive map where information is lost/forgotten— a reduction), and reorganisation (a slow process that happens over time, and with ample evidence to dislodge "incorrect" spatial knowledge) (Golledge, 1999b).

Not only is spatial information encoded with inaccuracies (Tversky, 1981; Weisman, 1981), but the act of *reconstituting* spatial knowledge is also full of errors (Baskaya et al., 2004; Chown, 1999; Golledge, 1999a, 1999b; Passini, 1984; Kim & Penn, 2004; Sadalla & Montello, 1989; Schneider & Taylor, 1999). However, what is often defined as error in fact allows individuals to use their cognitive maps efficiently. Chown (1999) believes that qualitative representations are more useful and efficient than metric representations of space since the world is constantly changing, thus maintaining accurate and detailed information is difficult (if not impossible). Cognitive maps of our environment contain information that is relevant to the tasks we need to perform. "Human cognitive maps are structured on this basis, emphasizing some information at the expense of other data" and the information is ready for use when we need it (Chown, 1999, p.353). Golledge (1999b) argues that cognitive maps, when quantitatively encoded or interpreted, "facilitate the manipulation of information using Euclidean geometry and mental trigonometry" (Golledge, 1999b, p.15). When qualitatively encoded, cognitive maps "provide information on order, inclusion, exclusion, or other topological relations" (Golledge, 1999b, p.15).

Information is lost and transformed in the process of externalizing internal representations. Most sketch maps, for example, contain scale and metric distortions (Passini, 1984, p.38-39). Consistent distortions in distance include the clutter effect (cognitive distance becomes longer if the route is more cluttered with intersections, barriers, curves, etc..), valance (if individuals have an affinity for a place they will shorten the distance required to get there) and regrouping (individuals often regroup spatial elements in large spaces into distinct areas. If two areas are perceived as separate, the distance will be longer than if they are perceived as being one area). Distance and time are often interchangeable, and some elements are omitted or selected in order to simplify cognition and/or reconstitution. Expectation can lead to the addition of elements that did not exist in the environment (Passini, 1984, pp.39-40).

"If a cognitive map is basically a registry of known places, then individuals differ greatly in the content of their cognitive maps and, according to studies of environmental learning, they also differ in the process of cognitive mapping" (Allen, 1999, p.73). However, cognitive maps and the process of cognitive mapping vary not only according to what is known, they also vary from person to person, even when exposed to the same environment. In other words, "different strategies of thought or decoding will lead to radically different results, even when the knowledge base is identical" (Kitchin, 1997, p.125).

2.2-Virtual environments

Virtual environments present unique challenges for the researcher. Many issues, in addition to those addressed in real environment spatial knowledge acquisition research, must be considered. For example: What kind of virtual environment should be used? How should individuals be permitted to view and explore the space in an experimental setting? What variables can (or must) be controlled?

We acquire spatial knowledge by experiencing or interacting with the environment (Golledge, 1991). This interaction can be direct (walking down the street, living in a neighbourhood) or "by accessing different sources of information" (Golledge, 1991, p.35) such as videos, movies, photographs or virtual models.

Wilson (1999) defines virtual environments as "[c]omputer-simulated three-dimensional environments that people can interact with and explore in real time" (Wilson, 1999, p.752). However, virtual environments can also consist of a series of photographs (static display) or real-time video (dynamic display) (Heft & Nasar, 2000; Zacharias, 2001) or imagined/created space (Golledge et al., 1995; Stamps, 2005a, 2005b, 2005c).

Participant exposure to virtual environments can take many forms: helmet-mounted displays (Arthur & Handcock, 2001; Darken & Sibert, 1996; Klatzky et al., 1998), computer monitors (Belingard & Péruch, 2000; Cubukcu & Nasar, 2005; Golledge et al., 1995; Heft & Nasar, 2000; Jansen-Osmann & Berendt, 2002; Murray et al., 2000; Nohara & Mori, 2002; Péruch et al., 1995; Ruddle et al., 1997; Tlauka & Wilson, 1996; Wilson, 1999; Zacharias, 2006), projection screens (Steck & Mallot, 2000; Vidal et al. , 2004), and even driving simulators (Aginsky et al., 1997).

It has been shown that desktop virtual environments allow for better efficiency in navigation as compared to immersive virtual environments, however individuals are more likely to become disoriented in a desk-top virtual environment (Jansen-Osmann & Weidenbauer, 2004). Immersive virtual environments have the distinct disadvantage of *after-effects*, such as motion sickness, disturbance of balance and drowsiness (Jansen-Osmann & Weidenbauer, 2004). These can be carefully controlled or monitored, yet the reaction of one participant is not a reliable indicator of what others may experience.

Environment and interface fidelity are essential variables to consider as well. Environmental fidelity— "...the quality of the sensory information provided to the user by the simulator" (Lathrop & Kaiser, 2005, p.250) — has been shown to impact spatial performance. In addition, interface fidelity— "...one's actions used to generate this information..." or "...one's mode of exploration during travel" (Lathrop & Kaiser, 2005, p.250)— has an influence on the way in which sensory and motor input interact. For example, "[l]ow-fidelity systems [e.g., nonimmersive-desktop-display platforms] provide sensory/motor couplings that are only symbolic in form" (Lathrop & Kaiser, 2005, p.250).

The method of exploration in a virtual environment can be controlled as well. In some cases, participants are free to explore the virtual environment (Belingard & Péruch, 2000;

Tlauka & Wilson, 1996; Wilson, 1999; Zacharias, 2001, 2006), and others are lead along a pre-determined path (Golledge et al., 1995; Heft & Nasar, 2000; Klatzky et al., 1998).

2.2.1-Spatial knowledge acquisition in virtual environments

Virtual environments have proven to be very useful tools with respect to spatial cognition research. The environments are easily controlled and variables are easy to introduce or exclude. Nearly any kind of environment can be simulated. Participants can easily navigate with some instruction and, if desired, navigation can be measured on-line (Jansen-Osmann & Weidenbauer, 2004).

Studies of spatial knowledge acquisition in virtual environments have often been conducted under the assumption that virtual and real environment exploration will result in the same type of spatial knowledge acquisition (Belingard & Péruch, 2000, for example). "There is evidence of substantial similarities in the spatial knowledge that is acquired in real and virtual environments…" (Wilson, 1999, p.753). Tlauka & Wilson (1996) believe that "…navigation in computer-simulated and real space lead to similar kinds of spatial knowledge" (Tlauka & Wilson, 1996, p.647), and Arthur et al. (1996) consider interaction with small-scale virtual environments as comparable to real-world experience, with respect to the resulting spatial representations of an environment. Specifically, it has been shown that people can acquire landmark and route knowledge (Lathrop & Kaiser, 2005) and survey knowledge (i.e., knowledge about directions and distances) (Jansen-Osmann & Weidenbauer, 2004; Lathrop & Kaiser, 2005; Witmer et al., 2002) in virtual environments. Nonetheless, some researchers are concerned about this assumption, and have tested the use of virtual environment models in terms of their strengths and weakness in spatial knowledge acquisition (Heft & Nasar, 2000). Others are aware of this issue and try to control for these "unknowns" in their methodologies (Zacharias, 2006).

2.2.1.1-Movement

Moving through an unknown environment allows an observer to acquire spatial knowledge (thereby developing a mental representation or cognitive map) of the environment, which is improved upon as the time spent exploring, and/or the number of exposures to the environment, increases (Péruch et al., 1995). "Walking through an environment is…a physical experience, which we know from distance decay effects in walking to be a powerful inhibitor" (Zacharias, 2001, p.351). However, movement is more than simply a physical experience— it is a visual experience as well. Heft and Nasar (2000) discuss the changes that a subject (or in their terminology, *perceiver*) experiences while moving through an environment: optical flow[2], motion parallax[3], and optical occlusion and disloclusion[4]. Movement is also a temporal experience, since "…time expresses the experience of moving through space, and distance is an abstraction thereof" (Passini, 1984, p.40). Thus, exploration of virtual environments can include the effect of movement with respect to the visual and temporal experience.

One common concern about the use of virtual environments in spatial knowledge acquisition research is the lack of proprioceptive sensory information, "[h]owever, evidence indicates that missing proprioceptive feedback might not be crucial regarding spatial learning" (Jansen-Osmann & Weidenbauer, 2004, p.348).

2.2.1.2-Static and dynamic representations

Heft & Nasar (2000) examine the differences between knowledge acquisition in static (freeze frames of route segments) and dynamic (videotaped segments taken along a route) virtual environments. "Results indicated that assessments of static displays do not simply parallel those of dynamic displays" (Heft & Nasar, 2000, p.301). "Investigations of some environmental variables using static displays with the assumption that perceivers' reactions to these displays will be identical to their reactions to dynamic displays, and by extension to environments in situ, rest on unwarranted assumptions" (Heft & Nasar, 2000, p.314). Several studies have shown that space characteristics "are better integrated into an internal representation from dynamic rather than from static visual information" (Péruch et al., 1995, p.3).

Zacharias (2001) cautions us about the potential weaknesses of using virtual environments that consist of photographs in behaviour studies: "Photos may well be highly reliable surrogates for preferences in the real environment, but do not provide a sense of spatial relationship..." (Zacharias, 2001, p.351) therefore, the use of photos "cannot likely be used with confidence as a surrogate for predicting behaviour in the real world" (Zacharias, 2001, p.351).

2.2.1.3-Types of exploration of real and virtual environments

Arthur & Hancock (2001) define active exploration as *free VE*, or the exploration of the environment with or without the choice of itinerary or speed, and passive exploration is defined as *static VE*, or observation of the environment from a fixed view-point. Péruch et al. (1995) define active perception (or exploration) as "changing points of view through active motion" (Péruch et al., 1995, p.3). Wilson (1999) defines active participants as those who "explored a desktop three-dimensional computer-simulated environment" and passive participants as those who simply "watched a screen" (Wilson, 1999, p.752).

Many research projects have tested the effects of active or passive exploration of an environment on spatial knowledge acquisition, storage and recall (Wilson, 1999). Péruch et al. (1995) showed that active exploration resulted in higher memorization performance than passive exploration. Arthur & Hancock (2001) found that active exploration results in non-orientation specific representations, whereas static exploration results in orientation specific mental representations. "[C]oncerning the nature of displacement, some authors have found that the acquisition of the spatial properties of a natural environment is better achieved through active, rather than passive, exploration... although other studies have shown opposite results" (Péruch et al., 1995, p.3).

It is well documented that our spatial knowledge improves or progresses "more or less automatically as experience increases" (Aginsky et al., 1997, p.318), but what does experience mean, exactly? Appleyard (1970) showed that, "car passengers [passively exploring] learn less than drivers [actively exploring] about the layout of a town route" (Wilson, 1999, p.753). Two people (a passenger and a driver) have the same time exposure to the environment, they visit the same places, yet they will have very different experiences of the environment (Aginsky et al., 1997). "[O]ne important variable that may have influenced the outcome of the experiments is attention" (Wilson, 1999, pp.752-753). The driver must make decisions, watch for obstacles and control the vehicle— in other words, be very attentive. The passenger is not required to be attentive in this way.

When a participant was told their spatial abilities were being tested, active and passive exploration of a virtual environment resulted in equal ability (orientation, memory for objects, etc..) (Wilson, 1999). When participants were misinformed about the goal of the experiment, "active explorers concentrated more on locations because their attention was directed to negotiating the route through the environment, whereas passive explorers were better able to direct their attention to memorizing the objects" (Wilson, 1999, p.755). Wilson (1999) found that "there is little if any benefit to orientation performance from active exploration over passive observation" (Wilson, 1999, p.761). Differences could also be due to sensitivity to information, kinds of information available and the kinds of activities involved (Péruch et al., 1995, p.3).

2.2.2-Benefits of virtual environments in academic research and beyond

With virtual environments, the researcher has the ability to control the environment in a way not possible in the real world. An obvious criticism is that testing in virtual environments leads to results or conclusions that have no value or weight in the real world, but this criticism is too general. The way in which people understand space is very complex, and virtual environments allow researchers to address specific issues that would be near to impossible to address in the real world. For example, a researcher may wish to test if the number of pedestrians on a sidewalk influences individual wayfinding behaviour; While attempting to research the relationship between the number of pedestrians and wayfinding behaviour in a real environment, the researcher would be confronted not only with more or less pedestrians in the environment, they would also be unable to control additional variables such as the level of crowd noise, different smells, changing weather, lighting conditions, etc... In a virtual environment, it is possible to alter only the variable being tested, thereby reducing the effects of unknown/uncontrolled variables.

Learning an environment in a virtual model, as opposed to learning from a map, has the advantage of allowing one to learn about an environment without actually being there (and experiencing the frustration of getting lost in a large, foreign environment), and to acquire spatial knowledge orientation-free (Allen, 1999). Of course, there are countless benefits to exploring a real environment that can not be matched by a virtual environment exploration (for example, meeting new people, the immersive (full-body) experience of smells and sounds, etc..), but there are distinct benefits to virtual environment exploration as well: learning an environment that you cannot explore in person (due to distance, danger, mobility or time constraints), learning an environment in anticipation of eventual in-person exploration to reduce stress (students going away to college, patients preparing for a hospital stay, etc…), or learning an environment before it actually exists (which could allow for exploration and testing of the environment before the bricks and mortar have been laid).

There has been a recent explosion of spatial knowledge research that has accompanied the availability of affordable and user-friendly technological tools. It is now easier than ever to test the acquisition, coding and recall of spatial knowledge due to the ability to control the test (virtual) environment. Nevertheless, the debates discussed in this section continue unabated.

This project was motivated by the apparent assumption that the order of spatial knowledge tasks may have some effect on spatial knowledge acquisition or recall, which is evidenced in some current research methodologies. Specifically, this thesis project focuses on spatial knowledge recall and reconstitution. The results show that there is an effect of spatial knowledge recall task order, which has implications for the wider field of spatial knowledge research.

In the following sections, I will present the purpose, objective and hypothesis of this research project, followed by a detailed methodology that includes the design of the virtual environment and the testing methods used. I will then analyse the quantitative relations between recall task order and the reconstitution of spatial knowledge, and conclude by connecting the results of this project with several of the debates presented in section 2.

3-Purpose

The motivation of this research project was to explore an inconsistency in current research practice. A review of spatial knowledge research shows that many researchers are concerned with "balancing" their methods, either by varying the order of exposure to variables (Anooshian, 1996; Belingard & Péruch, 2000; Darken & Sibert, 1996; Heft & Nassar, 2000; Jansen-Osmann, 2002; Zacharias, 2001) or by varying the order of spatial knowledge recall tasks (Heft & Nassar, 2000; Schneider & Taylor, 1999; Steck & Mallot, 2000; Taylor & Tversky, 1992), even when the order of exposure or recall is not the variable being tested. There is an apparent underlying assumption that the order may have some effect. Interestingly, many researchers have chosen *not* to balance the order of spatial knowledge recall tasks (Arthur et al., 1997; Choi et al., 2006; de Kort et al., 2003; Foreman et al., 2005; Golledge et al., 1995; Wilson, 1999; Witmer et al., 2002). The need to balance some aspect of an experiment may be determined by the nature of the question being asked, however there is no consistency— researchers sometimes find the need to balance, and other times they do not. Is this extra work necessary? The essential point is that *we don't actually know*. A central aim of this project is to determine if there are spatial knowledge recall differences according to the order in which tasks are performed after spatial knowledge has been acquired from a virtual environment. In other words, does recall of particular types of spatial knowledge inform or influence any subsequent spatial knowledge recall task? Thus, this project was undertaken with the intention of expanding on the theoretical basis of spatial knowledge recall and of informing future research methods. This research project has been designed as an exploration, not a confirmation, of the nature of spatial knowledge recall and reconstitution (Golledge et al., 1995).

4-Objective

The objective of this research project was to determine if the order in which different types of spatial recall tasks were performed had any effect on the reconstitution of spatial knowledge. Specifically, when participants were asked to recall the itinerary taken through the virtual environment or the location of colours seen during the tour, did the order in which they were asked to perform the tasks influence their ability to reconstitute these two types of spatial knowledge?

5-Hypothesis

Difference in recall order will have an effect on the reconstitution of spatial knowledge acquired from a tour through a virtual environment.

6-Methodology

6.1-Participants

The participants were 40 undergraduate students or teaching staff in the department of Geography, Planning and Environment at Concordia University in Montreal, Quebec. Participants were recruited from urban planning/geography courses or by means of posters displayed in the department. All participation was voluntary; however some participants were offered credit by their professors for their participation. They were informed of the purpose of the study orally (by the researcher) and in writing (on the consent form).

6.2-Materials

A three-dimensional environment was created using SketchUp Pro software. This environment was presented to participants by means of a laptop-based, dual display output to a 21-inch flat monitor. The virtual environment consisted of hallways and rooms, where seven rooms contained coloured walls (one colour per room) (see Figure 6-1). The walls were 11 units high throughout, and the hallways travelled were approximately 10 units wide. All rooms entered had openings 10 units wide.

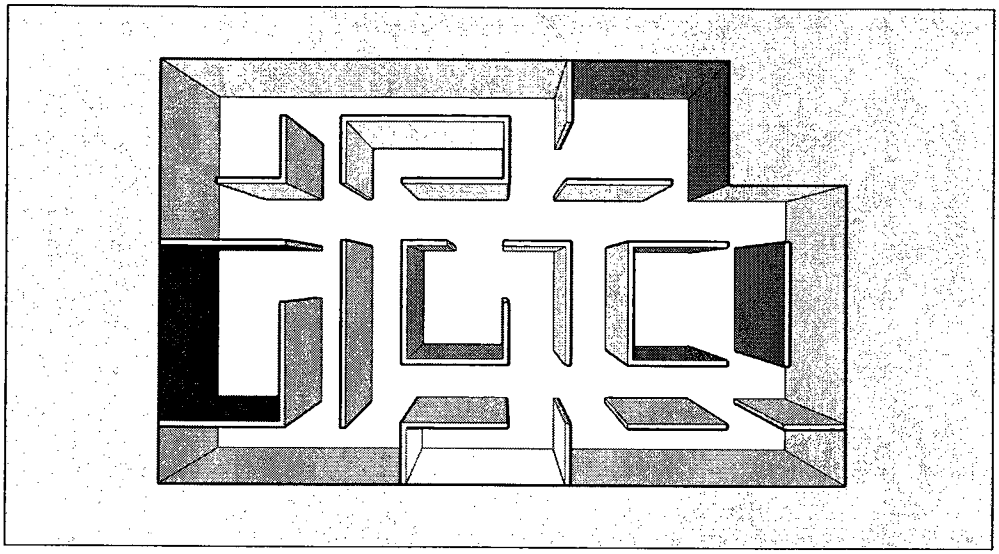

Figure 6-1: Virtual environment viewed from above, showing coloured walls

Participants "explored" the environment by traveling along a pre-determined route (or itinerary) (see Figure 6-2). The route consisted of 64 scenes, advancing at a rate of five units per scene, with a 1.5 second transition period. The scenes were "stitched together" to enable smooth transition. Each scene advanced through the environment at a rate of 3.33 units per second (five units per 1.5 seconds), and the total distance travelled through the environment was approximately 320 units. All turns made in the environment were 90 degree turns, and each consisted of one scene, thus rotation speed was 60 degrees per second. Participants stopped at the destination for 3 scenes (4.5 seconds) before returning to the starting point. The route through the environment took 100.5 seconds. In total, the participants were exposed to the environment for approximately 7 minutes, taking into consideration the time required for the program to return to the starting point after the first, second and third exploration as well as the time required to start the program at the first scene (approximately 30 seconds in total).

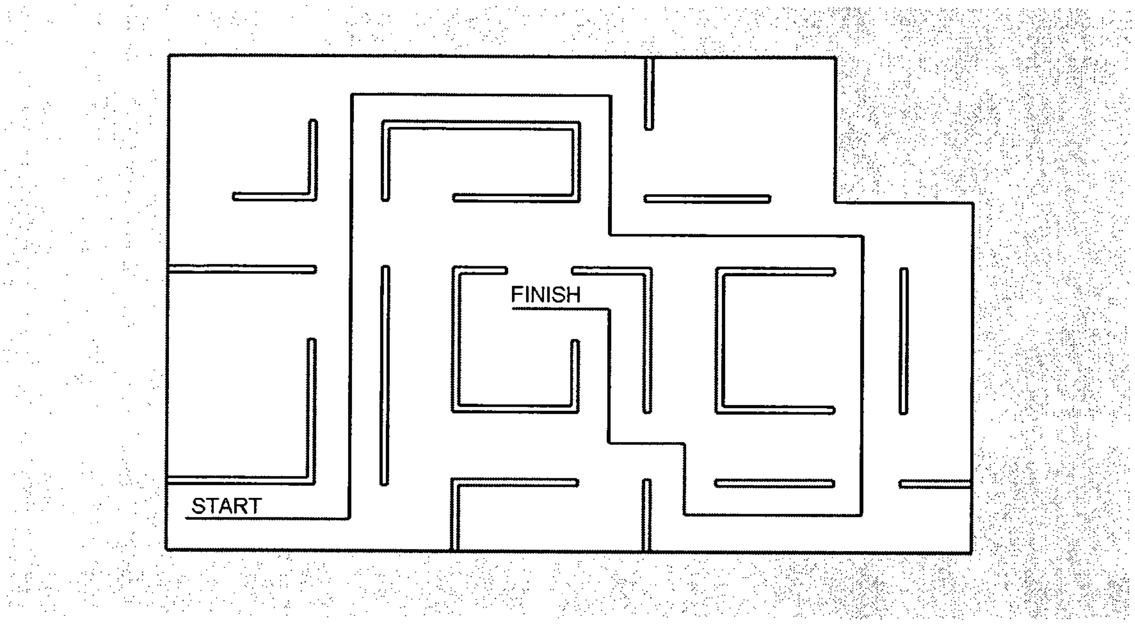

Figure 6-2: Route taken on tour (itinerary) of the virtual environment

The route consisted of 10 turns and participants entered three distinct spaces (rooms with coloured walls, identified as PURPLE, ORANGE and GREEN, or *colours visited*). On the route, participants were exposed to four additional rooms (identified as BLUE, PINK, RED and YELLOW, or *colours viewed*) with coloured walls— these spaces were not entered, thus acting as visual cues. All other walls, and the ceiling, were grey, and the floors were white (see Figures 6-3, 6-4 and 6-5). The environment contained no doors or windows.

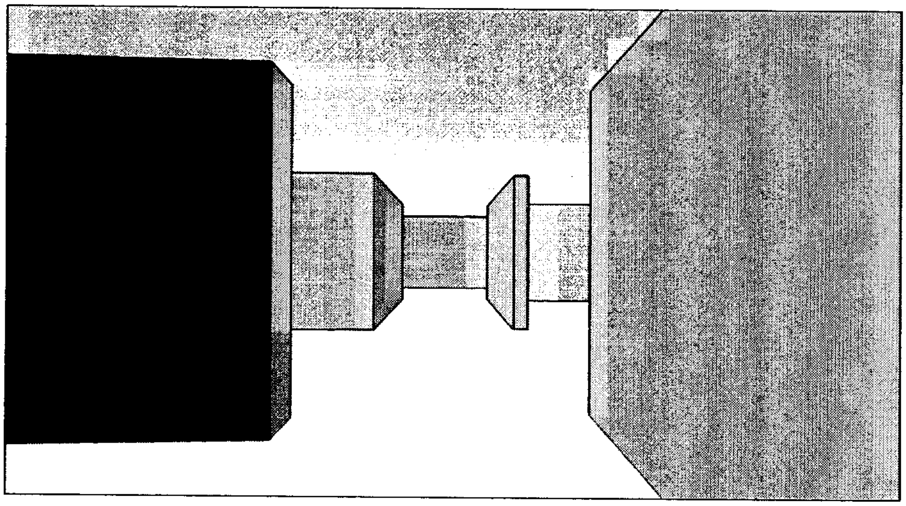

Figure 6-3: View of the virtual environment (seen from polygon 2)

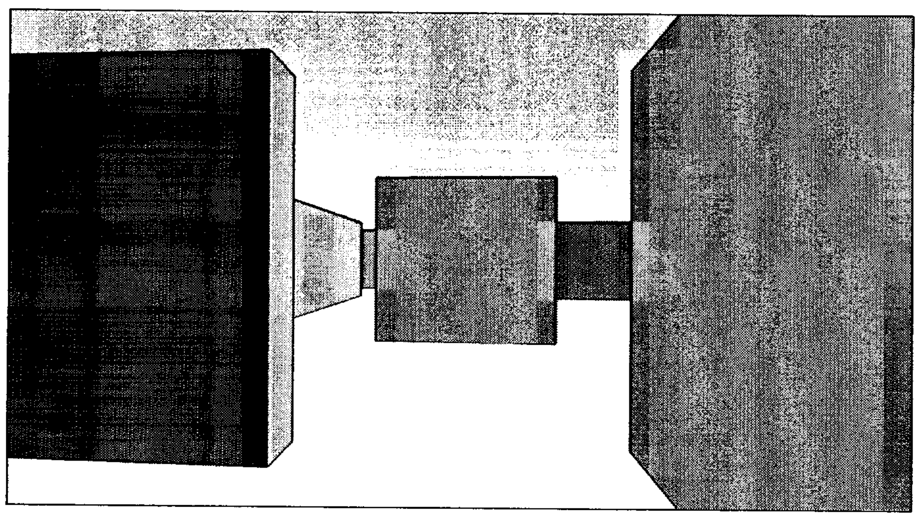

Figure 6-4: View of the virtual environment (seen from polygon 6/7)

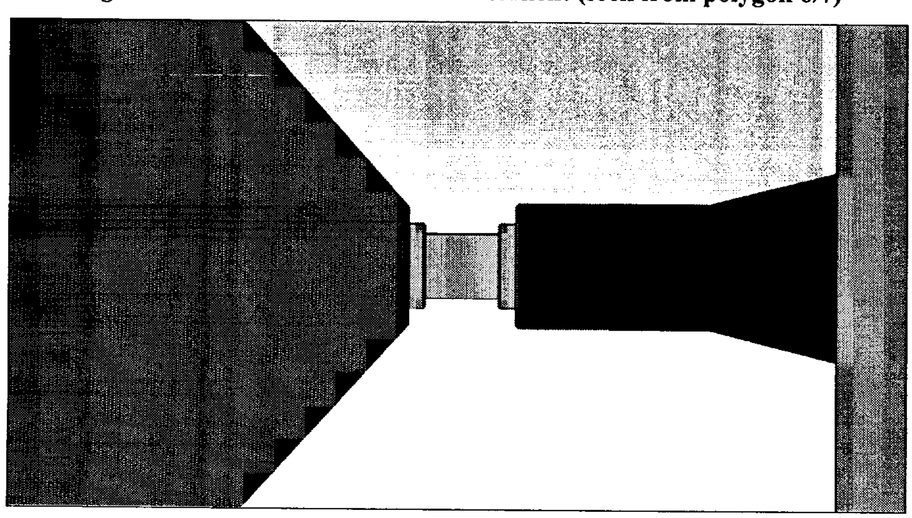

Figure 6-5: View of the virtual environment (seen from polygon 11)

As participants traveled along the route in the environment, they were visually exposed to the PINK and RED spaces more than once, although these spaces were not entered. All other coloured spaces were passed once (BLUE and YELLOW), seen once and then entered later along the route (PURPLE and GREEN) or seen for the first time directly en route to entering the space (ORANGE). Spaces that had been entered were not seen again once they had been exited (PURPLE and ORANGE) or served as the destination point (GREEN). The destination point was given a colour (GREEN) so it would be easier to determine if participants were able to recall where the destination was, either in terms of actual location or serving as the destination of their reconstituted route.

The environment was explored four times by participants in both groups. Once they had completed the exploration activity, they were asked to complete two tasks— a route task and a colour task, both of which were completed on an 8.5x11 paper layout of the environment.

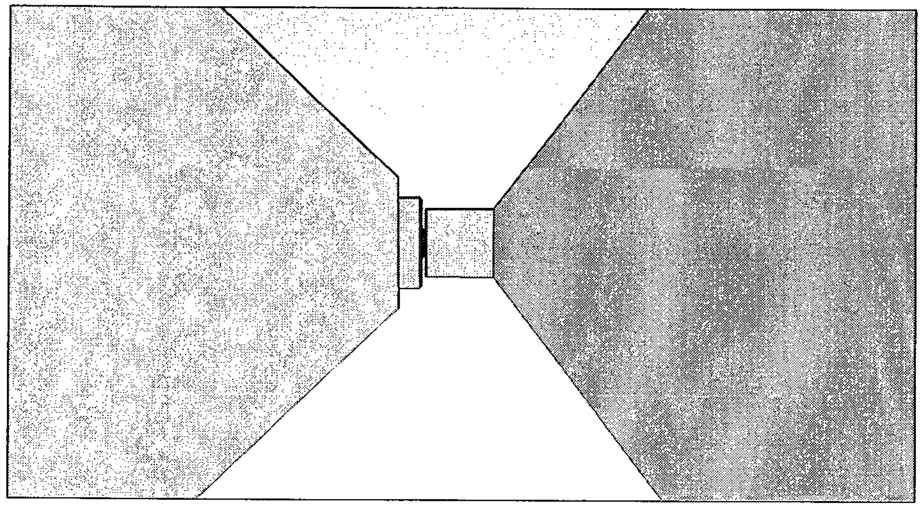

Figure 6-6: Starting point of virtual tour

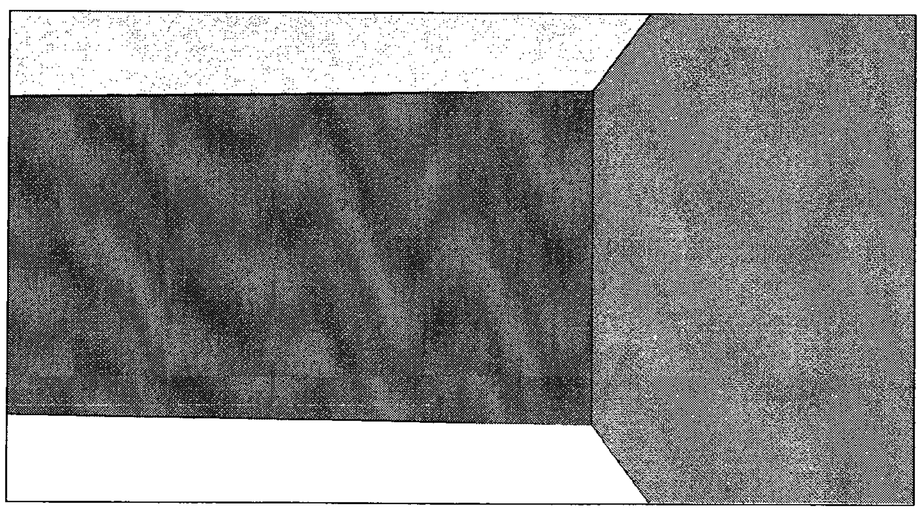

Figure 6-7: Destination point of virtual tour

6.3-Design and Procedure

6.3.1-Pre-test

The itinerary and the design of the virtual environment were established after multiple pre-tests. Several environments were created using different levels of complexity of layout and itinerary, and well as the colours used. Issues of concern were over-exposure to the environment (long views and multiple exposures to coloured rooms), confusion over colours (confusing yellow and orange, or blue and purple, for example) and motion sickness due to turns encountered in quick succession. These issues were taken into consideration in the design and exploration of the final environment.

6.3.2-Testing

Participants were assigned to one of two groups according to the order in which they signed up to participate in the experiment.

When the participants entered the room where they would be shown the virtual environment, they were asked to read and sign a consent form that explained the nature of the experiment. All participants were warned about the risk of after-effects (such as motion-sickness), and were told they could request that the experiment stop at any time, for any reason. They were informed they would explore a virtual environment and complete two tasks, but the nature of the tasks was not revealed. Participants were told that their only responsibility was to observe and explore the environment as they were taken on a virtual tour. Extra time was allotted for participants to ask questions or discuss the research project once the tasks had been completed. The participants were tested individually.

Participants sat at a table, in front of a flat-screen monitor and were asked to adjust their seat so that they were at a comfortable viewing level. The researcher sat on the opposite side of the table, facing a laptop (see Figure 6-8). When the participant indicated that he or she was ready, the researcher began the tour through the environment. After the first tour, the researcher asked the participant if he or she were experiencing after-effects. When the participants indicated that they felt fine, the researcher reset the tour and started again. (None of the participants felt any after-effects during the virtual tour.) The participants toured the environment four times.

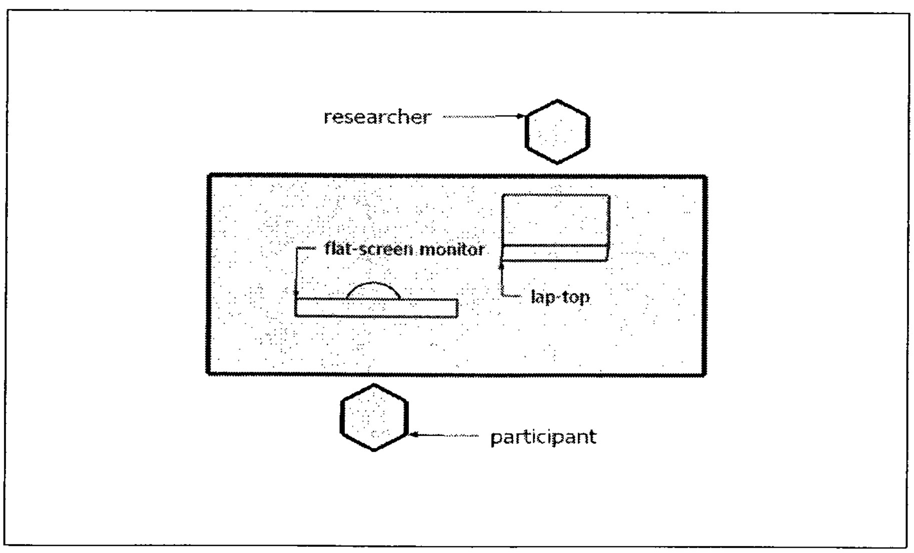

Figure 6-8: Positions of participant and researcher during testing

The test phase consisted of two tasks. The route task required participants to reconstitute the itinerary with a black ink pen. The colour task required participants to reconstitute observed colour placement with colour stickers. Group I (n=20) was asked to complete the route task first, followed by the colour task. Group II (n=20) was asked to complete the colour task first, followed by the route task. Before starting the first task, all participants were shown the starting point and heading on the paper layout, and the paper layout was oriented as it appears in Figure 6-2.

Each individual was informed of the second task only once the first task had been completed. In addition, participants were not permitted to alter the results of the first task once the second task had been revealed (for example, Group II participants could not change the location of a colour sticker once they had been informed of, or had started, the route task). There were no time restrictions for the tasks, but most participants completed their session within 20 minutes.

7-Analysis and Results

Participants were asked to perform two tasks, and these tasks provided two distinct types of data: reconstituted routes (the participants' attempts to reconstitute the itinerary on the layout) and colour placements (the participants' attempts to correctly locate the areas of colour, as seen in the virtual environment, on the layout). Reconstituted routes were analyzed according to polygons (see Figure 7-1), and colour placements were analyzed according to boundaries of acceptable colour location (see Figure 7-5).

In this section, the data is analyzed separately, staring with the reconstituted routes, followed by colour placements. Finally, the data is tested for correlation between the success of itinerary and colour location reconstitution.

7.1-Reconstituted routes

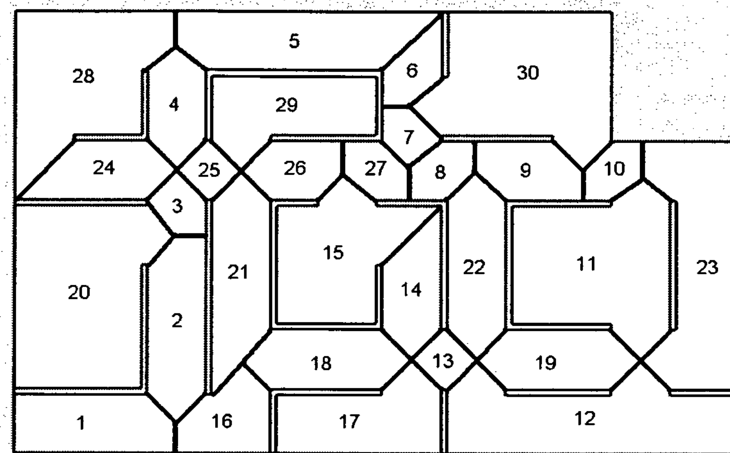

Figure 7-1: Polygons

Figure 7-1 shows the configuration of polygons on the layout of the virtual environment. Polygons enabled the standardization of reconstituted routes on the paper layout. (See Appendix A for samples of participants' reconstituted routes and colour placements)

Figure 7-2 shows the frequency of route reconstitution through specific polygons at any point in the reconstituted route, by group. Both groups made 290 visits to one of the 30 polygons. Group I made 237 polygon visits to polygons 1-15 (polygons visited during the tour) and 53 polygon visits to polygons 16-30 (polygons not visited during the tour). Group II made 225 polygon visits to polygons 1-15 (polygons visited during the tour) and 65 polygon visits to polygons 16-30 (polygons not visited during the tour).

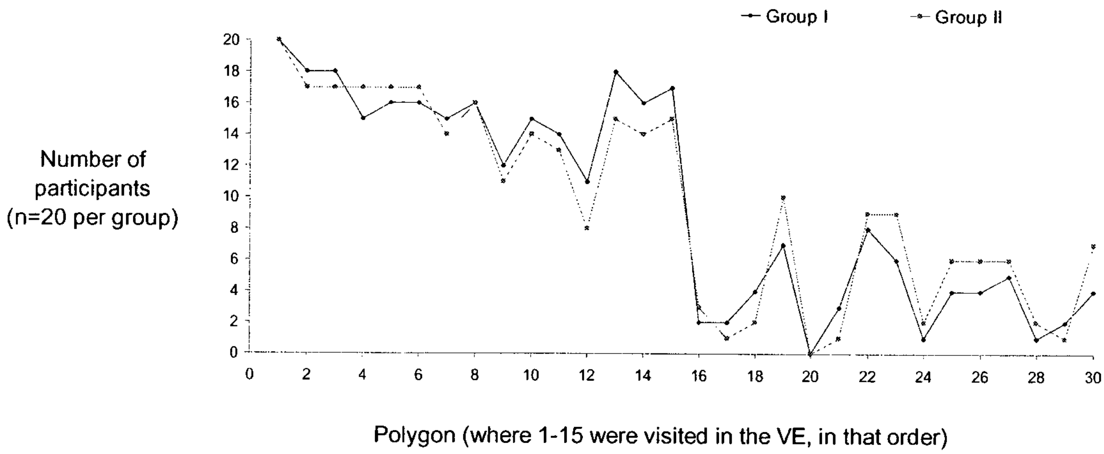

Figure 7-2: Number of participants who traveled through a polygon in any sequence, by group

Figures 7-3 and 7-4 show the number of participants who reconstituted their route through a particular polygon, in addition to showing the number of participants who reconstituted their route through the correct polygons (1-15) in the correct sequence, per group. In total, Group I made 172 visits to polygons 1-15 in the correct sequence, and Group II made 135 visits to polygons 1-15 in the correct sequence (see Table 7-1) (see Appendix B, Figure 11-3).

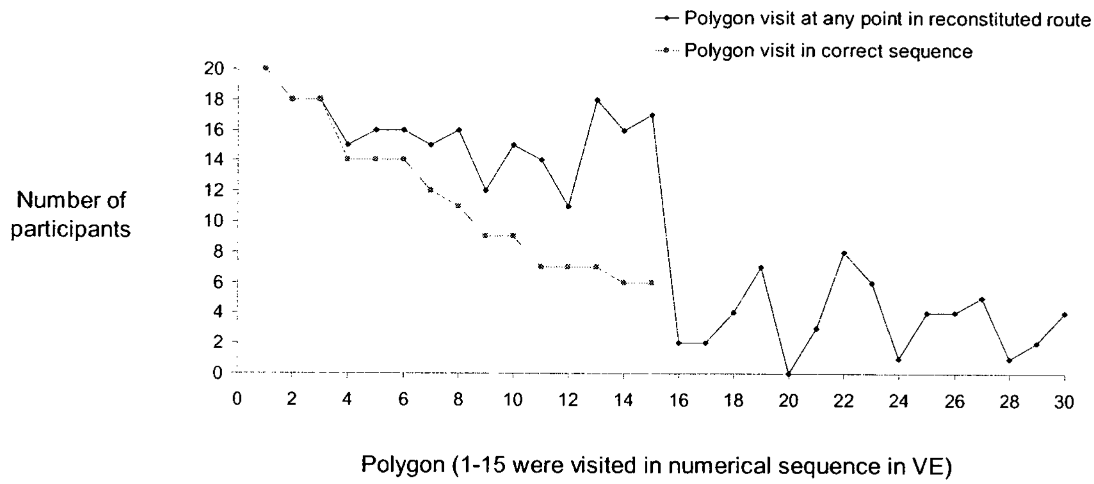

Figure 7-3: Number of participants who reconstituted their route through a particular polygon, Group I

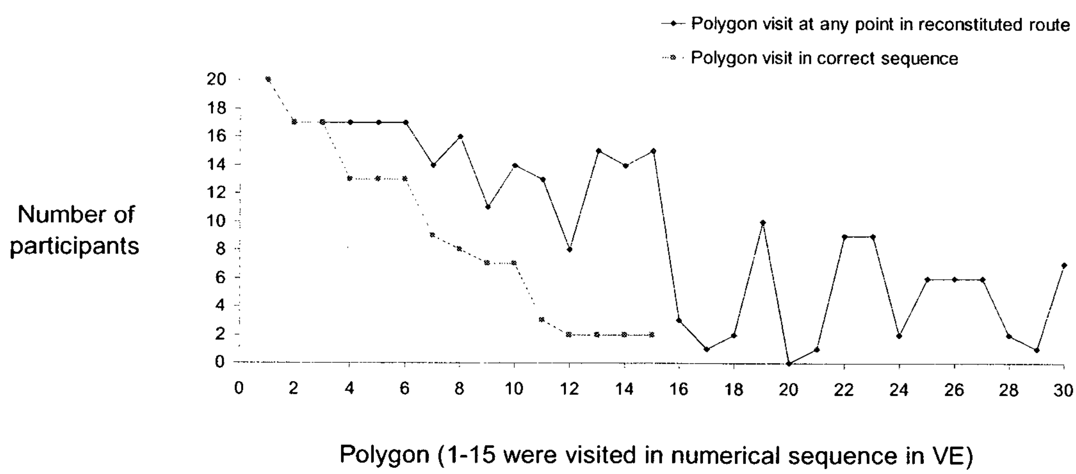

Figure 7-4: Number of participants who reconstituted their route through a particular polygon, Group II

	Group I (n=20)	Group II (n=20)	Total (n=40)
Total visits to polygons	290	290	580
Visits to polygons 1-15 in correct sequence	**172**	**135**	**307**
Visits to polygons 1-15 in incorrect sequence	65	90	155
Visits to polygons 16-30	53	65	118

Table 7-1: Polygon visits in reconstituted route, by group

7.2-Colour placement

Figure 7-5 shows the boundaries of the coloured spaces, within which a colour placement on the layout is considered correct. The colours can be found in the following polygons: BLUE (20), PINK (29), RED (30), PURPLE (11), ORANGE (12), YELLOW (17), and GREEN (15)[5].

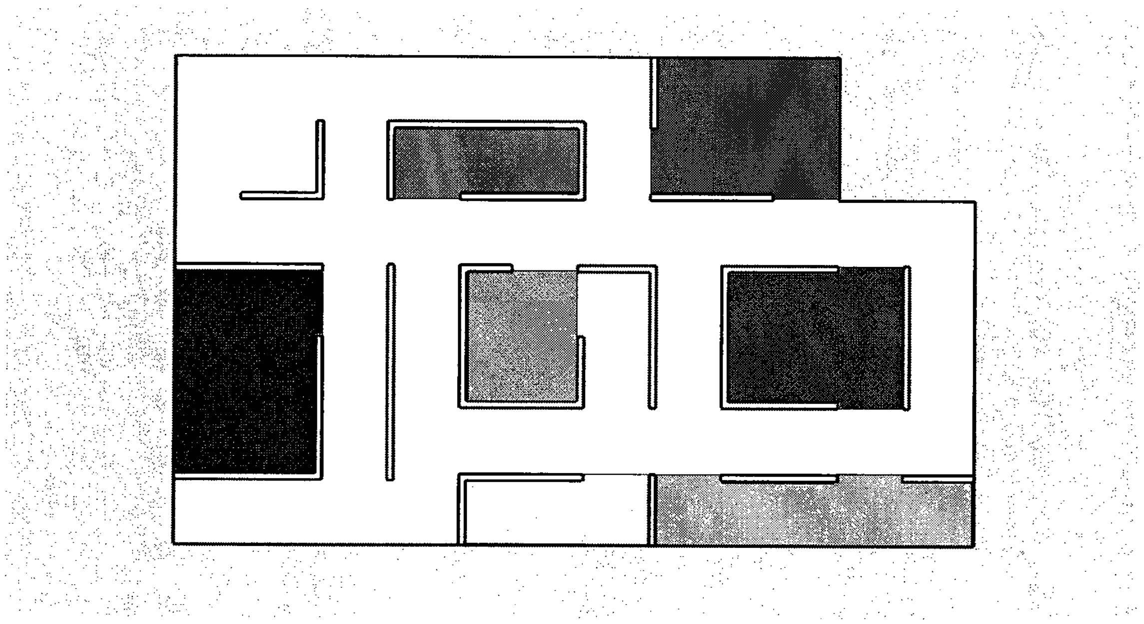

Figure 7-5: Colour boundaries in colour placement analysis

Figure 7-6 shows the number of participants who placed colours correctly on the layout, by group. Figures 7-7 shows the correct colour placement for coloured spaces not entered during the tour (*colours viewed*), and Figure 7-8 shows the correct colour placement for coloured spaces entered (or "walked through") during the tour (*colours visited*). Table 7-2 shows the number of colour placements by category.

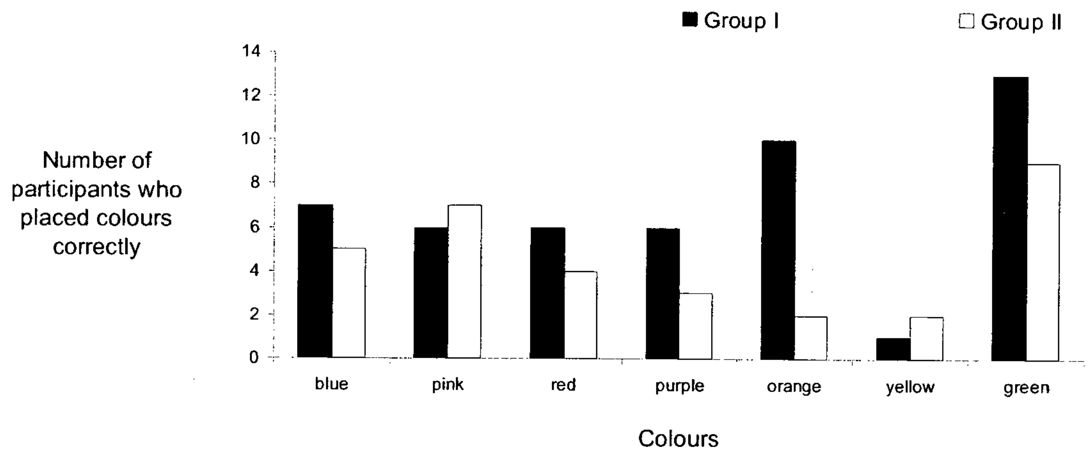

Figure 7-6: Correct colour placement, by group

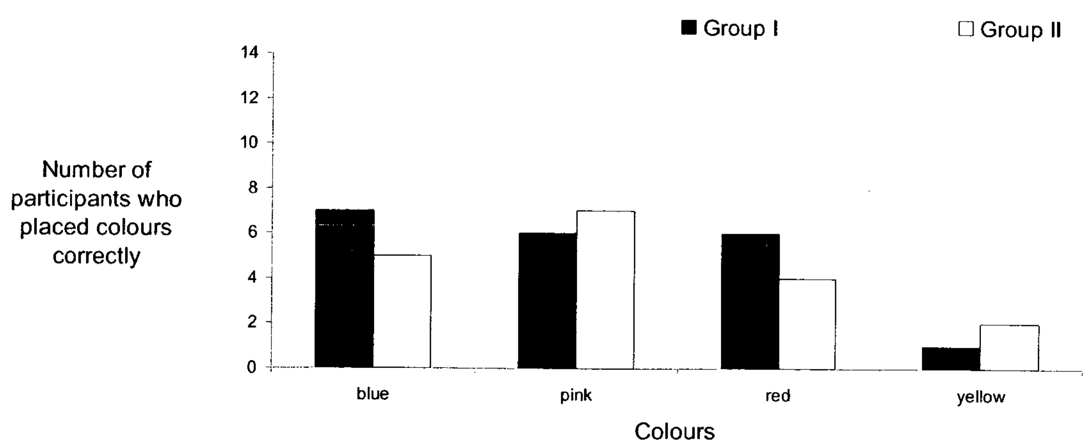

Figure 7-7: Correct colour placement of colour spaces not entered along route (*colour viewed*), by group

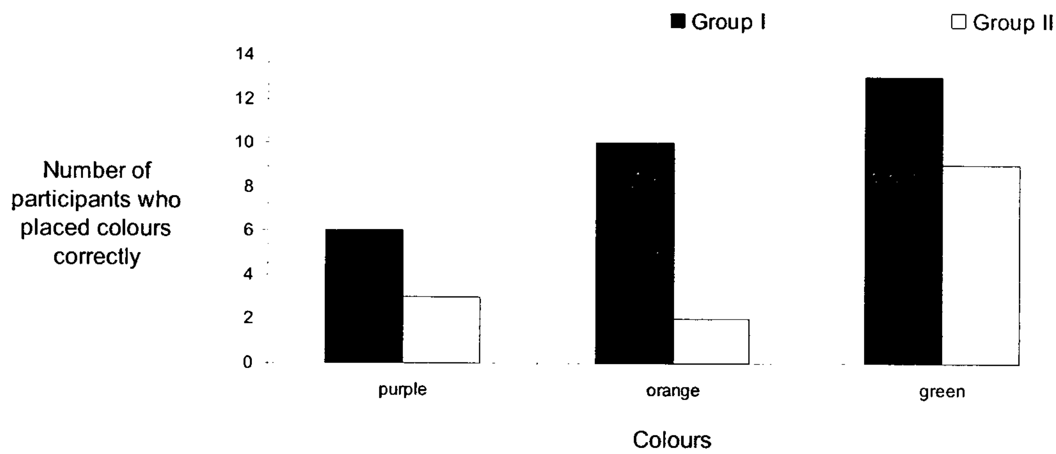

Figure 7-8: Correct colour placement of colour spaces entered along route (*colour visited*), by group

	Group I (n=20)	Group II (n=20)	Total (n=40)
Total colour placements (7 colours)	140	140	280
Total correct colour placements	49	32	81
Correct colour placements for colours visited in VE	29	14	43
Correct colour placements for colours not visited in VE	20	18	38

Table 7-2: Colour placements by category

Figure 7-9 shows the means of proportions of correct reconstitution of the itinerary and colour placement, by group.

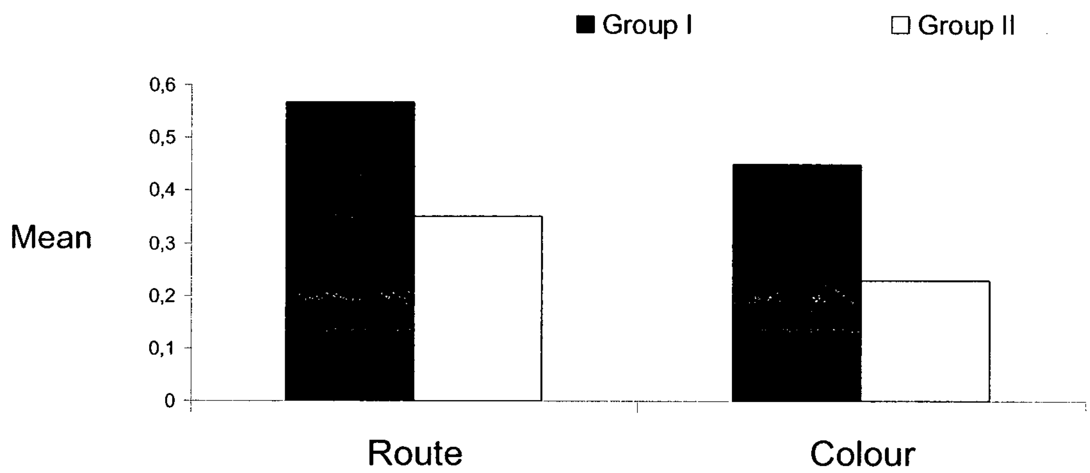

Figure 7-9: Means of proportion of correct reconstitution of the itinerary or colour placement, by group

7.3-Calculations[6]

7.3.1-Mann-Whitney *U*-test

Statistical analysis in the social sciences often uses parametric tests which require assumptions about the populations from which the samples where obtained. Non-parametric (or distribution-free) tests, however, can be used when the population distribution is unknown or unspecified (Burt & Barber, 1996). Non-parametric statistical tests are advisable when testing with small sample sizes due to the risk of undetected violations of the assumptions required for the successful use of a parametric test.

The Mann-Whitney *U*-test is one of the most powerful non-parametric tests (Siegel, 1956). It is a rank-order non-parametric test that corresponds to the parametric *t* test for independent means. A rank-order test is a type of data transformation for non-normal distributions that corrects for ties, thus the distribution of rank-order tests is known exactly since each value has an equal number of scores (one). Rank-order tests allow the use of actual scores as ranks.

Group scores were analyzed using the Mann-Whitney *U*-test (2-tailed), which indicated that there was no significant difference regarding this measure for order of recall:

Test	U	$U_{critical}$	variance (U)	p-value	alpha
Route reconstitution	141.500	112.500	575.302	0.234	0.05
Colours (overall)	34.500	24.500	60.442	0.221	0.05
Colours viewed	9.500	8.000	11.714	0.714	0.05
Colours visited	8.000	4.500	5.250	0.200	0.05

Table 7-3: Mann-Whitney *U*-test results for reconstituted route and colour placement

7.3.2-Pearson's product-moment correlation coefficient (Pearson's r)

Pearson's r was calculated to determine if there was a linear relationship between the route reconstitution and colour placement per group. The proportion of correct polygons visited (in the case of route reconstitution) and correct colour placement were used. To calculate the proportion of correct polygons visited per individual, the number of correct polygons visited was divided by the total number of polygons visited per individual (as the number visited in total varied by individual). To calculate the proportion correct for colour placement, the number of correct placements was divided by seven (the number of possible correct placements). These two proportions per individual were then used to calculate Pearson's r per group.

Both groups showed a moderately strong positive correlation. The correlation in Group I ($r = 0.7367$) was slightly stronger than the correlation in Group II ($r = 0.6582$) (see Appendix C for scatter plots and Appendix D for individual proportions).

8-Discussion

This project was undertaken to explore the differences in recall with respect to the reconstitution of a tour through a virtual environment. Spatial knowledge acquired on the tour was evaluated through the completion of two tasks: reconstitution of the itinerary and colour placement on a layout of the virtual environment. The results were then analyzed to determine if there was a significant difference between the performances of Group I (who completed the route task, followed by the colour task) and Group II (who completed the colour task, followed by the route task). Group scores were analyzed using a Mann-Whitney *U*-test, which indicated that there was no significant difference between the two groups.

However, to say that there is no difference between the two groups would be an over-simplification of the results. Indeed, Group I consistently reconstituted spatial knowledge with less error than Group II. What could explain the errors that were made by the groups (collectively or separately), and what might explain the differences in group performance?

8.1-Reconstitution of the itinerary

Group I and Group II reconstituted the itinerary on the layout of the virtual environment, and the routes were analyzed using polygons. Both groups made the same number of visits through a polygon (290), yet the distribution of these reconstituted routes is not the same.

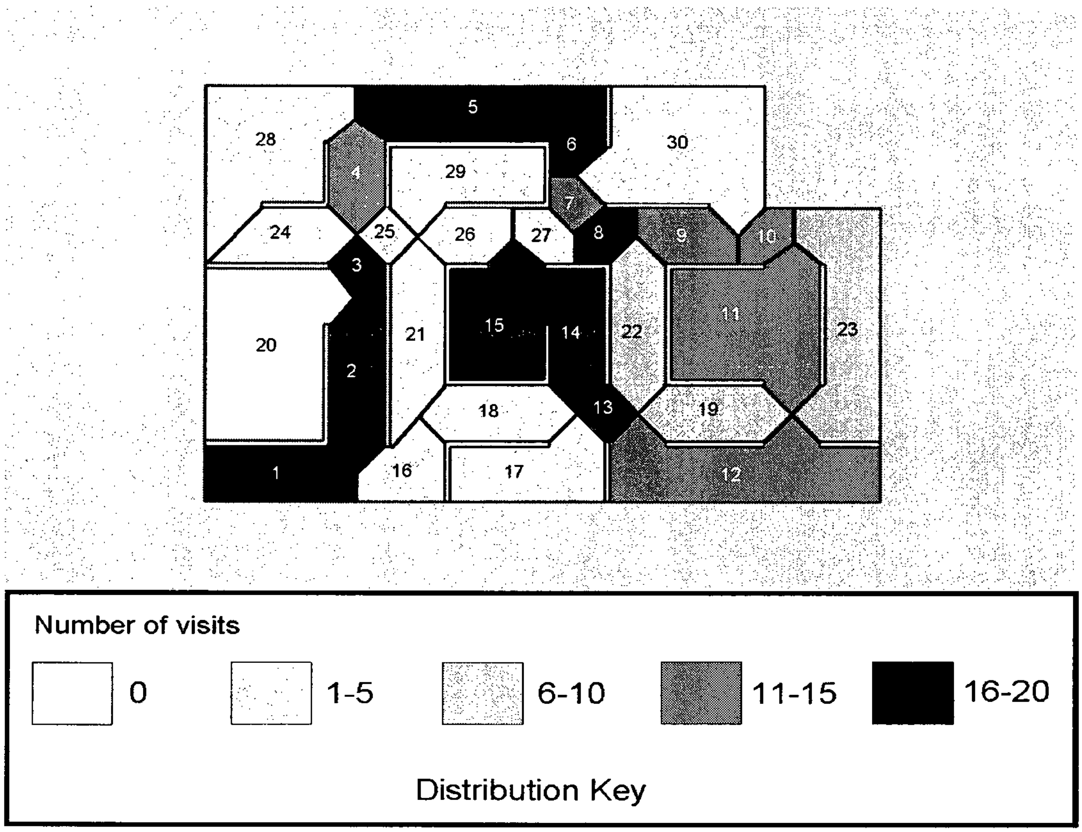

Figure 8-1: Group I reconstituted route distribution

Figures 8-1 and 8-2 show the distribution of reconstituted routes on the layout of the virtual environment. Group I tended to reconstitute routes through polygons 1-15 more than Group II (see Table 7-1). When participants in Group I made errors in their route, they drew the route through polygons 19, 22 and 23 whereas Group II participants additionally strayed (in larger number than Group I) into polygons 25, 26, 27 and 30. Participants in Group I correctly reconstituted their route through polygon 12 more often than participants in Group II. We can also see that polygon 8 acts as a hub for both groups.[7]

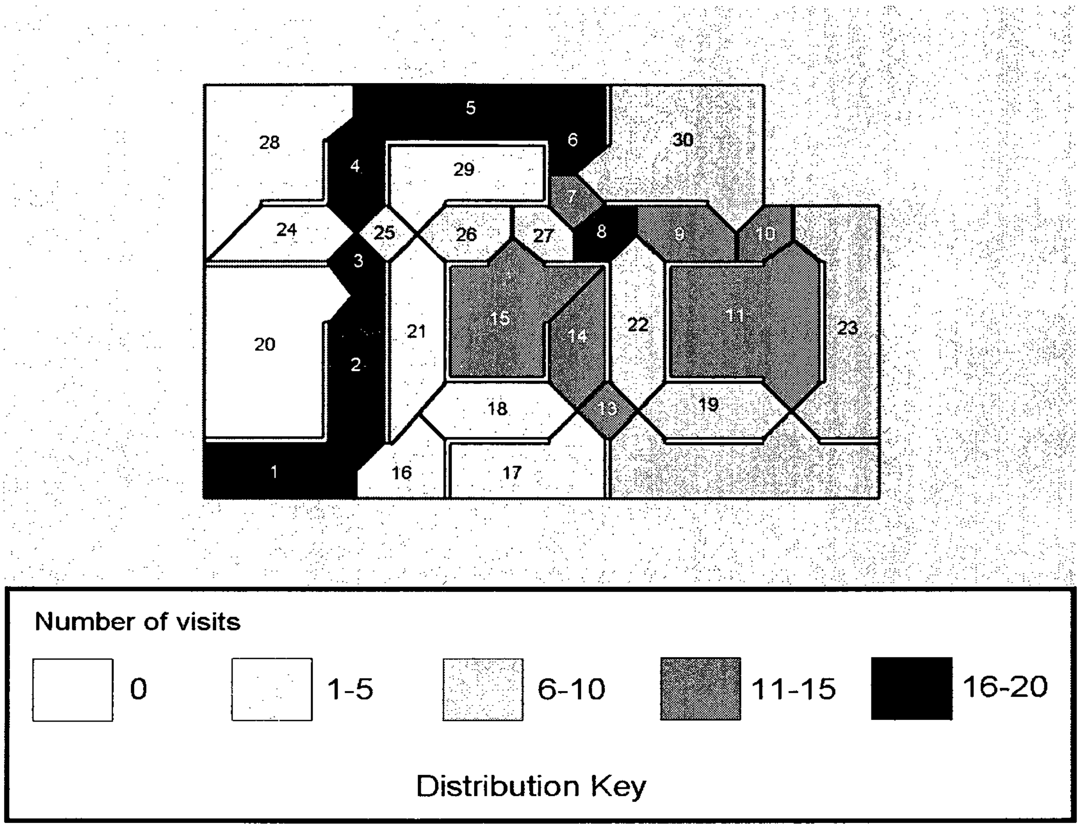

Figure 8-2: Group II reconstituted route distribution

Could possible direction choices at each polygon explain the mistakes being made? To exit polygon 3, there are four possible choices (straight ahead, turn 180°, turn 90° to the left or turn 90° to the right)— this is also true for polygon 11 and 13 (See Appendix E). However polygons 6, 8 and 10 have only three possible direction choices (and the correct choice for polygon 6 and 8 is straight ahead). Polygon 12 has four possible direction choices, yet no one makes their first error at polygon 12. The number of direction choices doesn't consistently explain the errors being made in the reconstitution of the itinerary.

Last successful polygon visit, by polygon	Number of participants: Group I	Proportion of participants*: Group I	Number of participants: Group II	Proportion of participants*: Group II
1	2	0.100	3	0.150
3	4	0.222	4	0.235
6	2	0.143	4	0.308
7	1	0.083	1	0.111
8	2	0.182	1	0.125
10	2	0.222	4	0.571
11	0	0	1	0.333
13	1	0.143	0	0

Table 8-1: Last successful polygon visited in reconstituted route, by group

*Note that the proportion includes only participants who have reconstituted the itinerary correctly up to and including the polygon in question.

Are participants making the correct direction choice, but at the wrong place? For example, participants may be making a 90° turn to the right at polygon 3 instead of continuing to polygon 4 and then (correctly) turning 90° to the right to enter polygon 5. The same can explain errors at polygon 6 where participants turn 90° to the left at polygon 6 (to enter polygon 30) instead of (correctly) continuing straight to polygon 7 and turning 90° to the left to enter polygon 8. Polygon 8 and polygon 10 may also be examples of turning too early (90° to the right at polygon 8 to enter polygon 22, instead of continuing straight to polygon 9 and 10, and then turning 90° to the right to enter polygon 11), or too late (continuing straight through polygon 10 to enter polygon 23, and then turning 90° to the right). Polygon 11 is another example of turning too early (90° turn to the right to enter polygon 19 instead of continuing straight into polygon 12, where one is forced to (correctly) turn 90° to the right or to (incorrectly) turn 90° to the left in polygon 12). This explanation would support the argument that participants may be remembering turn sequences, but is this the case?

Participant: Group I	Last correct polygon	Subsequent polygon entered incorrectly	Participant: Group II	Last correct polygon	Subsequent polygon entered incorrectly
I	1	16	1	1	16
P	1	16	4	1	16
A	3	24	19	1	16
G	3	25	5	3	25
K	3	25	7	3	24
L	3	25	14	3	25
H	6	30	20	3	24
Q	6	30	6	6	30
J	7	27	16	6	30
E	8	22	17	6	30
M	8	22	18	6	30
O	10	23	15	7	27
T	10	23	12	8	22
R	13	17	2	10	23
B	15	-	8	10	23
C	15	-	9	10	23
D	15	-	13	10	23
F	15	-	3	1	19
N	15	-	10	15	-
S	15	-	11	15	-

Table 8-2: Last correct polygon visited and subsequent polygon entered, by participant, for Group I and Group II

Looking at some examples of individual performance, 8 participants (from Group I and Group II) made their first error at polygon 3, where five of them made a 90° turn to the right to enter polygon 25 and the remaining three made a 90° to the left to enter polygon

24. Of the five who turned 90° to the right to enter polygon 25 (and thus may have made the right turn at the wrong location), none of them were able to reach the correct destination (polygon 15). These participants do not seem to be remembering turn sequences, nor have they accumulated enough survey knowledge to reach the correct destination (polygon 15) in their reconstituted route after making an error in the itinerary.

Participant: Group I	Last correct polygon	Correct polygon (#15) at destination	Correct green placement (polygon #15)
I	1		
P	1		
A	3	X	X
G	3		
K	3		
L	3		
H	6	X	X
Q	6	X	X
J	7		
E	8	X	X
M	8		X
O	10	X	X
T	10	X	X
R	13		
B	15	X	X
C	15	X	X
D	15	X	X
F	15	X	X
N	15	X	X
S	15	X	X
Total		**12**	**13**

Table 8-3: Destination polygon of reconstituted route, Group I

Participant: Group II	Last correct polygon	Correct polygon (#15) at destination	Correct green placement (polygon #15)
1	1	X	X
4	1		
19	1		
5	3		
7	3		
14	3		
20	3		
6	6	X	X
16	6	X	X
17	6		
18	6		
15	7		
12	8	X	X
2	10		
8	10	X	X
9	10	X	X
13	10	X	
3	1	X	X
10	15	X	X
11	15	X	X
Total		**10**	**9**

Table 8-4: Destination polygon of reconstituted route, Group II

Those who made their first error at polygon 10 had already successfully reconstituted two-thirds of the itinerary— Of the six participants who made their first error at polygon 10 (entering polygon 23 instead of turning 90° to the right to enter polygon 11), all but one reached the correct destination (polygon 15). In this case, it is possible that participants have remembered turn sequences. Possibly, these participants have acquired sufficient survey knowledge to reconstitute their route to reach polygon 15 even though they made an error in the itinerary as their reconstituted route exits polygon 10.

Indeed, Figures 8-3 and 8-4 show that at least half of the participants reconstituted their route to reach the correct destination of polygon 15. Twelve participants from Group I and ten participants from Group II reconstituted their route to include their destination in polygon 15. (Of these, all twelve participants from Group I and nine participants from Group II were also able to correctly place GREEN in polygon 15.)

Does the polygon where the error is made have any relationship with the ability of the participants to reach the destination (polygon 15)? Participants from Group I who reached the destination made their first error in polygons 3 (1 participant), 6 (2 participants), 8 (1 participant) and 10 (2 participants), and participants from Group II who reached the destination made their first error in polygons 6 (2 participants), 8 (1 participant), 10 (3 participants), 11 (1 participant) and 1 (1 participant). Thus, the polygon where the first error is made does not relate to the participants' ability to reconstitute their route to the correct destination polygon.

Overall, Group I made fewer errors in the reconstitution of the itinerary. Six participants from Group I were able to reconstitute the itinerary successfully and an additional six participants were able to reach the correct destination after making errors in the itinerary. Only two participants from Group II were able to reconstitute the itinerary correctly, and an additional eight participants were able to reach the correct destination after making errors in the itinerary. Comparatively, Group I participants were better able to reconstitute the itinerary and/or reach the correct destination, whereas Group II participants were less able to reconstitute the itinerary yet were successful, in slightly larger number than Group I, in reaching the correct destination polygon after making an error in the itinerary.

8.2-Reconstitution of colour location

Figure 8-3 shows where participants in each group placed *colours viewed.* The colour placements are scattered throughout the layout, but in some cases there are clusters of colour placements in or around the correct location. Comparing Group I BLUE and Group I RED colour placements, the clusters in and around the actual colour location are especially evident. Overall, Group I was more successful at placing *colours viewed* in the correct location.

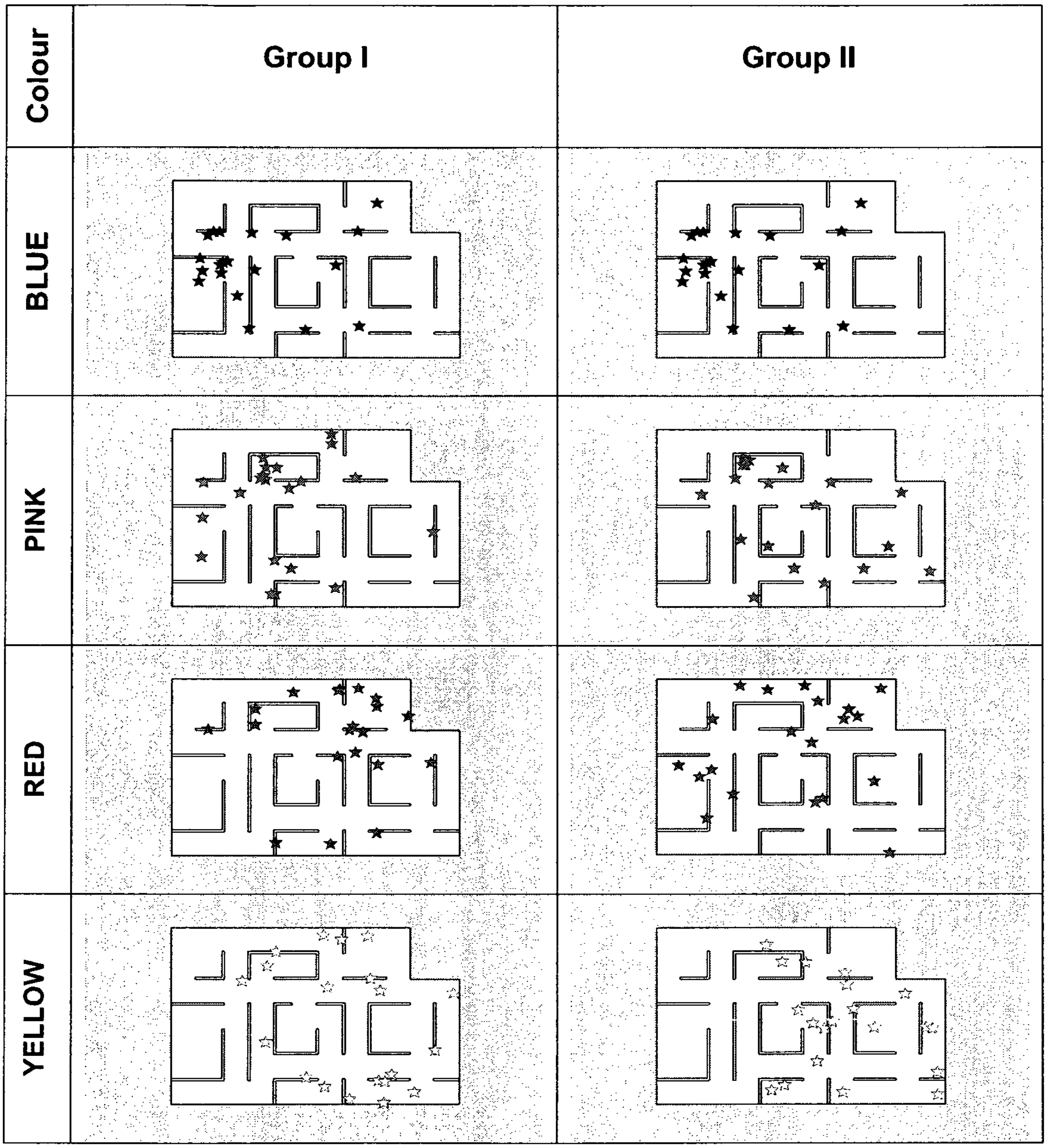

Figure 8-3: Colour placement charts— *colour viewed*

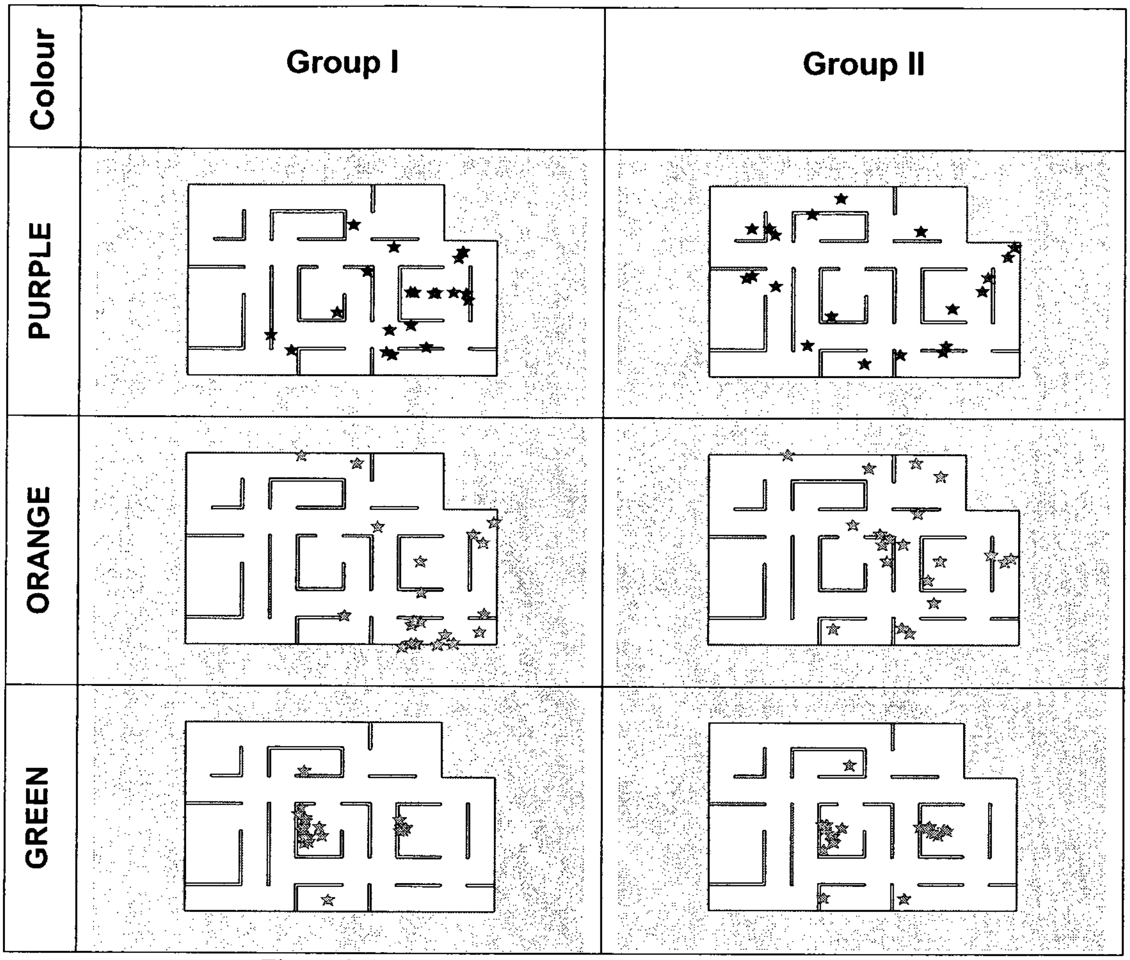

Figure 8-4: Colour placement charts— ***colour visited***

Figure 8-4 shows where participants in each group placed *colours visited.* Clustering is evident here as well. The placement of GREEN is of particular interest since the destination of the itinerary was in the same polygon as GREEN (polygon 15).

For Group I, 13 participants correctly placed GREEN in polygon 15 (and 12 of these participants also ended their route in polygon 15), and an additional five participants placed GREEN in polygon 11 *(which served as their destination point).* Group II participants placed GREEN in polygon 15 nine times (and all nine participants also ended their route in polygon 15), and an additional eight participants placed GREEN in polygon 11 (and seven of these participants also ended their route in polygon 11). Therefore, although many participants incorrectly placed GREEN in polygon 11, almost all participants, from both groups, correctly placed GREEN in the destination polygon of their reconstituted route.

Participant: Group I	Destination Polygon	GREEN Placement
A	15	15
B	15	15
C	15	15
D	15	15
E	15	15
F	15	15
G	11	11
H	15	15
I	11	11
J	11	11
K	11	11
L	11	11
M	29	15
N	15	15
O	15	15
P	29	29
Q	15	15
R	17	17
S	15	15
T	15	15

Table 8-5: Destination polygon of reconstituted route and GREEN placement, Group I participants

Participant: Group I	Destination Polygon	GREEN Placement
1	15	15
2	17	17
3	15	15
4	11	11
5	11	11
6	15	15
7	29	29
8	15	15
9	15	15
10	15	15
11	15	15
12	15	15
13	15	11
14	11	11
15	11	11
16	15	15
17	12	12
18	11	11
19	11	11
20	11	11

Figure 8-6: Destination polygon of reconstituted route and GREEN placement, Group II participants

The results show that Group I made less errors placing colours overall. Group I was more successful placing *colours visited* (29) than *colours viewed* (20). Group II was more successful placing *colours viewed* (18) than *colours visited* (14).

8.3-Correlation between route reconstitution and colour placement

Calculating Pearson's r revealed a moderately strong positive correlation for both groups with respect to the reconstitution of route and colour placement. The correlation in Group I ($r = 0.7367$) was slightly stronger than the correlation in Group II ($r = 0.6582$). Group I is more successful at reconstituting the itinerary and correctly placing the colours on the layout, but this does not mean that Group I should necessarily have a stronger correlation between these two variables. A possible explanation for this correlation could be that one type of spatial knowledge recall is informing the other— specifically, Group I was better able to place colours after reconstituting the route because the recall of the itinerary is informing the subsequent recall of the colour locations. Group II had more difficulty performing both tasks successfully, and the correlation between reconstituting the route and correctly placing the colours on the layout is not as strong as that of Group I. Therefore, when participants in Group I are better able to reconstitute the route, they are also better able to place colours in the correct location. In addition, when participants in Group I are less successful at reconstituting the route, they are also less successful at placing colours in the correct location. For Group II, this relationship is less strong. This may be because completing the colour task first did not help in the reconstitution of the itinerary as much as completing the route task first helped in identifying correct colour locations.

8.4-Effect size and power

In a two-tailed (or non-directional) test, the phenomenon is said to exist only if the parameters (mean, proportion, etc.) between two populations differ. The parameters may differ, but is the difference significant or not? In this experiment, the Mann-Whitney *U*-test has shown that the difference is not statistically significant; thus the null hypothesis cannot be rejected. When an experiment is unable to reject the null hypothesis and is found to have power that is low, one should "regard the negative results as ambiguous, since failure to reject the null hypothesis cannot have much substantive meaning when, even though the phenomenon exists (to some given degree), the *a priori* probability of rejecting the null hypothesis was low" (Cohen, 1988, p.4).

Effect size is best understood as a measure of the size of the "effect" of the independent variable (which, in the case of this project, is the order of recall tasks performed by participants). If the order of the recall tasks has no effect (i.e., the phenomenon does not exist), the effect size will be zero. The null hypothesis holds that there is no difference between the parameters of two populations and if there is no difference between the parameters of the two populations, the effect size will be zero. Therefore, effect size is "the degree to which the phenomenon is present in the population" or "the degree to which the null hypothesis is false" (Cohen, 1988, pp.9-10). When the null hypothesis is true, the effect size can be treated as a parameter which takes on the value of zero. If the null hypothesis has not been rejected yet the effect size is not zero, there is indeed an effect, even though the effect may not be a statistically significant one.

In order to determine if the difference in the means for *each* polygon (those visited during the tour) and *each* colour placement was an important difference (even if overall the difference per group was not significant), the magnitude of effect size was determined (see Tables 8-7 and 8-8).

The formula used was Cohen's *h*, calculated as $h = |\Phi_1 - \Phi_2|$ (non-directional), where Φ_1 is the transformation of the proportions of Group I, and Φ_2 is the transformation of proportions of Group II. Cohen (1988) defined three levels of *h* used to determine effect size: small, medium and large. A small effect size is represented by values between 0.20 - 0.49, a medium effect size is represented by values between 0.50 – 0.79, and a large effect size is represented by values larger than 0.80.

Polygon	Group I Proportions	Group II Proportions	Grp. I Φ	Grp. II Φ	*h*-values	Effect Size	Power
1	1	1	3.142	3.142	0	small	0
2	0.90	0.85	2.489	2.346	0.143	small	8
3	0.90	0.85	2.489	2.346	0.143	small	8
4	0.70	0.65	1.982	1.875	0.107	small	6
5	0.70	0.65	1.982	1.875	0.107	small	6
6	0.70	0.65	1.982	1.875	0.107	small	6
7	0.60	0.45	1.772	1.471	0.301	small	16
8	0.55	0.40	1.671	1.369	0.302	small	16
9	0.45	0.35	1.471	1.266	0.205	small	10
10	0.45	0.35	1.471	1.266	0.205	small	10
11	0.35	0.15	1.266	0.795	0.471	small	35
12	0.35	0.10	1.266	0.644	0.622	medium	50
13	0.35	0.10	1.266	0.644	0.622	medium	50
14	0.30	0.10	1.159	0.644	0.515	medium	35
15	0.30	0.10	1.159	0.644	0.515	medium	35

Table 8-7: Effect size and power values for polygons visited during the tour

Colours	viewed or visited	Group I Proportions	Group II Proportions	Grp.I Φ	Grp.II Φ	*h*-values	Effect Size	Power
Blue	viewed	0.35	0.25	1.266	1.047	0.219	small	11
Pink	viewed	0.30	0.35	1.159	1.266	0.107	small	6
Red	viewed	0.30	0.20	1.159	0.927	0.232	small	12
Purple	visited	0.30	0.15	1.159	0.795	0.364	small	20
Orange	visited	**0.50**	**0.10**	**1.571**	**0.644**	**0.927**	**large**	**82**
Yellow	viewed	0.05	0.10	0.451	0.644	0.193	small	9
Green	visited	0.65	0.45	1.875	1.471	0.404	small	24

Table 8-8: Effect size and power values for colours

Although the data do not allow for the conclusion that the parameters between Group I and Group II differ significantly, there *is* a difference. Effect sizes were calculated for each of the polygons that were visited during the tour and for each of the colours— for most polygons, the effect size is small (where only polygon 1 showed no effect since participants had no choice but to reconstituted their route through polygon 1). For polygon 12 through 15, there is a medium effect size. This is reflected in the distribution figures (Figures 8-1 and 8-2), which show a difference in the number of participants who reconstituted their route through these polygons. However, the small effect size does not reflect the visual difference seen in the distribution figures for polygon 4. This is important to note, since different visual representations of data can be misleading— here, the effect size gives a solid number with which to determine the actual difference of performance between the two groups with respect to specific polygons. In reality, the difference in the distribution between the two groups, for polygon 4, is only one participant.

Effect sizes for colours are small (0.107-0.404), with the exception of ORANGE, which has a large effect size (0.927). The performance of individuals with respect to the placement of ORANGE is interesting, since10 participants in Group I placed ORANGE correctly yet only two participants in Group II placed ORANGE correctly. The reason for the difference of this one colour cannot be explained by the results obtained in this experiment.

The power values represent the probability that the test will yield a significant result. In the case of the power values for the polygons, the largest value is 50, thus the test is not very powerful. In the case of the colour placements, power values go as high as 82 (for ORANGE), but otherwise range from 6- 24. In order to increase the power of the test, the sample size would have to be increased.

Effect size can be used to establish the number of participants needed to maximize the power of an experiment (Cohen, 1988). With the current results, a sample group of at least 200 (Group I n= 100 and Group II n= 100) would be needed in order to maximize the power of the experiment and increase effect sizes (so, for example, at least half the polygons would have a medium-to-large effect size).

As human geographers often work with a lack of sufficient (and designated) space to conduct experiments, testing is usually conducted in temporarily available space—classrooms, science labs, colleagues' or supervisors' offices, or even storage spaces—that have to be set-up and dismantled repeatedly. Methodologies (especially those that involve virtual environments as testing tools) usually require one-on-one testing of participants; Sample sizes are thus necessarily small in order to successfully conduct the experimental phase of a research project in a reasonable length of time (Golledge et al., 1995). In addition, finding university students in the department who are willing to participate during their semester (and who are available when the space is available) is an additional challenge. This researcher struggled to find even 40 subjects who met the criteria, especially after a considerable number of potential participants were exposed to some version of the virtual environment in the pre-testing phase. The exploratory nature of this project makes the number of participants less of a concern; however, any conclusions drawn from the results must include the recognition of a small sample size.

9-Conclusion

9.1-Results

Group I performed the route task followed by the colour task, and Group II performed the colour task followed by the route task. Group I was better able to reconstitute the itinerary and place colours in the correct location. In addition, Group I had a stronger correlation between the two recall tasks.

Although the results are not statistically significant, there is an effect of the order of the tasks performed. It would seem that recall of colour locations did not help in the reconstitution of the itinerary as much as recall of the itinerary helped in identifying colour locations: i.e., the first recall task appears to be influencing the succeeding recall task. The nature of this relationship remains unclear, and the lack of power of the experiment makes any broad conclusions impossible. Nevertheless, these results have implications for future research and address current debates in the field.

9.2-My contribution to the study of spatial knowledge

The biggest challenge that spatial knowledge researchers face is that of trying to reach conclusions about internal spatial representations using external (symbolic) spatial representations. For example, the way spatial knowledge is recalled or reconstituted (i.e., externalized) may or may not tell us something about how spatial knowledge is acquired, coded or stored (i.e., internalized). Golledge (1999b) warns that reconstituted "spatial products" may not accurately reflect stored spatial knowledge or that reconstituted spatial knowledge may be tainted by the methods used to externalize internal spatial representations (such as observed behaviour, verbal or written directions, or map-drawing skills). Passini (1984) argues that spatial information is lost or transformed when one attempts to externalize it— specifically, individuals with identical spatial knowledge can produce different results when asked to reconstitute spatial knowledge due to varying strategies of thought or decoding (Kitchin, 1997). With this in mind, are we able to conclude anything at all about internal representations based on results obtained from analyzing external spatial representations? Indeed, researchers must be cautious in their conclusions.

Taylor and Tversky (1992) warn us that task expectations may influence how and what participants remember- as there is no way of knowing what exactly was going through participants' minds during the exploration of the virtual environment (i.e., were they attempting to guess what the tasks would be, which in turn influenced the acquisition, coding and storage of spatial knowledge), it is difficult to discount this effect on participants' abilities to acquire configurational knowledge and later recall and reconstitute the itinerary and colour placement.

Anooshian (1996) states that procedural measures and place measures are tied to different types of "remembering" (Anooshian, 1996, p.476), thus there should be no effect of the order of recall tasks if these two types of spatial memory are stored independently. However, the results of this project show that one type of spatial knowledge recall is influencing another. Based on the results of this research project, it would appear that there is a relationship between different types of spatial knowledge in spatial memory and recall, where reconstitution of the route is influencing the reconstitution of the colour placement.

This project was designed as an exploration, undertaken with the intention of expanding on the theoretical basis of spatial knowledge recall and of informing future research methods. I believe that these types of explorations are essential to the future growth of the field of spatial knowledge research. With this project, I have addressed the need to question current theoretical assumptions, as well as provided evidence that there may be some effect of recall differences on spatial knowledge reconstitution.

9.3-Recommendations

There are numerous improvements that could be made to this study. A small sample size has limited this study in the conclusions that can be made, and it has decreased the power of the experiment significantly. The reconstitution of spatial knowledge on paper layouts also limited the type of analyses that could be conducted— had participants be able to reconstitute their route and colour placement in the virtual environment, additional analyses could have been conducted, such as distance and direction recall, order of colour placement, the time required to reconstitute spatial knowledge, trial and error behaviour, etc...

9.4-Implications

Researchers must be mindful of the need for further testing of spatial knowledge recall and reconstitution as well as the ways in which current research design and methodologies may be distorting or biasing results. Researchers must also determine if balancing (for example, alternating methods of acquiring spatial knowledge or the tasks given to recall/reconstitute spatial knowledge) is necessary to maintain integrity in their work. If balancing is not necessary, many tests and calculations that are currently being done can be deemed unnecessary. If balancing is necessary, this area of inquiry warrants further research to ensure an understanding of how recall tasks may be influencing the variables being tested.

---

[1] "Mapped imagery" is Orleans (1973) term for a reconstituted cognitive map.
[2] "...a streaming or outflow of features from a center of expansion in the field of view accompanying forward motion..." (Gibson, 1979; in Heft and Nasar, 2000, p.303).
[3] "...differential rates of movement of stationary objects as a function of their relative distances from the perceiver..." (Gibson, 1979; in Heft and Nasar, 2000, p.303).
[4] "...the gradual covering and uncovering of objects behind other objects..." (Gibson, 1979; in Heft and Nasar, 2000, p.303).
[5] The colours reproduced here do not necessarily reflect the colours as they were seen in the virtual environment do to changes that occur when switching media (i.e., colours as viewed on screen compared to colours as viewed on paper).
[6] *XLSTAT* software was used for calculations.
[7] These distributions do not account for the sequence in which the polygons were entered. In other words, even though 16-20 participants entered polygon 8, they may have entered polygon 7, 9, 22 or 27 to get there. Thus, the distribution figure can correctly show 16-20 participants reconstituted their route through polygon 8 while only 11-15 participants reconstituted their route through polygon 7.

10-References

Aginsky, V., Harris, C., Rensink, R., & Beusmans, J. (1997). Two strategies for learning a route in a driving simulator. *Journal of Environmental Psychology, 17*, 317-331.

Allen, G.L. (1999). Spatial Abilities, Cognitive Maps, and Wayfinding: Bases for Individual Differences in Spatial Cognition and Behavior. In R. Golledge (ed.), *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes* (pp.46-80). Baltimore, Maryland: The John Hopkins University Press.

Anooshian, L.J. (1996). Diversity within spatial cognition: Strategies underlying spatial knowledge. *Environment and Behavior, 28*, 471-493.

Appleyard, D. (1969). City designers and the pluralistic city. In L.Rowin et al. (eds), *Planning, Urban Growth and Regional Development: the experience of the Guayana Program of Venezuela* (pp.422-452), Cambridge, MA: MIT Press.

Arthur, P. & Passini, R. (1992). *Wayfinding: People, signs and architecture.* New York: McGraw-Hill.

Arthur, E.J., Hancock, P.A., & Chrysler, S.T. (1997). The perception of spatial layout in real and virtual worlds. *Ergonomics, 40*, 69-77.

Arthur, E., & Hancock, P.A. (2001). Navigation Training in Virtual Environments. *International Journal of Cognitive Ergonomics, 5*, 387-400.

Bagulay, T., Lansdale, M.W., Lines, L.K., & Parkin, J.K. (2006). Two spatial memories are not better than one: Evidence of exclusivity in memory for object location. *Cognitive Psychology, 52*, 243-289.

Baskaya, A., Wilson, C., & Özcan, Y. (2004). Wayfinding in an unfamiliar environment: Different spatial settings of two polyclinics. *Environment and Behavior*, *36*, 839-867.

Belingard, L., & Péruch, P. (2000). Mental representation and the spatial structure of virtual environments. *Environment and Behavior*, *32*, 427-442.

Bernard, H.R. (1995). *Research Methods in Anthropology: Qualitative and Quantitative Approaches*. Walnut Creek, California: AltaMira Press.

Best, G.A. (1970). Direction-finding in large buildings. In D. Canter (ed.), *Architectural psychology* (pp.72-91). London:RIBA.

Brockmole, J.R., & Wang, R.F. (2002). Switching between environmental representations in memory. *Cognition*, *83*, 295-316.

Burt, J.E., & Barber, G.M. (1996). *Elementary Statistics for Geographers*. New York: The Gilford Press.

Chen, J.L., & Stanney, K.M. (1999). A Theoretical Model of Wayfinding in Virtual Environments: Proposed Strategies for Navigational Aiding. *Presence*, *8*, 671-685.

Choi, J., McKillop, E., Ward, M., & L'Hirondelle, N. (2006). Sex-specific relationships between route-learning strategies and abilities in a large-scale environment. *Environment and Behavior, 38,* 791-801.

Chown, E. (1999). Error Tolerance and Generalization in Cognitive Maps: Performance Without Precision. In R. Golledge (ed.), *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes* (pp.349-369). Baltimore, Maryland: The John Hopkins University Press.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences.* Hillsdale, New Jersey: Lawrence Erlbaum Associates, Inc., Publishers.

Coulelis, H., Golledge, R.G., Gale, N., & Tober, W. (1987). Exploring the anchor-point hypothesis of spatial cognition. *Journal of Experimental Psychology*, *7*, 99-122.

Cubukcu, E., & Nasar, J.L. (2005). Relation of physical form to spatial knowledge in large-scale virtual environments. *Environment and Behavior*, *37*, 397-417.

Darken, R.P., & Sibert, J.L. (1996). Wayfinding Strategies and Behaviors in Large Virtual Worlds. *ACM SIGCHI 96*, 142-149.

Darken, R.P, Allard, T., & Achille, L.B. (1999). Spatial Orientation and Wayfinding in Large-Scale Virtual Spaces II: Guest Editors' Introduction. *Presence, 8*, iii-vi.

De Kort, Y.A.W., Ijsselsteijn, W.A., Kooijman, J., & Schuurmans, Y. (2003). Virtual Laboratories: Comparability of Real and Virtual Environments for Environmental Psychology. *Presence, 12*, 360-373.

Dogu, U., & Erkip, F. (2000). Spatial factors affecting wayfinding and orientation: A case in a shopping mall. *Environment and Behavior, 32*, 731-755.

Downs, R.M., & Stea, D. (1973a). *Image and Environment: Cognitive Mapping and Spatial Behavior.* Chicago, Illinois: Aldine Publishing Company

Downs, R.M., & Stea, D. (1973b). Cognitive Maps and Spatial Behavior: Process and Products. In R.M. Downs & D. Stea (eds.), *Image and Environment: Cognitive Mapping and Spatial Behavior* (pp.8-26). Chicago, Illinois: Aldine Publishing Company.

Evans, G.W., Marrero, D.G., & Butler, P.A. (1981). Environmental learning and cognitive mapping. *Environment and Behavior, 13*, 83-104.

Foo, P., Warren, W.H., Duchon, A., & Tarr, M. (2005). Do Humans Integrate Routes Into a Cognitive Map? Map- Versus Landmark-Based Navigation of Novel Shortcuts. *Journal of Experimental Psychology, 31*, 195-215.

Foreman, N., Stanton-Fraser, D., Wilson, P.N., Duffy, H., & Parnell, R. (2005). Transfer of spatial knowledge to a two-level shopping mall in older people, following virtual exploration. *Environment and Behavior, 37*, 275-292.

Frick, R.W. (1995). Accepting the null hypothesis. *Memory & Cognition, 23*, 132-138.

Gärling, T., Böök, A., Lindberg, E., & Nilsson, T. (1981). Memory for the spatial layout of the everyday physical environment: factors affecting rate of acquisition. *Journal of Environmental Psychology, 1*, 263-277.

Gibbons, J.D. (1993a). *Nonparametric Statistics: An Introduction*. Newbury Park, California: SAGE Publications, Inc.

Gibbons, J.D. (1993b). *Nonparametric Methods for Quantitative Analysis.* Columbus, Ohio: American Sciences Press, Inc.

Golledge, R.G. (1991). Cognition of physical and built environments. In T. R. Gärling & W. Evans (eds.), *Environment, cognition, and action: An integrated approach* (pp.35-62). New York: Oxford University Press.

Golledge, R.G. (1999a). *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes*. Baltimore, Maryland: The John Hopkins University Press.

Golledge, R.G. (1999b). Human Wayfinding and Cognitive Maps. In R. Golledge (ed.), *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes* (pp.5-45). Baltimore, Maryland: The John Hopkins University Press.

Golledge, R.G., Dougherty, V., & Bell, S. (1995). Acquiring Spatial Knowledge: Survey Versus Route-Based Knowledge in Unfamiliar Environments. *Annals of the Association of American Geographers, 85,* 134-158.

Hahm, J., Lee, K., Lim, S.-L., Kim, S.-Y., Kim, H.-T., & Lee, J.-H. (2007). Effects of active navigation on object recognition in virtual environments. *CyberPsychology & Behavior*, *10*, 305-308.

Hart, R.A., & Moore, G.T. (1973). The Development of Spatial Cognition: A Review. In R.M. Downs & D. Stea (eds.), *Image and Environment: Cognitive Mapping and Spatial Behavior* (pp.148-161). Chicago, Illinois: Aldine Publishing Company.

Heft, H. & Nasar, J.L. (2000). Evaluating environmental scenes using dynamic versus static displays. *Environment and Behavior*, 32, 301-322.

Horan, M. (1999). What Students See: Sketch Maps as Tools for Assessing Knowledge of Libraries. *The Journal of Academic Librarianship, 25,* 187-201.

Jacobson, D., Lippa, Y., Golledge, R.G., Kitchin, R., & Blades, M. (2001). Rapid development of cognitive maps in people with visual impairments when exploring novel geographic spaces. *Bulletin of people-environment studies*, 1-8.

Jansen-Osmann, P., & Berendt, B. (2002). Investigating distance knowledge using virtual environments. *Environment and Behavior, 34*, 178-193.

Jansen-Osmann, P., & Weidenbauer, G. (2004). The representation of landmarks and routes in children and adults: A study in a virtual environment. *Journal of Environmental Psychology, 24*, 347-357.

Kim, Y.O., & Penn, A. (2004). Linking the spatial syntax of cognitive maps to the spatial syntax of the environment. *Environment and Behavior*, *36*, 483-504.

Kitchin, R.M. (1997). Exploring Spatial Thought. *Environment and Behavior*, *29*, 123-156.

Kitchin, R.M., & Fotheringham, A.S. (1997). Aggregation Issues in Cognitive Mapping. *Professional Geographer, 49*, 269-280.

Kitchin, R.M., Blades, M., & Golledge, R.G. (1997) Understanding spatial concepts at the geographic scale without the use of vision. *Progress in Human Geography, 21*, 225-242.

Klatzky, R.L., Loomis, J.M., Beall, A.C., Chance, S.S., & Golledge, R.G. (1998). Spatial Updating of Self-position and Orientation During Real, Imagined, and Virtual Locomotion. *Psychological Science*, 9, 293-297.

Kuipers, B. (1982). The "map in the head" metaphor. *Environment and Behavior, 14,* 202-220.

Lathrop, W.B., & Kaiser, M.K. (2005). Acquiring Spatial Knowledge While Traveling Simple and Complex Paths with Immersive and Nonimmersive Interfaces. *Presence, 14*, 249-263.

Lynch, K. (1960). *Image of the city.* Cambridge, MA: MIT Press.

Mallot, H.A., & Gilner, S. (2000). Route navigating without place recognition: What is recognized in recognition-triggered responses? *Perception*, *29*, 43-55.

McCormack, G.R., Cerin, E., Leslie, E., Du Toit, L., & Owen, N. (2008). Objective Versus Perceived Walking Distances to Destinations : Correspondence and Predictive Validity. *Environment and Behavior, 40*, 401-425.

Murakoshi, S., & Kawai, M. (2000). Use of knowledge and heuristics for wayfinding in an artificial environment. *Environment and Behavior*, *32*, 756-774.

Murray, C.D., Bowers, J.M., West, A.J., Pettifer, S., & Gibson, S. (2000). Navigation, Wayfinding, and Place Experience within a Virtual City. *Presence, 9*, 435-447.

Nohara, Y., & Mori, K. (2002). Can Man recognize the space by seeing video information?: The comparison between wayfinding behaviors in video-environment and real environment. From *Proceedings of the 5th EBRA International Symposium*, China.

O'Keefe, J., & Nadel, L. (1978). *The hippocampus as a cognitive map*. Oxford: Oxford University Press.

O'Neill, M.J. (1991a). Effects of signage and floor plan configuration on wayfinding accuracy. *Environment and Behavior, 23*, 553-574.

O'Neill, M.J. (1991b).Evaluation of a conceptual model of architectural legibility. *Environment and Behavior, 23*, 259-284.

Orleans, P. (1973). Differential Cognition of Urban Residents: Effects of Social Scale on Mapping. In R.M. Downs & D. Stea (eds.), *Image and Environment: Cognitive Mapping and Spatial Behavior* (pp.148-161). Chicago, Illinois: Aldine Publishing Company.

Passini, R. (1984). *Wayfinding in architecture.* New York, NY: Van Nostrand Reinhold Company.

Péruch, P., Vercher, J-L., & Gauthier, G.M. (1995). Acquisition of Spatial Knowledge Through Visual Exploration of Simulated Environments. *Ecological Psychology, 7,* 1-20.

Riecke, B.E., van Veen, H.A.H.C, & Bulthoff, H.H. (2002). Visual Homing Is Possible Without Landmarks: A Path Integration Study in Virtual Reality. *Presence*, *11*, 443-473.

Rossano, M.J., & Reardon, W.P. (1999). Goal specificity and the acquisition of survey knowledge. *Environment and Behavior, 31,* 395-412.

Ruddle, R.A., Payne, S.J., & Jones, D.M. (1997). Navigating Buildings in "Desk-Top" Virtual Environments: Experimental Investigations Using Extended Navigational Experience. *Journal of Experimental Psychology, 3,* 143-159.

Saarinen, T.F. (1973). Student views of the world. In R.M. Downs & D. Stea (eds.), *Image and Environment: Cognitive Mapping and Spatial Behavior* (pp.148-161). Chicago, Illinois: Aldine Publishing Company.

Sadalla, E.K., & Montello, D.R. (1989). Remembering changes in direction. *Environment and Behavior, 21,* 346-363.

Schneider, L.F., & Taylor, H.A. (1999). How Do You Get There from Here? Mental Representations of Route Descriptions. *Applied Cognitive Psychology, 13,* 415-441.

Siebert, P.S., & Anooshian, L.J. (1993). Indirect expression of preference in sketch maps. *Environment and Behaviour, 25,* 607-624.

Siegel, S. (1956). *Nonparametric Statistics for the Behavioral Sciences*. New York: McGraw-Hill Book Company, Inc.

Siegel, A.W., & White, S.H. (1975). The development of spatial representations of large-scale environments. In H.W. Reese (ed.), *Advances in child development and behavior: Vol.10* (pp.9-55). New York: Academic Press.

Stamps, A.E. (2005a). Enclosure and safety in urbanscapes. *Environment and Behavior, 37,* 102-133.

Stamps, A.E. (2005b). Isovists, enclosure, and permeability theory. *Environment and Planning B: Planning and Design*, *32,* 735-762.

Stamps, A.E. (2005c). Visual permeability, locomotive permeability, safety, and enclosure, *Environment and Behavior*, *37*, 587-619.

Stankiewicz, B.J., & Kalia, A.A. (2007). Acquisition of Structural Versus Object Landmark Knowledge. *Journal of Experimental Psychology, 33,* 378-390.

Stanney, K.M., Kingdon, K.S., & Graeber, D. (2002). Human Performance in Immersive Virtual Environments: Effects of Exposure Duration, User Control, and Scene Complexity. *Human Performance, 15*, 339-366.

Steck, S.D., & Mallot, H.A. (2000). The Role of Global and Local Landmarks in Virtual Environment Navigation. *Presence*, 9, 69-83.

Taylor, H.A., & Tversky, B. (1992). Descriptions and depictions of environments. *Memory & Cognition, 20*, 483-496.

Tlauka, M., & Wilson, P.N. (1996). Orientation-free representations from navigation through a computer-simulated environment. *Environment and Behavior, 28*, 647-664.

Tolman, E.C. (1948). Cognitive maps in rats and men. *Psychological Review, 56*, 144-155.

Tuan, Y.-F. (1975). Images and Mental Maps. *Annals of the Association of American Geographers*, *65*, 205-213.

Turner, P., & Turner, S. (2006). Place, sense of place, and presence. *Presence, 15,* 204-217.

Tversky, B. (1981). Distortions in memory for maps. *Cognitive Psychology*, *13*, 407-433

Van Ommen, C., & Painter, D. (2005). Mapping east London: Sketching identity through place. *South African Journal of Psychology*, *35*, 505-531.

Vidal, M., Amorim, M-A., & Berthoz, A. (2004). Navigating in a three-dimensional maze: how do egocentric and allocentric reference frames interact? *Cognitive Brain Research*, *19*, 244-258.

Weisman, G. (1981). Evaluating architectural legibility: Wayfinding in the built environment. *Environment and Behavior*, *13*, 189-204.

Wilson, P.N. (1999). Active exploration of a virtual environment does not promote orientation or memory for objects. *Environment and Behavior*, *31*, 752-762.

Witmer, B.G., Sadowski, W.J., & Finkelstein, N.M. (2002). VE-Based Training Strategies for Acquiring Survey Knowledge. *Presence*, *11,* 1-18.

Zacharias, J. (2001). Pedestrian Behavior and Perception in Urban Walking Environments. *Journal of Planning Literature, 16,* 3-18.

Zacharias, J. (2006). Exploratory spatial behaviour in real and virtual environments. *Landscape and Urban Planning, 78,* 1-13.

11-Appendices

11.1-Appendix A: Samples of reconstituted routes and colour placement

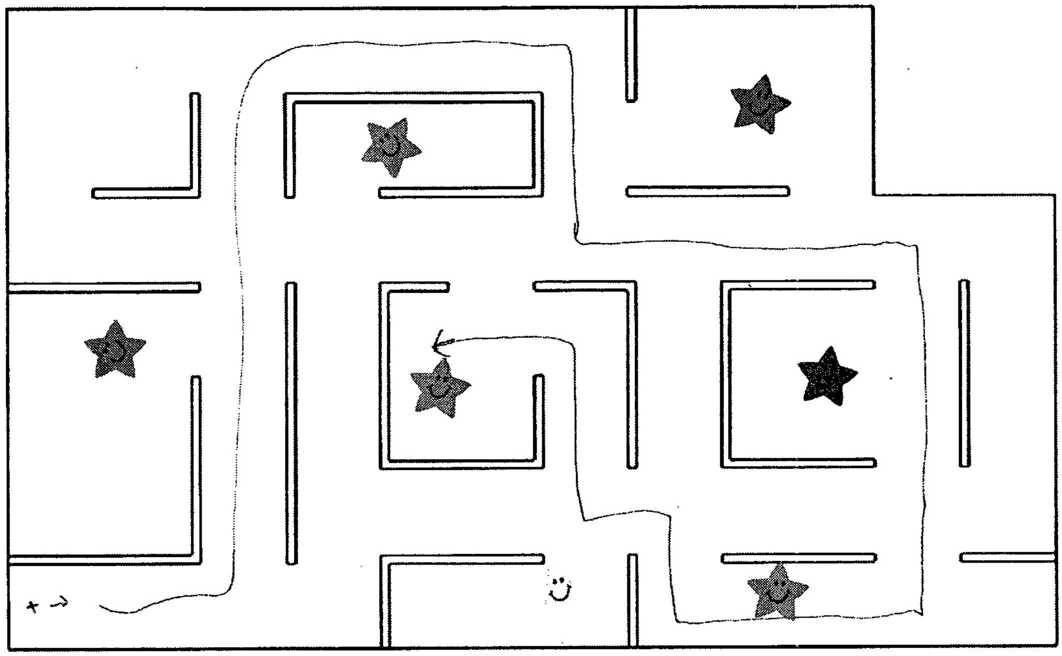

Figure 11-1: Reconstituted route and colour placement with no errors

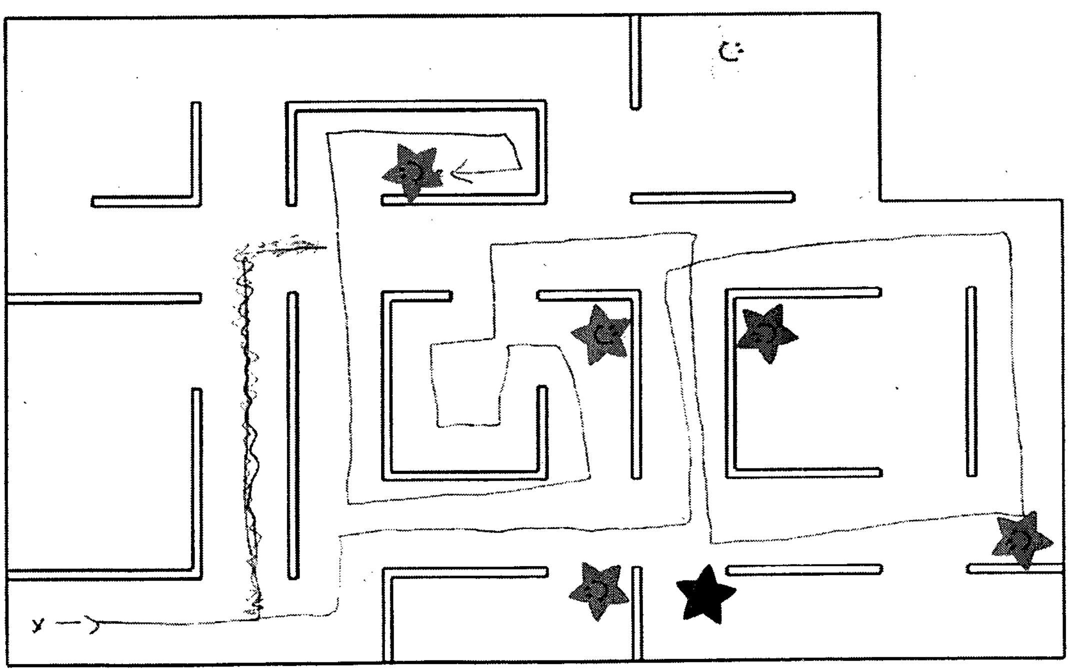

Figure 11-2: Reconstituted route and colour placement with many errors

11.2-Appendix B: Number of participants who reconstituted the route through each polygon in the sequence encountered in the virtual environment

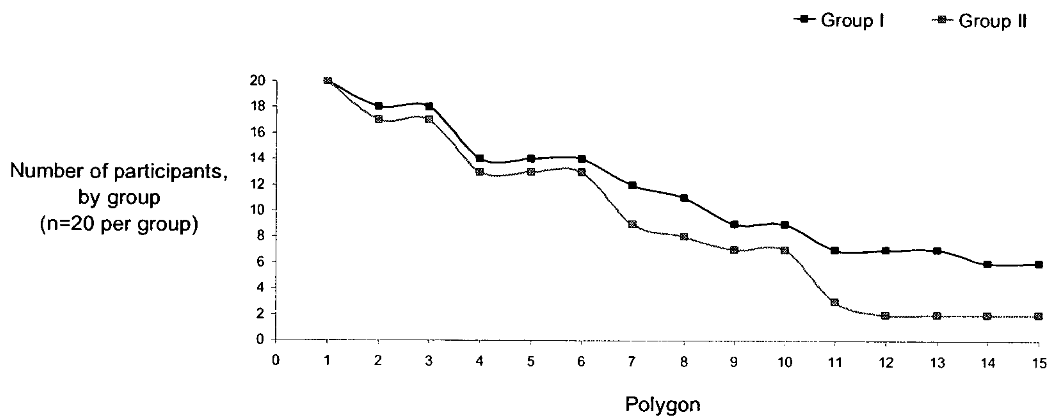

Figure 11-3: Number of participants who reconstituted the route through each polygon in the sequence encountered in the virtual environment, by group

11.3-Appendix C: Scatter plots

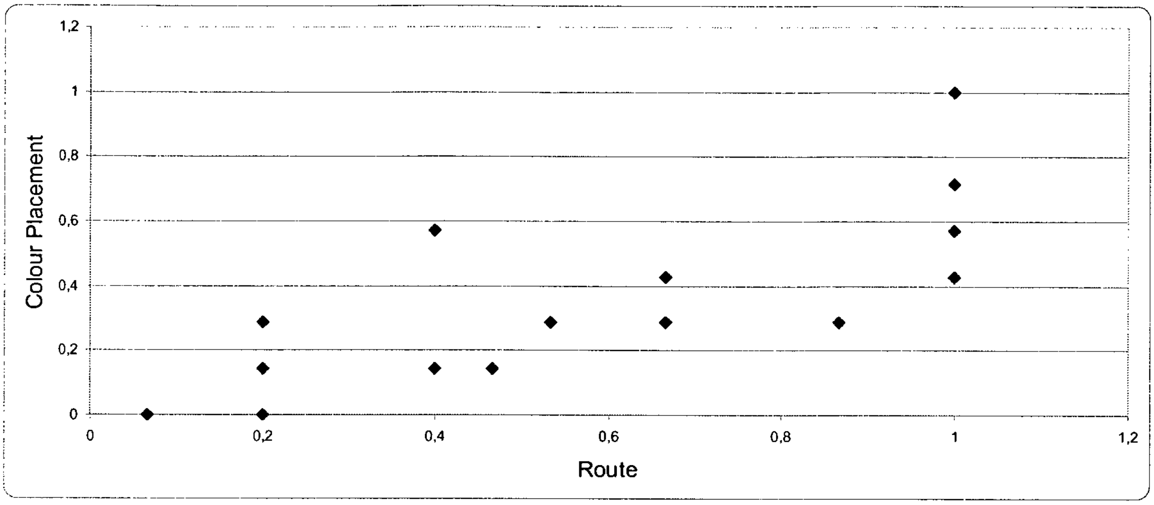

Figure 11-4: Scatter plot of correlation between colour placement and route reconstitution, Group I

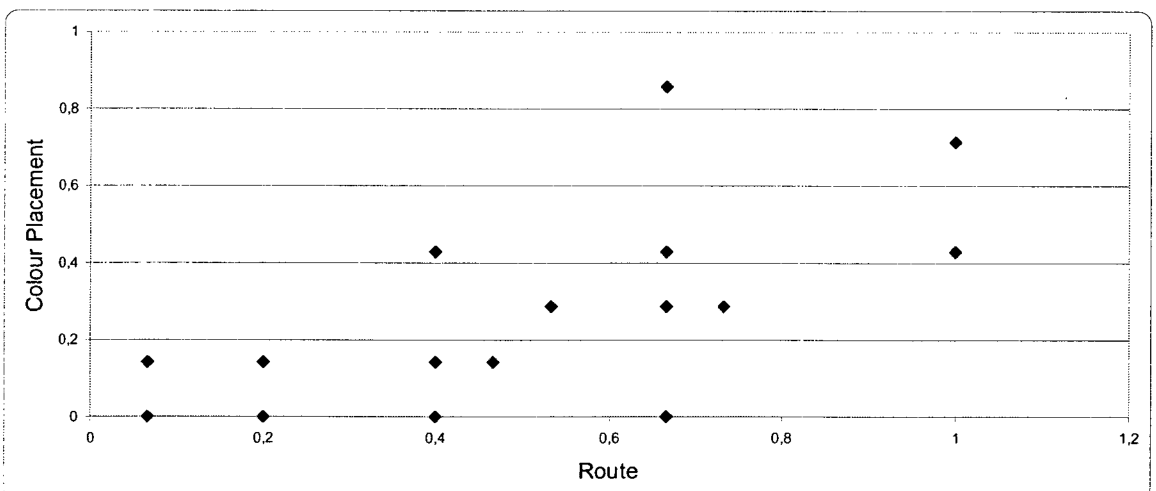

Figure 11-5: Scatter plot of correlation between colour placement and route reconstitution, Group II

11.4-Appendix D: Individual proportions for correct route reconstitution and correct colour placement reconstitution

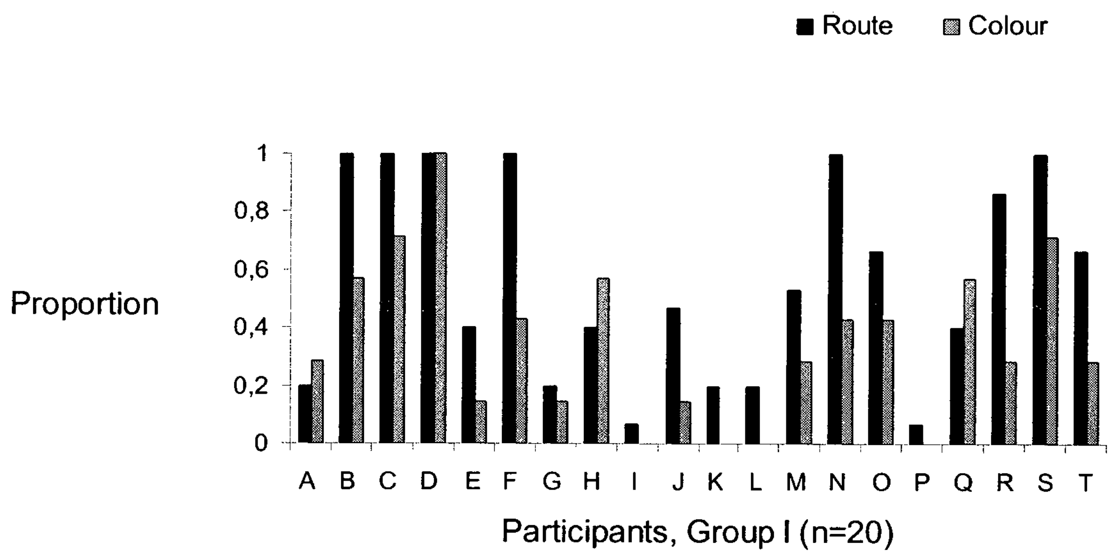

Figure 11-6: Individual proportions for correct route and correct colour placement reconstitution, Group I

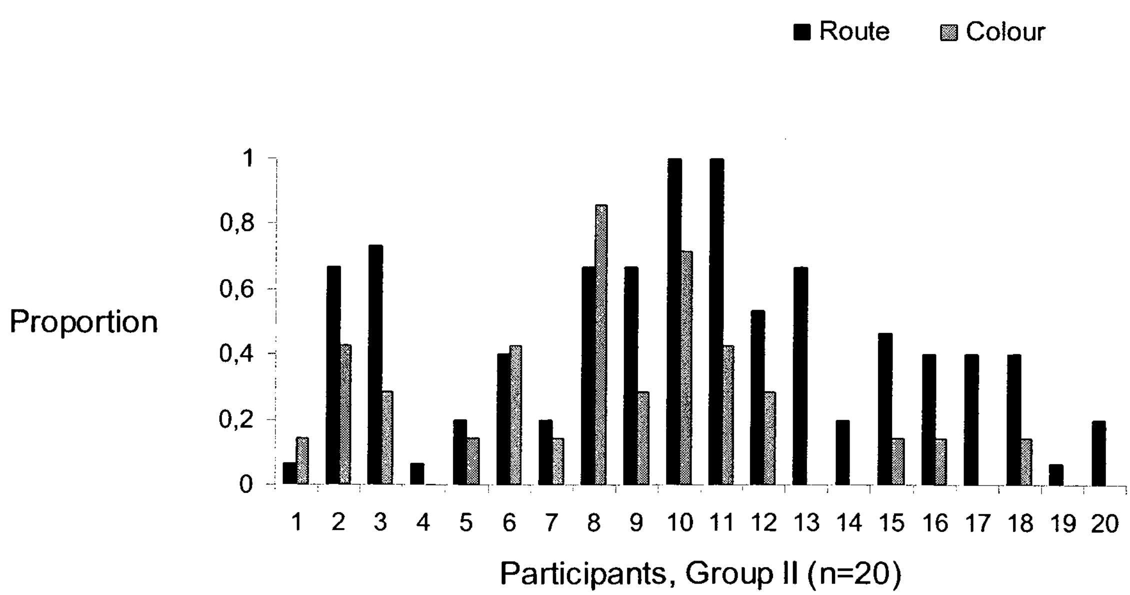

Figure 11-7: Individual proportions for correct route and correct colour placement reconstitution, Group II

11.5-Appendix E: Direction choices from polygons along itinerary

Polygon	straight	180° turn (or previous polygon)	90 ° turn left	90 ° turn right	Total direction choices to exit polygon
1	16		**2**		2
2	**3**	1			2
3	**4**	2	24	25	4
4		3	28	**5**	3
5		28		**6**	2
6	**7**	(5)	30		3
7		6	**8**	27	3
8	**9**	27		22	3
9	**10**	8	30		3
10	23	9		**11**	3
11	**12**	10	23	19	4
12	22	(11)	**13**	19	4
13	18	19	17	**14**	4
14		17	**15**		2

Table 11-1: Direction choices from polygons along itinerary

Note: correct choice is in **bold** and follows in numerical order