Representing space:
The development, content and accuracy of mental representations by the blind and visually impaired

Victor Roger Schinazi

A thesis submitted in conformity with the
requirements for the degree of Doctor of Philosophy (Ph.D.)

Centre for Advanced Spatial Analysis
The Bartlett School of Graduate Studies
University College London

March 2008

Word count: 100000

Abstract

This thesis reports on two studies on the perception and cognition of space by individuals who are blind and visually impaired. Research was conducted with students from Dorton College at the Royal London Society for the Blind (RLSB) in Kent. The first experiment examined the content and accuracy of mental representations of a well-known environment. Students walked a route around the RLSB campus and learned the position of ten buildings and structures. They were then asked to make pointing judgments, estimate distances and complete a spatial cued model of the campus. The second experiment considered the wayfinding strategies and spatial coding heuristics used to explore a complex novel environment. Students were asked to explore a maze and learn the position of six different locations. Their search patterns were recorded and analyzed using Geographic Information Systems (GIS) software. Students were tested using the same methods as in the previous experiment and their performance was related to the type and frequency of strategies used during exploration. Results were complemented with a mobility questionnaire, a low vision quality of life questionnaire and data from a literacy and numeracy assessment as well as ethnographic material collected by the author during the two years spent working and living at the RLSB.

The thesis begins with a discussion of disability and society framed within the context of geography, urban planning and design. The concepts of blindness and visual impairment are then examined with particular attention given to the psychosocial implications of visual loss. This is followed by a discussion of growth and development, and in-depth review of research on the development, content and accuracy of mental representations by the blind and visually impaired. Finally, the methods used to collect and analyse data for both experiments are considered in light of individual differences and the inadequacy of some statistical techniques to account for the heterogeneous nature of visual impairment.

Results from the first experiment revealed significant differences in the accuracy and content of mental representation between the sighted, visually impaired and blind groups for the pointing and model construction tasks. Performance in the distance estimation task was similar across groups. Large individual differences were identified, with the performance of individuals in the same group varying according to the type and requirement of the task. Results from the second experiment also revealed significant differences between the different groups, this time for all three tasks. Here again, large individual differences were found within each group. An analysis of distortions revealed that despite a disparity in accuracy, the blind and visually impaired shared many of the systematic distortions typically found in the mental representation of sighted individuals further confirming their ability develop functional mental representations of space. Performance in the pointing, distance estimation and model construction tasks were also related to the type and frequency of strategies used to explore the maze with the best performers using a combination of egocentric and allocentric strategies. In general, results from the two experiments support the amodal notion that the construction of accurate mental representations of space is not limited to any particular sensory modality but facilitated by the visual system. It also emphasizes the need for mutually supportive techniques that incorporate both quantitative and qualitative methods in the collection and analysis of cognitive data.

Table of contents

List of tables

List of figures

List of equations

Author's declaration

I, Victor Roger Schinazi, confirm that the work presented in this thesis "Representing Space: The development, content and accuracy of mental representations by the blind and visually impaired" is exclusively my own. The identity of all subjects that consented to participate in the two experiments has remained confidential and anonymous. Where information has been derived from other sources, I confirm that this has been appropriately referenced. The views expressed in this publication are those of the author alone.

To Lisette and Roger

"It is only with the heart that one can see rightly, what is essential is invisible to the eye" - Antoine de Saint Euxpéry (1943, p.68)

Preface

During the past four years, I cannot remember how many times I was asked about the reason as to why I chose the study the mental representations of space of the blind and visually impaired. This is a legitimate question. After all, I came to London to study town planning at the Bartlett and this topic was nothing less than an abrupt change from my original plan. The truth is, no matter how hard I try to pinpoint a specific reason I always come out short. It seems that research like any other passionate pursuit is more often than not the fruit of serendipity – the culmination of a series of unrelated events all of which at certain point begin to make sense.

I can think of two incidents that prompted my curiosity and made me forget about pedestrian movement in English town centres. The first and the most bizarre occurred in October 2003 after spending three hours in London rain studying a housing project in Hackney for a class taught by Professor Mark Tewdwr-Jones. I was exhausted, wet and could only think of getting home (actually it was a hall of residence) to remove my shoes and take a hot shower. I was not happy but across the street, *waiting for the 29,* stood another slightly unhappier soul. There she was, drenched with a stern look in her face clutching to her white cane, desperately lost not knowing what bus to take or where it would stop. The sociologist George Simmel was right, city life makes us *blasé* and like everyone else there I just stood and stared.

I thought about that incident for a while but like everything else that year it soon became a memory of a rainy day in London. I am not sure how many months passed but by the time I stumbled into Reginald Golledge's 1993 article on geography and the disabled, I had already written the proposal for my Ph.D. on pedestrian movement in shopping streets in Newcastle. I read the article. Actually I did not read it - I devoured it! Then I read Gleeson's (1996), Imrie's (1996) and Butler's (1994) reply and the articles that followed and no matter how much disagreement there was between these authors the tone was passionate enough to convince me that this was a topic worth pursuing. A few weeks later, I left the Bartlett town planning and drafted a new Ph.D. proposal. This time the topic was the perception and cognition of space by the blind and visually impaired. Professor Mike Batty at the Centre for Advanced Spatial Analysis (CASA) was intrigued and the rest, like they say, is history.

Acknowledgments

First and foremost, I would like to thank my supervisor Professor Michael Batty. Really, there is nobody like Mike. Thank you for your time, patience and support with every aspect of my research. Above all, thank you for making me feel at home at CASA. It has been a true honour to be your student and it is something that I will always cherish. I also want to thank my second supervisor Professor Gary Rubin. Thank you for your patience during those long meetings in your office and for sharing with me some of your expertise in visual impairment research. This thesis would not be a reality without your insight.

For two and a half years I lived and worked at the Royal London Society for the Blind and frankly I would not have any subjects, results or any idea about the field of visual impairment and blindness if it were not for the lifetime opportunity given to me by Mr. Brian Cooney, Mr. Graham Williams, Ms. Lesley Robbins, Ms. Sharon Lake, Ms. Amanda Quincy, and Ms. Agnes Flynn. Thank you for all your support and for allowing me to be part of the RLSB. During my years at the RLSB, I also had the privilege of working with an outstanding team many of which became very close friends and who are far too important not be individually mentioned: Tracy, Simona, Kim, Jamie, Sally, Alexandra, Jan, Anna, Susie, Meredith, Simon, Teresa, Mark, Andrew and Gareth. Thank you for the long nights, midnight snacks in the staff room, rag week but above all for teaching me so much about disability and care. To my knowledge there is not a harder working and more devoted team in the entire society. You guys make it all worth it and I am truly privileged for having, if only briefly, shared some of these hours with you. I am also greatly indebted to the entire maintenance team for the crash course in woodcutting, pole making and fence building. Sam, Mark, Denis and Claire I dedicate my entire second experiment to you. For your patience, expertise and above all your friendship.

I would also like to thank all my students for participating in my experiment but more important for giving such a beautiful insight to the world of blindness and visual impairment. Thank you for teaching me to listen and dance to rap music, for making me become snooker's greatest fan and for keeping me company during Holly Oaks and cringing together during Big Brother and Lost. Thank you for your love of sport and for the cheers and jubilation every time Arsenal, Manchester United, Chelsea, Liverpool, England and even Nottingham Forest scored. For FIFA and snooker in the x-box and treacle tart, malted loaf, bacon sandwiches and Neapolitan ice cream.

This has definitely been a long journey and it would not be possible without the support of so many friends and family. Lisette, Roger, Joy, Robert and Sara thank your for being the greatest family in the world and for putting up with me during these last years. Dave Botines and Juan Pablo thank you for making London a happier a city, for the countless hours in the pubs and great laughs at Galicia. Alex, Daniel, Yoni, Aviv and Davin thank you four your support an indefatigable interest. Thanks to everyone at CASA student, researcher or professor but special thanks to Junior for being like a big brother. Your patience, wisdom and listening skills are truly magnificent. Thank you Sonja and Andy for EPB, *Sketch Map,* but more important for the perfect Friday evenings at Charlotte Street and the now boycotted wine bar. Thank you Dan Montello for bringing me to Santa Barbara and sharing your wisdom and *joie-de-vivre*. Professors Reginald Golledge and Martin Raubal thank you for all the comments and suggestions. Meg, Michael, Drew Nick and Martin thank you for making Santa Barbara an unforgettable experience. Thank you Hannah Terrey, Suzanne Bull, and Maria Oshodi for your help during the early stages of this research. And then… just when everything seemed to be coming to an end, I fell in love. Angela Cronk, Roxy and Lobo you are responsible for making me smile and consequently every well-written passage in this thesis.

Chapter 1
Introduction

"Our deepest fear is not that we are inadequate. Our deepest fear is that we are powerful beyond measure. It is our light, not our darkness that most frightens us. We ask ourselves: Who am I to be brilliant, gorgeous, talented, fabulous? Actually, who are you not to be? ...Your playing small does not serve the world. There is nothing enlightened about shrinking so that other people won't feel insecure around you. We are all meant to shine... It is not just in some of us; it is in everyone. And as we let our own light shine, we unconsciously give other people permission to do the same. As we are liberated from our own fear, our presence automatically liberates others." – Marianne Williamson (1992, p. 190-191)

1.1 Vision, mobility and spatial knowledge

The eye is truly a magnificent organ and our primary link to the outside world. It is estimated that around 60% of information perceived by humans arrives through the visual channel (Zeevi & Kronauer, 1975). By transforming light waves into visual images, we are able to make almost instantaneous sense of our environment. Without much effort, our eyes allow us to apprehend distal information and anticipate our actions by providing detailed information on the size, shape and colour of elements in the environment (Hollyfield & Foulke, 1983). The eye also allows for the quick update and the calibration of movement offering quick feedback from our actions. Rosa and Ochaíta (1993) estimate that someone with full vision can within one minute of walking pick up information up to 76 meters from their body. Within instants, the eye can provide us with information regarding our position in relation to other elements in the environment. Information that with the help of simple head and body movements can be easily integrated helping us to situate ourselves and navigate with minimal effort.

Navigation is considerably different in situations when vision is totally or partially absent. Blindness and visual impairment can impose three basic limitations on the life of individuals (Lowenfeld, 1981), many of which have important repercussions in the construction of mental representations that are used during wayfinding and exploration. First, individuals are restricted in the range and variety of their experiences. The total or partial absence of vision forces individuals to use other type of sensorial information in order to build their representations of the world. In the case of partial loss, individuals can learn to effectively combine their residual vision with information from other senses. When there is total loss, the individual must rely on auditory, tactile, kinaesthetic and olfactory information. Auditory cues can provide important information regarding the distance and direction of objects in the environment but needs to be complemented by tactile and kinaesthetic sensations if the size, shape and texture are to be grasped.

Blindness and visual impairment can also impose some direct difficulties on the ability to navigate in both well-known and novel environments. A blind person walking with a cane is limited in terms of the information that can be anticipated (usually 1 meter for each cane movement). In this manner, navigation and simple object avoidance relies to a greater extent on memory, which consequently makes the formation and externalization of mental representations more cognitively taxing. Navigation in novel and complex environments can be particularly stressful. Blind and visually impaired individuals must rely on other sensory modalities in order to collect the information that is necessary for navigation. Touch, sound and proprioception can provide effective cues but these are sequential and require continuous integration on the part of the individual. In the absence of vision, time can also be used to coordinate movement and it is not uncommon for the blind and visually impaired to think of spatial relationships in temporal terms. Successful navigation will depend on careful planning. Hill and Ponder (1976) argue that in the absence of vision this depends on (a) the collection of information, (b) the analysis and categorization of this information in terms of its consistency, familiarity and intensity, (c) the selection of the appropriate information, (d) the planning of future actions and movements and (e) the execution of these plans.

The total and partial absence of vision also imposes a restriction in the control of the environment and the self in relation to it. The absence of vision can lead to a detachment from both the physical and social world. Sight plays an important role in development and the total and partial absence of vision can limit this interaction. Play, an activity crucial during development, is often affected as the blind child lacks the stimulation and incentives usually provided by vision. This inability to locate, manipulate and interact with objects in the environment often results in delays in the formation of a body image, the coordination of body parts and the overall development of motor-skills that are necessary for action and movement in both small and large-scale spaces (Hill & Hill, 1980). Independent mobility is also related to psychosocial adjustment and the development of a positive self-concept and self-esteem (Golledge, 1993; Hill & Ponder, 1976). The lack of mobility can be debilitating by limiting social interaction, access to work and education often leading to seclusion and depression (Lowenfeld, 1981). Golledge (1993) estimated that in the United States alone, approximately five hundred thousand blind individuals are confined to their homes and constantly rely on friends and family for the participation and execution of even the simplest tasks and activities.

Classic theories on the development of spatial knowledge (Siegel & White, 1975; Hart and Moore, 1973) have argued for a stage *like* development parallel to those proposed by Piaget and his collaborators (Piaget & Inhelder, 1956). These theories have influenced much of the work on the spatial abilities of the blind and visually impaired with the blind often being regarded as egocentric only capable of learning routes and unable to develop Euclidean concepts necessary for a configurational knowledge of the environment where information is synthesized into a complete and coherent whole. During the last decade, these theories have come under considerable criticism and new approaches have been suggested that take into account the growing evidence regarding the ability of both adults and children to quickly understand and represent the Euclidean and metric properties of new environments (Montello, 1998). For research in blindness and visual impairment this has meant a reassessment of the spatial abilities of this population to take into consideration the role of proprioception, context and the importance of convergent and redundant information in the construction of mental representations (Millar, 1994).

A variety of navigational aids have been developed in order to assist the mobility of blind and visually impaired individuals. The *Sonic Guide*, the *Mowat Sensor* among several others can help in the detection of objects and barriers and can assist navigation in terms of obstacle avoidance and path selection. More recently, GPS technology has been successfully used in an attempt to provide these individuals with specific route instructions during navigation. Unlike other travel aids, these machines act as complements to the white cane and are specifically designed to help in the construction of more precise representations of the environment. Yet, despite these technological advances it seems that we still do not have a clear idea regarding the accuracy and the format of these representations (Rieser et al., 1982). Throughout the years enough evidence has been collected regarding the ability of the blind and visually impaired to successfully complete a variety of spatial tasks, evidence that questions the central role occupied by vision in the formation of mental representations. Almost four decades ago, Ittelson (1973) had already commented on the multimodal characteristics of environments arguing that perception and cognition were in essence a selective process where individuals must sift through redundant and sometimes contradictory information before selecting what is appropriate. If vision is not the only sensory modality that can convey spatial information, what remains to be seen is the extent to which the other senses can act as substitutes or complements in the formation of mental representations.

1.2 Statement of the problem

Everyday a significant number of individuals who are blind or visually impaired interact with an urban environment that is little responsive to their needs. In general, the existing urban infrastructure can be disorienting, difficult to interpret and navigate and at times even intimidating (Imrie & Hall, 2001). In the recent years, there has been a growing recognition of the need to design spaces that can accommodate people with different disabilities, including the blind and visually impaired. This has been coupled with the increasing interest in the perceptual and cognitive processes involved in the acquisition of spatial knowledge and the externalisation of this knowledge during navigation, exploration and wayfinding.

This thesis is about ability - the ability to understand and mentally represent space in the total or partial absence of vision. It reports on three years of research at the Royal London Society for the blind (RLSB) with teenagers who are blind and visually impaired. This thesis is also about education – the education of the self and society. The changing of beliefs and attitudes towards disability rely on the education and the raising of awareness not only of the needs of the disabled but also of their abilities. Progress is the fruit of education and the work reported in this thesis will try to make evident some aspects of the spatial abilities of the blind and visually impaired as it relates their mobility and overall independence.

The objective of this research is to examine how individuals who are blind or visually impaired perceive and mentally represent different elements of the built environment during navigation and how the accuracy and format of these representation compare to those constructed with vision. Research consisted of two experiments. The first experiment was designed to test the content and accuracy of mental representations of a well-known environment. Students were asked to walk a route around their college campus and learn the position of ten buildings and structures. They were then asked to make heading judgements, estimate distances and complete a spatial cued model. The second experiment examined the strategies used to explore a novel and complex environment. Students were asked to explore a maze and learn the location of different places. Their search patterns were recorded and analyzed using GIS software. Students were tested using the same methods as in the previous experiment and their performance was correlated with the strategies used to explore space.

This thesis will attempt to answer two interrelated questions:

1. Can individuals who are blind or visually impaired understand and represent space for the purpose of navigation?
    a. Do they understand geographic concepts such as location, distance, direction and overall configuration?
    b. How accurate are these representations?
    c. Are there any similarities in the format of these representations to the ones constructed by the sighted?

This first question deals with the content, accuracy and format of mental representations of space. Content is defined as the sum, range and type of what has been perceived, discovered or learned. Here we are interested in the different characteristics and elements that make up the environment where the subject is tested. In the first experiment, this includes the buildings and structures that make up the Royal London Society of the Blind campus. In the second experiment, these are tables (representing different locations in a city) located inside a maze. When studying the content of mental representations we are particularly interested in the role of familiarity and experience. Accuracy is defined as the quality of being true, correct or exact – free from error. Accuracy can also be understood as the "extent to which a measurement agrees with the standard value for that measurement" (Dictionary.com, 2007). Accuracy will be assessed through a variety of tests that calculate the difference between the real and represented environment and will depend on knowledge of the absolute and relative position of the elements that make up the environment. Finally, the format of representations will be considered by comparing the type of errors and distortions committed by the sighted, visually impaired and blind subjects. Here the focus is not on accuracy but whether the mental representations of the blind and visually impaired share some characteristics in common with those constructed on the basis of vision.

The second question is concerned with exploratory strategies that can be used to learn a novel and complex environment:

2. Are there specific strategies that can be used to explore space that will facilitate the development of mental representations?

a. Are these related to performance in spatial tasks?

This question takes more of a developmental approach towards the construction of mental representations. Focusing on exploratory strategies, defined as elaborate and systematic navigation plans of action, it is concerned with differences in the ontogenesis of mental representations. It considers the role of strategies as coding heuristics used during spatial exploration and the construction of mental representations. That is, whether different taught orientation and mobility or individually devised strategies can facilitate the development of spatial knowledge and whether a relation exists between the type (egocentric and allocentric) and frequency of use of these strategies and the accuracy of mental representation determined by performance on a variety of spatial tasks.

1.2.1 The difference theory and an amodal interpretation

In the 1980's the Canadian researcher J.F. Fletcher proposed three theories (deficiency, inefficiency and difference) as a way to categorize the history of research on the spatial abilities of the blind and visually impaired (Fletcher, 1980). The deficiency theory holds that vision is essential to the formation of mental representations and that the congenitally blind are incapable of spatial thought because they have never experienced the perceptual process necessary to comprehend spatial information. The inefficiency theory states that the blind and visually impaired are able to understand and manipulate spatial concepts but that their knowledge is inferior when compared to the sighted. The difference theory believes that the blind and visually impaired are functionally equivalent to the sighted in their ability to process spatial information but that these representations are built in a different (and sometimes slower) manner.

In an attempt to answer the two questions presented above, the work conducted in this thesis will provide evidence in support of an amodal interpretation of the difference theory. This will build on the work conducted by the Spanish researchers Carreiras and Codina (1992), which questions the central role of vision in the acquisition and manipulation of spatial knowledge. In line with Susanna Millar's work (Millar, 1994), it will argue that no sensory modality is in itself necessary or sufficient for spatial coding. The content, accuracy and development of mental representations will depend on redundant, convergent, overlapping and complementary information acquired by the different sensory modalities. Individuals who are blind or visually impaired are able to understand and represent space but that these representations are built from information acquired through different sensory modalities and proprioception. The accuracy of these representations will also depend on the implementation of specific strategies (both mental and physical) for capturing and processing spatial information. Differences in the accuracy of these representations (variation in performance in spatial tasks) will be explained by the lack of convergent information, familiarity, intelligence and confidence.

1.2.2 Motivation and rationale for research

There is no shortage of research on the mental representations of space by the sighted. A considerable amount of work also exists in relation to the spatial abilities of the blind and visually impaired. The driving force behind this work however, derives from two limitations of past research. The first problem is related to the large number of contradictory results found in the literature regarding the spatial abilities of the blind and visually impaired. The second limitation is related to the methods that have been previously used in the analysis of mental representations. Care needs to be taken in the classification of subjects into different groups based of their visual acuity or any other characteristic of their vision (i.e., field restriction, photophobia) in order to account for the highly heterogeneous nature of visual impairment.[1] This is particularly relevant if statistics based on the mean and a Gaussian distribution are used in the analysis of data. Results from statistical analysis must go through careful scrutiny and complemented by qualitative data before any conclusions can be made.

There are several benefits for conducting this research. At a theoretical level, comparing the ability of the blind and visually impaired to understand and represent space in either well-known or novel and complex environments can provide important information on the role of vision in the accuracy, form and development of mental representations. Is vision essential for the construction of mental representations? Can individuals who are blind or visually impaired build representations that are also functionally equivalent to the sighted? Do these representations share any characteristics in relation to form and content? The work conducted in this thesis benefits from the wealth of data and ethnographic experiences collected by the author during his stay at the RLSB and is a welcome change to past research that has studied the spatial abilities of the blind and visually impaired focusing strictly on differences in visual acuity. This thesis will also use Geographic Information Systems (GIS) in the analysis of spatial data. GIS is now a widely used tool in geography but its impact in psychology is still somewhat limited and more so in studies dealing with the blind and visually impaired. GIS will be shown to be

[1] Unfortunately sometimes not even the best scenario (conducting research at a college for the visually impaired) can provide the researcher with all the necessary data. Despite the wealth of details accumulated on the visual characteristics of each subject, only data on visual acuity was complete and consistent to be used in the classification of subjects in this research.

a particularly useful tool in the extraction and analysis of different strategies during exploration.

At a practical level, knowledge of the spatial abilities and the benefits of different exploratory strategies used in spatial exploration can help in the development of orientation and mobility programs, electronic travel aids and the design of tactual maps or displays. Hutchinson et al. (1998) note that over half of individuals who are blind or visually impaired require some form of assistance when moving about, but only five percent of them receive adequate mobility training. Despite continuous advances in the field of orientation and mobility the process of spatial learning and its relation to independent and functional mobility is still not clearly understood. Individuals vary not only in their level of independent mobility but also regarding the type of techniques they adopt. This thesis proposes a more systematic approach to the study and application of the impact different orientation and mobility techniques can have on the construction of mental representations. Finally, results from this thesis can help architects, planners and urban designers to better understand the characteristics and needs of the blind and visually impaired. Results can help in the formulation of plans and guidance for buildings and environments that are safer and more inclusive.

1.3 The Royal London Society for the Blind

The Royal London Society for the Blind (RLSB) was established by Thomas Mark Lucas in 1838. Formerly known as the London Society for Teaching the Blind to Read, the RLSB was the first institution in the United Kingdom to introduce the Braille system developed in France 17 years earlier by Louis Braille. Ever since its inception, the RLSB continues to offer individuals who are blind or visually impaired a variety of academic and professional opportunities and has been committed to empowering these individuals to lead successful, self-sufficient and independent lives in a sighted world. The RLSB comprises a nursery, a school and a college for further education as well as an adult professional training program and an industrial workshop. The Society offers a variety of specialized courses covering a wide range of academic subjects. All students are automatically enrolled in orientation and mobility courses and taught life-skills on a daily basis. These life skills lessons, formal or informal, in private or in-group, incorporate all the training that is required for the furtherance and promotion of independence. Depending on the student and maturity level, lessons can range from simple washing, ironing and cooking to informal psychological support and professional advice. Life-skills tutors are supported by occupational language/speech therapists and psychologists.

The nursery, school[2] and college teach a variety of students and offers support for pupils with learning disabilities and additional needs. This is a direct consequence of recent changes in the education and integration laws in the United Kingdom that have allowed for the incorporation of students with multiple disabilities in specialized schools. All students at the RLSB are either blind or have a visual impairment. However, the major disability is not always visual. Visual impairment in the western world is often the result of another major condition and many of the academic and life-skills problems faced by these students are not directly related to vision. While it is too early to judge whether this integration approach is beneficial or not for both teachers and students, it has forced the RLSB to adopt educational programs that are specifically catered to meet the individual needs of each student. This "custom made" program has become one of the chief strengths of the RLSB where numeracy and literacy level as well as independent mobility and life skills are assessed in relation to visual condition in order to determine the most appropriate care program and academic curriculum.

All the students that participated in this research did not have any additional disabilities. They were all students of Dorton College; some attended classes at the RLSB campus but the vast majority were integrated into mainstream education and attended classes either at West Kent College, Bromley College or Hadlow College. All students were also currently taking mobility courses at the RLSB and were sufficiently advanced in their life skills.

1.3.1 Theory meets practice: The ethnographic complement

It suffices to say that this research is a reality mainly because of the positive and edifying attitude present in all departments of the RLSB. The chance to live and work among prospective subjects is nothing short of a researcher's dream, a dream not only because of the ready availability of subjects but also because of the relationship and understanding that develops between the researcher and subjects. Ethnographic research has been used as a complement in a variety of disciplines but it is of particular significance when it is used in conjunction with more quantitative methods. This form of participant observation

[2] The school is a non-maintained special school: These are non-profit establishments. Pupils are usually funded through the public purse. These schools usually cater to students with extreme and low incidence learning difficulties.

and journalistic description of social phenomena serves as an important contribution to the analysis of data and an important complement to other statistical techniques. [3]

The role of the life skills tutor, the one occupied by the author during the course of this research,[4] and the bonds that subsequently developed as a result of the daily interaction between the author and students allowed for a trustful, supportive and friendly relationship. No other occupation in the RLSB has so much contact and understanding of the needs of these students as the life skills tutor. This is a valuable position for the researcher and open for the collection of rich and detailed insights about the daily lives of the subjects. Teaching life skills has allowed the author to gather specific psychosocial data about each of his subjects. The day-to-day behaviour and occurrences although somewhat trivial at first, are slowly decoded into comprehensible patterns. Phenomenologically speaking the relationship between the tutor and the students is a window to each of subject's constructed reality. A snapshot of each individual's experience captured in its natural context before any causal explanations are imposed upon it (Fewtrell & O'Connor, 1995). Observation and description in this manner are the most appropriate tools to understand these phenomena. Examples derived from these experiences will be presented throughout the thesis and will be used in specific cases as complements to statistical analysis.

1.4 Overview of the thesis

Chapter 2 explores the notion of disability and society framed within the context of geography, urban planning and design. The medical, social and biosocial models of disability are presented and it is argued that it is time to assess the practical relevance of

[3] Ethnography is the descriptive study of a particular group of society. There are a variety of methods (1-direct and participant observation of behaviour; 2-formal and informal interviews/conversation; 3-detailed work with key consultants; 4-case studies) associated with type of research. While there is no convention regarding the manner the ethnographic experience should be reported, the richness and engaging character of dialogue make it the method of choice. Ethnographic research however, does not necessarily have to be based on dialogue (this is only one form of reporting experience) but on the fieldwork and participant observation undertaken by the researcher. That is, the researcher lives and interacts with the subjects for a considerable amount of time (usually a year or more) for the purpose of developing close relationships that can provide detailed insights on a group's way of life. In this thesis, although efforts were made (see last section of chapter 3) to include snippets of the dialogue between the author and the subjects, the ethnographic complement should be understood as the insights gained by the author, through participant observation, and how this wealth of information helped to understand and interpret the behaviour of the subjects in the different spatial tasks. Ethnography stands to complement statistical data, shaping (and enriching) the overall hypothesis and allowing for the description and interpretation of individual cases.

[4] This critical role in the education of these students is often undermined by more academic positions. The effort put in the provision of care unfortunately is neither well acknowledged nor highly compensated. This disparity of recognition is only a small reflection of a much larger problem faced daily by nurses in the medical world.

these models. The chapter considers the work conducted by the World Health Organization regarding the definition and differentiation between disease, impairment, disability and handicap. This is complemented by a brief discussion of legislation and the reality of the built environment with a special focus on the provision of access and information for navigation for individuals who are blind and visually impaired.

Chapter 3 is an introduction to the field of blindness and visual impairment. It begins by exploring some of the myths and misconceptions associated with visual loss. Special attention is given to terminology and the differences between medical and functional classifications of visual impairment are presented. The prevalence of visual impairment and blindness in the population (UK) is discussed and statistical data on the distribution is presented. The chapter concludes with a discussion of psychosocial adjustment based on the author's experience working as a life-skills tutor at the RLSB.

Chapter 4 brings together the discussion of disability and visual impairment to the acquisition and development of spatial knowledge. The chapter opens with a discussion of the different characteristics and definitions of space. A functional definition that focuses on the nature of experimental space and spatial tasks is then proposed as a matter of conciliating this debate and moving it from a philosophical to a scientific arena where specific hypotheses can be tested. The work of Jean Piaget and his critics is then considered and special attention is given to his now challenged idea of egocentric to allocentric shift in spatial coding and the failure of stage theory to account for individual differences. Domain specific, multiple intelligence and information processing theories are presented as complements to Piaget's work. The chapter concludes by setting the ground for an investigation on the role vision plays in the acquisition of spatial knowledge and the developmental differences that exist between the sighted, the visually impaired and the blind.

Chapter 5 discusses growth and development in relation to blindness and visual impairment. It begins by presenting some of the advantages vision holds over the other sensory modalities while considering the type and quality of information that can be gathered through touch, sound and proprioception. The work of Jean Piaget is then reconsidered along with other theories and studies on the development and acquisition of spatial knowledge in the total or partial absence of vision. The chapter concludes with a discussion of frames of reference, Newcombe and Huttenlocher's re-weighting theory (2000) and Susanna Millar's (1994) CAPIN (convergent active processing in interrelated networks) model and their application to the perception and cognition of space by the blind and visually impaired.

Chapter 6 presents a review of classic *cognitive mapping* theory that focus on a stage like development of spatial knowledge. This is followed by a discussion of Montello's (1998) continuous framework where the development of spatial knowledge, particularly the manipulation of metric or Euclidean concepts is seen as developing continuously – quantitatively enriched. The chapter concludes with a discussion of the concept of hierarchy and distortions in mental representations.

Chapter 7 is an in-depth review of a variety of experiments on the acquisition of spatial knowledge and the spatial abilities of the blind and visually impaired. The chapter begins by considering the three theories (deficiency, inefficiency and difference) that have been put forward regarding this population's ability to understand and represent space. The experiments are classified in relation to the scale of the space and discussed in terms of imagery, memory, inference, mental rotation or mapping. Navigation, curiosity and exploration in the absence of vision is also considered and Hill et al. (1993) study on the exploratory strategies used by the blind in an object location task is reviewed and presented. The chapter concludes by looking at some of the different exploratory strategies taught in orientation and mobility and others developed through research with the blind and visually impaired. Strategies are classified in terms of egocentric or allocentric and their role in spatial coding is discussed.

Chapter 8 reviews several methods used in the collection and analysis of data on spatial representation and wayfinding and serves as an introduction to the techniques used in the two experiments conducted at the RLSB. The concept of individual differences is revisited this time with the focus on the inadequacy, misinterpretation and weaknesses of some commonly used statistical techniques. The chapter concludes by considering the importance of describing the characteristics of the participants and the usefulness of ethnographic qualitative data as a complement to statistical results.

Chapter 9 presents and discusses the results for the first experiment conducted with students from Dorton College at the Royal London Society for the Blind campus. It begins with a detailed description of the different areas, buildings and structures that make up the RLSB campus. Next, the experiment is explained and the participants along with the rationale for their classification are presented. The three tasks are then explained and the results for each task are presented and analysed. Special attention is given to the similarity in the systematic distortions by the sighted, blind and visually impaired group in all three tasks. The last section presents the results from the intelligence, mobility, low vision quality of life and the debriefing questionnaires in an effort to further comprehend the results and as a rationale and incentive for the second experiment.

Chapter 10 presents and discusses the results for the second experiment. The chapter begins with a detailed description of the experiment focusing on the construction of the maze. The results from the pointing estimation, the distance estimation and the model construction tasks are then presented and discussed in relation to the accuracy of mental representations and the similarity of systematic distortions across groups. Special attention is also given to individual differences and the large variation in performance within groups. Similar to the first experiment, results from the intelligence, mobility, low-vision quality of life and debriefing questionnaires are discussed in relation to performance in the three tasks in an effort of deriving a model regarding the factors affecting performance in spatial tasks in the total and partial absence of vision.

Chapter 11 examines the movement patterns and strategies used by the subjects while exploring the maze. The methods for capturing, decoding and analysing movement patterns are described and Geographic Information Systems are introduced as a powerful and promising tool for the analysis of dynamic data. The differences in the exploratory patterns between different groups are presented and individual tracks are coded into different exploratory strategies. Performance in the different spatial tasks is then related to the type and frequency of strategies used during the exploration of the maze.

The thesis concludes in chapter 12 where the results for both experiments are considered in relation to past research on the content and accuracy of mental representations by the blind, visually impaired and the sighted. First, the accuracy of mental representations is discussed in relation to well-known and novel environments and particular attention is given to individual differences and the value of multiple converging techniques in the analysis of cognitive data derived from a heterogeneous population. It is argued that both vision and familiarity although not essential have a facilitating effect in the formation and accuracy of mental representations. Next, the similarity of distortions in the mental representations of the different groups is discussed in relation to the pointing, distance and model construction tasks. Here it is argued that despite differences in accuracy, the mental representation of the blind and visually impaired, although constructed on the basis of proprioception and information collected from other senses, share many characteristics in common with those of the sighted. The role of intelligence, mobility and quality of life is considered in relation to performance in the three tasks and different models are presented that question the indispensable role of vision in the formation and accuracy of mental representations. The chapter concludes by reviewing the relation between performance and the different strategies that can be used to code space, in particular the differences between the frequency and use of egocentric and allocentric strategies. The thesis also includes a bibliography and an appendix with details on each subject as well as the rationale for the ranking of subjects and the coding of exploratory strategies.

Chapter 2
Geography and disability

> "Teach the ignorant as much as you can. Society is to blame for not giving free education; it is responsible for the darkness it creates. The soul in darkness sins, but the real sinner is he who caused darkness." – Victor Hugo (1982, p. 32)

2.1 Introduction: Disability – Where do we stand?

If there is one message, one lesson the author wishes to convey in this chapter is that words are not enough. We have done our share of talking (and by no means this should stop) but the time has come for us to transform some of these words into action. Let us begin by clarifying a potential ambiguity. This is not a critique of the literature on disability. For almost four decades we have seen a growing body of work on a variety of topics that relate in some way or another to the concept of disability and the manner in which it is understood and adopted by society. Authors such as Lowenfeld, Imrie, Gleeson, Butler, Oliver, Golledge, Nagy (to mention only a few) have dedicated much of their academic and professional careers for the purpose of educating society. No matter how different their backgrounds may be, they stand together with the ultimate goal of removing both the physical and social barriers that marginalize the disabled and frustrate their integration. Journals and magazines that specialize on disability have provided an important outlet for the dissemination of this knowledge. Together with the work of the World Health Organization (WHO) and a variety of NGO's they have raised awareness with much of their work acting as the backbone for the revision, creation and implementation of policy and legislation on integration and access in a variety of countries. Yet, despite all their efforts, it seems that the desired ripple effect of their words continues to be drowned by a common reality – the fact that we live and will continue to live in an able-bodied society.

2.1.1 Don't call it pessimism: Actions speak louder than words

Disabled people are different and this is not a pessimistic view. The sooner we come to terms with this reality the sooner we will be begin to make concrete progress towards integration and respect. The relationship between pessimism and reality is so often misunderstood that in some cases it has dominated the debate on the provision of rights, access and integration for individuals with disabilities. Golledge (1993) was very clear when he remarked that too much attention has been given to the discussion of political correctness involved in using the term *disabled* rather than solving problems or even understanding the problems faced by disabled people. Golledge's remark however, undermines the importance associated with the clarification and coherence of models and definitions. Imrie (2004) argued that the definitions proposed by the World Health Organization (WHO) as well as other disability groups and the subsequent work conducted by academics and professionals in the evaluation, alteration, rectification and application of definitions constitutes the actual backbone for research (both theoretical and practical) in disability in variety of disciplines that in many ways helped to shape progressive and integrating social policy. Yet, there is still a feeling that more can be done regarding the practical applications of theory. This is echoed by Tom Shakespeare in the introduction of his most recent book, Disability Rights and Wrongs, when he remarks that he is "conscious that there is a pressing need for new qualitative and quantitative data in disability studies [and feels] slightly embarrassed to be offering yet another volume of theory" (Shakespeare, 2006, p. 3). It is our duty as researchers to make the abilities of the disabled evident to the wider society. It is only through knowledge of the outstanding and many times undisclosed potential of this population that these differences will come to be celebrated.

To refocus the debate on disability is not an easy task and the first question that comes to mind is: How do we achieve this? The answer depends on two interrelated elements. The first, as it has already been mentioned, is the education of society through the dissemination of knowledge regarding both the differences and abilities of this population. The second relates to an important shift that began to take place in academia during the early 90's regarding the move of research from a positivist stance to one that is interpretive, emancipatory and empowering (Oliver, 1992). In other words, research should not be solely conducted "on" the disabled but also "for," "with" or "by" the disabled (Jacobson, 1999; Butler, 1994). The work conducted for this thesis on the spatial abilities of the blind and visually impaired attempts to do exactly this. It is a piece of research conducted "for" and "with" the disabled regarding the differences and sometimes outstanding abilities of blind and visually impaired individuals to build mental representations of space that can be used during navigation.

This chapter will explore the notion of disability and society framed within the context of geography, urban planning and design. It will present different models of disability and argue that disability must be understood in relational terms (Imrie, 2004). That the relationship between the body and society is dialectical and the development of a non-reductive model of disability requires an understanding of the relationship between the impaired body and social, cultural and political barriers faced by disabled people. It will consider the work conducted by the WHO regarding the definition and differentiation between disease, impairment, disability and handicap. This will be complemented by a discussion of legislation and the reality of the built environment with a special focus on the provision of access and information for navigation for individuals who are blind or visually impaired.

2.2 Models of disability

For long time now we have grown accustomed to using models when presenting or discussing disability. Models attempt to frame reality and can be useful tools in the description and understanding of concepts (i.e., impairment, disability, function). They can also provide important insights regarding attitudes, conceptions and prejudices of different groups in society. Models however, tend to be static and incomplete. They do not always necessarily reflect the real world, are hard to generalize and should be treated with a fair amount of scepticism. Although a variety[5] of models have been proposed, disability is usually discussed in relation to two dichotomous philosophies. The first, the basis for the medical model, sees the disabled as dependent upon society with their ability to fulfil social roles and actively participate in society limited by their impairment. The second, the basis for the social model, sees disability as a consequence of environmental, social and attitudinal barriers that prevent the individual with impairment from participating in society. These two models have served as an important basis for the discussion on disability. The friction between them enough to raise awareness and portray with considerable impact both the limitations imposed by impairment and discriminatory practices of society. Over thirty years ago Paul Hunt[6] published a letter to *The Guardian*

[5] For further information on the application and interpretation of different models of disability refer to: http://akmhcweb.org/ncarticles/models_of_disability.htm

[6] Paul Hunt's letter (short note) to *The Guardian* is often seen as the starting point for a united struggle against discrimination in the UK.

(Hunt, 1972) calling for a rejection of the medical model and equality for the disabled.[7] The social model attempted to address some of these issues but in recent years seems to have stagnated (Shakespeare, 2006) unable to offer a balanced, rational and coherent analysis of disability. Clearly, there is no correct or superior model. The models in themselves should not be regarded as mutually exclusive but complements. What follows is a brief review of these models, their strengths and weaknesses along with a proposal for accepting a middle-ground model, the biosocial model, as a manner of settling this debate and moving on to take concrete action towards exposing the abilities and empowering disabled people. As we shall see, the biosocial model attempts to construct an alternative view where disability is neither reduced to an individual medical problem nor ignores the limitations imposed by impairment. After all, disability is a "complex and multidimensional phenomenon" (Imrie, 2004) that cannot and should not be easily understood by the contrasting polar models or discourses (Imrie, 2004).

2.2.1 The medical/individual model of disability

The medical model considers disability as an individual problem and a direct result of impairment. It focuses on bodily abnormality, disorder or deficiency that lead to a disability or function limitation (Barnes et al., 1999). As a result, individuals are responsible for curing or *fixing* what is wrong. In the medical model, disability is seen a social burden and a personal tragedy – a somewhat absurd view considering the disabled are not necessarily sick and many times cannot be cured by medical treatment.

The notion of seeking a cure or a solution to the impairment causing the disability has led many researchers to argue that the medical model fuels a culture of *normality*. That is, in order to be part and to function within society individuals affected by impairment must first seek to fix and relieve themselves from their impairment. This separation between the disabled individual and society is further reinforced by the power relationship that is created between the expert (most of the time a non-disabled person) who diagnoses the disability and the disabled individual. This medicalisation of disability often leads to feelings of guilt and inadequacy as disabled individuals become socialized into believing that their dependence on others is acceptable and that they should be thankful of this charity.

[7] The "Disability Studies" department at the University of Leeds offers a variety of documents and newspaper clippings regarding disability: http://www.leeds.ac.uk/disability-studies/archiveuk/titles.html

Charity is a central concept in the medical model of disability. The push for homogenization or normality often depicts the disabled as pathetic, needy and dependent on others. While it is indisputable the role that charities play in funding the education and rehabilitation of these individuals, charities can also be disempowering, segregatory and sterilizing. That is, they victimize and separate those affected by putting them in hospitals (sometimes coercing these individuals to go through painful medical procedures) and special schools creating a culture of care. The medical model also affects the manner in which the disabled think about themselves. Feelings of pity, dependency and abnormality can sometimes lead the disabled into believing that their impairments automatically prevent them from fulfilling an active role in society. A vicious circle where false beliefs fuel low self-esteem and inaccurate notions about ability and independence. Finally, the medical model can have important implications for the design of city and building space. The creation of inaccessible environments can be seen as a concrete result of the inadequacy of this philosophy - placing the fault on the individual absolves many architects, designers and property developers from addressing accessibility issues in the creation or modification of city projects.

2.2.2 The social model of disability

> "My darkness has been filled with the light of intelligence, and behold, the day-lit world was stumbling and groping in social blindness" – Helen Keller (1920, p. 11)

The social model is a reaction to the medical model of disability (Oliver, 1996b). In the social model, disability is no longer something the person *has* but instead something that is *done* to the person (Swain et al., 2003). The disabled are those that are excluded from society by any form of physical, legal or cultural barriers (or any combination of these) that limit their experiences as human beings. In other words, blindness and low-vision are not in themselves barriers to full participation in society but rather barriers are erected by society as a result of attitudes, beliefs and the socio-political agenda of the non-disabled. Simply put, the social model makes an important distinction between impairment and disability where impairment is no longer the cause of the disability. In the social model, to be disabled is to be socially disadvantaged or oppressed (Barnes et al., 1999). One of the key concepts in this model is the idea of inclusion. As Oliver (1990) remarked, disability is not a bodily state of impairment but instead a socially inferior status that people with physical and mental impairments are forced into due to the perpetuation and propagation of social attitudes, prejudices and practices of an able-bodied society.

Instead of fixing or curing the individual, the social model aims to alter the manner in which disability is understood. This in turn shifts the focus to the educational actions and training programs that are put in place to overcome prejudice and stereotype. French (1993) argues that most problems faced by impaired individuals can be solved by social manipulation. The social model does not necessarily deny the existence of bodily impairment or physiological differences but instead it looks at these conditions without imposing value judgements. The social model is about giving the disabled the same chances and opportunities as the non-disabled in terms of education, employment, housing and access. It is about breaking the direct link between impairment and disability by considering that society, through its organization and actions, can prevent people with disabilities from functioning to their fullest.

The social model also considers the relationship between the *expert* and the disabled as disabling. Veering away from the concept of pathology or normality, the social model of disability exposes the potential consequences of power relations and puts them aside in favour of changes in attitudes and the eradication of social barriers. It is not up to the expert to make decisions regarding the life of the disabled. It is about providing the disabled with equal rights and the freedom to make their own decisions in a society that allows for indiscriminate access regardless of the purpose and location of the activity. The model provides the disabled with a sense identity. Unlike the medical model, the social model pushes for rights not charity. It works as a political tool in the fight for inclusion and human rights. The only way to consider the disabled in an even plane is by granting them the same rights to participate in society as everyone else. The provision of what politically speaking can be considered as human rights is far more pressing than the immediate cure of a condition.

Regarding the design and layout of physical space, the model holds that inaccessibility is partly due to ignorance - a function of a thoughtless and uneducated insensitivity to the needs of disabled people. But it is also the result of a perpetuation of beliefs that the disabled do need to be provided for. As Davis (1990) notes "for as long as these people [property developers] are able to maintain the idea that it is our bodies that are at fault, the social structure they have created can be protected" (p. 2).

2.2.3 The middle ground: The bio-social model

It is one thing to blame society for imposing barriers; it is another to be conscious of the impact and obstacles imposed by impairment. Impairment of different bodily functions will carry, to a certain degree, some medical and psychological effects. As noted by Hutchinson et al. (1998) "to acknowledge – rather than ignore – the physical, emotional and psychological effects of an impairment is, in itself, liberating and empowering" (p. 59). Self-awareness is the first step towards empowerment. To be conscious of our abilities and needs is what allows us to understand and recognize the hurdles and limits imposed by society. The over reliance in the social model however, has led to a form of reification of reality. The notion that emancipation and empowerment can be achieved solely through social change is incomplete and has in many ways done a disservice to the entire disability movement.

The social model was developed as a reaction to the dominance of the medical model but to think of these two models as dichotomous can be seriously damaging. Shakespeare (2006) argues that disability thinking is being "contaminated" by a narrow minded ideological combat where too much time and energy are put into the categorization, differentiation and definition of concepts (medical vs. social, impairment vs. disability, disabled vs. non-disabled) while the only way forward depends on the understanding of the complexities of identity and experience. Neither the social nor the medical model can provide the whole picture. It is unrealistic to deny the limitations imposed by an impairment of the body and the brain. Using the example of visual impairment, French (1993) argues that it would be wrong to think that the restriction imposed by a visual impairment can be solved solely by applying the principles of the social model. As remarked by Shakespeare "nobody wants their experience to be medicalised, but nor do we want to reject medicine" (p. 1). For this reason, it is important to understand the interaction between individual needs and how these are limited by both the impairment and the social context.

Not all our physical differences are socially created (Morris, 1991). The social model was born out of the idea that society is disabling and made one of its main tenants to combat this disabling society. This has lead to the erroneous notion that since society has for the most part been arranged by and for non-disabled people these are directly liable and automatically consigned to the "enemy camp" (Shakespeare, 2006; Kitchin, 2000; Barnes & Mercer; 1997). It is in this area that the social model has done the greatest harm to the disability agenda. The notion that only disabled people can really know what it is to be disabled and thus should be the only people responsible for conducting disability research is flawed and elitist in itself. The non-disabled are not the enemy. Although disability research may not be fully representative of disabled people's experiences and knowledge (Oliver, 1992), the relationship between professionals, teachers, doctors and researchers that are non-disabled should not be regarded as a power relation but as discourse. Research by the non-disabled is not alienating or disempowering. These individuals should be seen as allies in the fight for both rehabilitation and inclusion. We are dealing with a situation of disability in an able-bodied society and correct interpretation of data requires input from both camps.

The biosocial model acknowledges that impairment has the potential to debilitate the body but recognizes the complex interactions between physiology, culture and the wider socio-economic and political forces. It connects the experience of impairment with the disabling potential of society (French, 2003). Table 2.1 illustrates how elements of the medical and social model are combined in the biosocial model.

Table 2.1 - The biosocial model

Medical	Social	Biosocial
Personal tragedy theory	Social oppression theory	Bio-social theory
Personal problem	Social problem	Personal/social problems
Individual treatment	Social action	Individual/social action
Medicalisation	Self-help	Medical/self-help
Professional dominance	Collective responsibility	Collective responsibility
Expertise	Experience	Expertise to complement experiences
Individual identity	Collective identity	Individual/collective identity
Prejudice	Discrimination	Prejudice/discrimination
Care	Rights	Care combined with rights
Control	Choice	Control combined with choice
Policy	Politics	Political and policy change
Individual adjustment	Social change	Individual adjustment & social change

Source: Imrie & Hall (2001)

Colenbrander (2005) applied the concepts of the biosocial model to the specific case of visual impairment (figure 2.1). In this model, visual loss is divided into four different aspects. *Visual disorder* and *visual impairment* are directly related to the organ and the anatomical and functional changes that affect the quality of the eye. Interventions focus on the affected organ and range from medical and surgical procedures to visual aids, adaptive equipment and environmental modifications that can be made in order to improve quality of life. At the same time, *visual disability* and *visual handicap* affect individual skills and abilities and can potentially have psychosocial and economic consequences. The improvement of quality of life depends on interventions such as training and the education of the self and society. Quality of life however, can also be improved with the correct implementation of adapted equipment and environments that will allow for the realization of individual potential and the development of positive self-esteem. The biosocial model allows for specific attention to be given to the individual while still acknowledging the role of society in recognizing their skills, abilities and possible interventions that can be put in place.

Figure 2.1 - Clinical and social aspects of visual loss

Visual Disorder	**Visual Impairment**	**Visual Disability**	**Visual Handicap**
← The organ →		← The person →	
Anatomical changes	Functional changes	Skills & abilities	Psychological, social & economic consequences
QUALITY OF THE EYE		**QUALITY OF LIFE**	
↑	↑	↑	↑
Medical/surgical intervention	Visual aids, adapted equipment & environmental modification		Social interventions, training, counselling & education

Source: Adapted from Colenbrander (2005)

In his book Disability Rights and Wrongs Tom Shakespeare (2006) argues that disability movement in Britain has stagnated.[8] This stagnation being the result of not only the extremism inherent in some social approaches (at its most extreme, some social discourses of disability have rejected the role of biology and the impact of impairment on the person as an organic entity) but also the lack of clarity about future priorities. For Shakespeare (2006), the notion of society as disabling was a good idea but one that "became ossified and exaggerated into a set of crude dichotomies which were ultimately misleading" (p. 13). There are no such things as barrier free environments but we can definitely conceive of spaces that can minimize some of the inconveniences of impairment (Shakespeare, 2006). Shakespeare (2006) however, goes beyond criticism to offer a new conception of disability, which echoes many of the ideas of the biosocial model. Of particular interest is the notion that the social model is only one of the progressive approaches committed to improving the lives of disabled people. By looking at disability writing in the UK produced before the "overtake" of the social model such as those proposed by the *Liberation Network of People with Disabilities* and disability theory in different countries, he argues for a relational model based on an interactional understanding of the interplay between the individual and a wide variety of social and other structural factors. This is a critical realist approach in which there is an acceptance of an external reality and allows for the recognition of the body and body impairment - a holistic approach that incorporates both the notion of individual and extrinsic factors imposed by the culture, policy and the overall surrounding. It avoids the reductionist criticism given that limitations are understood as the interplay between impairment and the particular context/environment. As we shall see in the next section, many of these ideas are echoed in the International Classification of Functioning (ICF), which can be considered perhaps the most important and progressive revision of International Classification of Impairments, Disabilities and Handicaps (ICIDH) proposed by the Wold Health Organization in the 1980's.

2.3 The concept of disability

The concept of disability is ambiguous, subject to interpretation and as a consequence has acquired variety of meanings many of which continue to be the subject of debate among professionals and the disabled. Imrie and Hall (2001) remark that even in our modern days disability "is a highly contested and culturally fluid term in that there is no singular meaning or understanding of it which easily transcends time and place" (p. 43). An individual's conception of disability and even the language used to when talking about a disabled person will depend on several factors and can be influenced by television, radio, contact with other disabled people, personal experience with a disability, family and friends.

The definition of the word disability has gone through some important changes in recent history. Traditionally, the concept of disability focused almost specifically on the limitations imposed by the physical, perceptual, emotional and intellectual characteristics of the impairment. Since the 60's there has been a series of attempts to develop a conceptual schema that would describe and explain the relationship between illness, impairment, disability and handicap (Oliver, 1996a). By the 1980's the WHO published the International Classification of Impairments, Disabilities and Handicaps (ICIDH). For years this manual would serve as the basis for academic and professional studies on disability and the provision of goods and services relating to the consequences of disease and disorder. The following definitions were given (Wood, 1980):

1. Impairment: Any loss or abnormality of psychological, physiological or anatomical structure or function (i.e., loss of eyes, limbs).

[8] Shakespeare mentions that this stagnation is also the result of a generational effect as many important lobbyists have retired or passed away.

2. Disability: Any restriction or lack (resulting from an impairment) of ability to perform an activity in the manner or within the range considered normal for a human being (i.e., the inability to walk resulting from the loss of a limb or to the inability to see resulting from the loss of eyes).
3. Handicap: A handicap is a disadvantage resulting from impairment or a disability that limits or prevents the fulfilment of a role that is normal (depending on age, sex, and social and cultural factors) for that individual (i.e., the inability to read print).

Not long after publication, these definitions were criticized for emphasizing the concept of normality. By classifying impairment as an abnormality in function and disability and handicap as the inability to perform an activity or a social role that is considered normal, the guidelines provided by the WHO absolved society from any form of ableism. In the UK the Union of the Physically Impaired against Segregation (UPIAS) had already proposed (early 70's) a set of definitions that moved away from the concept of normality. These would later from the basis of the social model (Oliver, 1983):

1. Impairment: Lacking all or part of a limb, or having a defective limb, organ or mechanism of the body.
2. Disability: The disadvantage or restriction of activity caused by contemporary social organization that takes no account of people who have physical impairments and thus excludes them from participation in mainstream social activities.

Only two years after the publication of the ICIDH the Disabled People's International (DPI) was one of the first bodies to challenge and rework these definitions by proposing the following alternative definitions (DPI, 1982):

1. Impairment: The functional limitation within the individual caused by physical, mental or sensory impairment.
2. Disability: The loss or limitation of opportunities to take part in the normal life of the community on an equal level with others due to physical and social barriers.

Oliver (1996a) argues that a basic element that separates these definitions is the issue of causality. In the definitions proposed by the WHO there is a clear causal relation between impairment, disability and handicap. The DPI definition however, moves away from the causal link between impairment and disability as disability is strictly considered a social construct. However noble this argument may be it seems that in the attempt to "cure" the definitions developed by the WHO, the DPI placed the full blame on society and ignored the reality of living with a functional limitation. As it is has been previously argued, this type of dichotomous thinking is fruitless. In the early 90's Nagy (1991) proposed a definition of disability that at least attempted include both the reality of functional limitation as well as the disabling character of society:

1. Active pathology: Interference with normal processes
2. Impairment: An anatomical, physiological or mental deficit.
3. Functional limitation: Restriction of one of more of the senses (hearing, seeing, walking, touching/grasping) or the ability to perform mental tasks
4. Disability: Limitation in performing socially defined roles either in family life, education or work.

In the 1990's the WHO began a long process of re-examining the definitions proposed in the ICIDH. It was an attempt to correct for overlaps in the manner impairment, disability and handicap were operationalised. The goal was to further develop the concepts of disability and handicap as social constructs in order to achieve an international standard that would enable comparisons to be made between different societies and culture. The new definition would also incorporate a fourth dimension regarding the impact of the environment and social barriers and move away from more reductionist views (Imrie, 2004). The ICDH-2 and later the International Classification of Functioning (ICF) proposed three dimensions by keeping the term impairment but replacing the concepts of disability and handicap by the neutral terms activity (or activity limitation) and participation (or participation restriction). In this manner, disability was defined as the outcome of the interaction between people with impairments and the environmental and attitudinal barriers they may face. This was an important step in the development of a balanced and rational definition of disability, which much like its predecessor will surely influence public policy worldwide (Bickenbach, 1999). The ICF is not merely a shift to the social model (as this would be reductionist in itself). Disability is seen as a relational phenomenon, a link between impairment and the socially created barriers and disadvantages faced by disabled people. Table 2.2 provides a formal definition of these concepts along with others used in the ICF.

The ICF stresses health and functioning rather than disability. It mainstreams the experience of disability and acts as a tool for the measurement of functioning in society (WHO, 2002). In addition, it builds on the biosocial model by adding a psychosocial perspective that synthesizes the interaction between health condition and other contextual factors. This includes environmental factors (social attitudes, architectural characteristics as well as legal and social structures) and personal factors (gender, age, character, social background, education, coping style as well as a variety of other factors that can influence the individual's experience with disability).

The ICF was envisioned as a "scientific tool for a paradigm shift from the purely medical model to an integrated biopsychosocial model of human functioning and disability (WHO, 2002, p. 19).[9] It is without any doubt a welcome change to the definitions found in the original ICIDH and will serve as an important basis in the measurement and formulation of policy affecting all types of disability. The concepts of activity and participation (limitation and/or restrictions) have added an important dimension to the overall model by reconceptualizing the relationship between impairment disability and handicap.

Table 2.2 - Concepts as defined by the ICF

Body functions are physiological functions of the body systems (including psychological functions).
Body structures are anatomical parts of the body such as organs, limbs and their components.
Impairments are problems in body function or structure such as significant deviation or loss.
Activity is the execution of a task or action by an individual.
Participation is involvement in a life situation.
Activity limitations are difficulties an individual may have in executing activities.
Participation restrictions are problems an individual may experience in involvement in life situations.
Environmental factors make up the physical, social and attitudinal environment on which people live and conduct their lives.

Source: World Health Organization, 2002

Imrie (2004) evaluated the theoretical underpinnings of the ICF and noted that although positive and constructive, the framework still provides a somewhat "uneven guide through the competing conceptions of disability" (Imrie, 2004, p.19). He argues that the ICF fails provide enough details regarding the relational nature of disability limiting its capacity to influence and educate users. For Imrie, the ICF requires further development in three particular areas. First, the redefinition of the nature of impairment to make more explicit the body constraints imposed by impairment and the manner in which the impaired body is capable of "enframing life experience" (Imrie, 2004, p. 9). That is, how

[9] For more details please consult the WHO manuscript: "Towards a common language for functioning, disability and health" (WHO, 2002).

the biological body can and does influence functioning and health. Second, the clarification of the content of *biopsychosocial* theory to incorporate the theoretical origins of the model as well as a justification for the adoption of the biopsychosocial model as the basis for the ICF. Third, the clarification of the meaning and implications of universalisation and the idea that universal policies are unable to take into account the wide variety of human situations inevitably projecting or prioritizing the interest of specific groups (see Imrie, 2004). This is perhaps the most important criticism as it has important repercussions in the development of disability-oriented policies.

2.4 Geography and disability: Implications for planning and design

Geography is fundamental to the understanding of the social, economic and political opportunities and constraints that affect the lives of the disabled (Imrie, 2000). As noted by Imrie and Edwards (2007) social identity and process are "not independent of spatial or geographic points of reference" (p. 623). We have come a long way since Golledge first published his visionary article on geography and the disabled (Golledge, 1993).[10] His call for geographic expertise to lend a hand in solving many of the problems faced by the disabled when negotiating the physical and built environment has led to countless research projects in cognitive mapping, accessibility, mobility and design. A quick browse through the latest proceedings of the American Geographers Association conference in San Francisco (AAG, 2007) is enough evidence that disability has become an important topic and that it has attracted the attention of a variety of researchers from different branches in geography. Geographical research on disability can be crudely separated into two interrelated branches. The first deals with the design and planning of the built environment. That is, the adaptations, modifications that can be made in order to create an environment that is more responsive to the needs of the disabled. This branch also includes all types of assistive technology that can be used to facilitate the mobility and navigation in these environments. The second branch, one that often runs analogous to research conducted in psychology, deals with the perception and cognition of space and the organization and relationship of objects contained within it. This section will discuss disability and geography strictly in the sense of planning and design. The remainder of this thesis will address the second question in the context of blindness and visual impairment.

[10] The author chanced on this article while still an MPhil student in Urban Planning at the Bartlett. In time this article and the discussions that followed (Imrie, 1995; Gleeson; 1995 and Butler; 1995) proved to be one of the major motivations for his doctoral work.

City space was built for the sighted. It has been constructed with no or little reference to the needs of the disabled and more specifically those who are blind or visually impaired. It does not matter where you are in the world it is obvious within minutes of walking that the design and layout of the urban environment, urban furniture (posts, telephone booths) and signage favour the visual sense. For blind and visually impaired pedestrians this environment presents a variety of barriers that prevent safe movement and access. Design, is ultimately a reflection of social attitude – attitude being shaped by experience and education. Imrie and Hall (2001) identify at least four fallacies about disability that propagate unconscious design and inhibit change.

1. Demand fallacy: The false belief that there is insufficient demand expressed by the disabled for the creation of accessible environments. That is, the notion that there are too few disabled individuals using public (or private) facilities in order to justify modification or the creation of new accessible environments. Clearly this is a self-fulfilling logic given that if environments do not provide for the disabled, the disabled will choose not to frequent it.
2. Cost fallacy: The exaggerated notion that the provision of accessible buildings and environments is prohibitively expensive. Land markets are profit oriented but according to Imrie and Hall (2001), the provision of access does not usually exceed more than 1.5% percent of the total cost of design. In addition, by providing for the disabled property owners are tapping into a "hidden economy."
3. Wheelchair fallacy: The tendency to reduce disability to a singular form of mobility impairment. Despite the variety of impairments, disability is often associated with wheelchair use. This notion dominates government documents and directives (see section 12 of the DDA) affecting the manner property owners, architects and designers conceive of space. The provision of access to accommodate for wheelchair use is insufficient. In the UK, it is estimated that only 5% of the total disabled population are dependent on wheelchair for mobility[11] and of these only 1% are depend on it at all times (Imrie and Hall, 2001).
4. Technical & technological fallacy: The false notion that the problem of accessibility can be solved through technical and technological design changes without recourse to political and cultural attitudes and practices. Providing for access is more than changing fixtures and fittings. Technical and technological innovations must be accompanied by social change.

Given the heterogeneous nature of impairment, it seems impossible that a specific design will cater to the access needs of the entire disabled population. Each disabled person will have his/her own access needs. This however does not mean that it is impossible to create environments that are friendly and welcome to different forms of disability. Clearly there will be overlaps. Property developers, architects, designers and consultants should capitalize in situations where the needs are similar. Designers and architects tend to

[11] Source: http://www.teachernet.gov.uk

perpetuate aesthetic ideas, which are based on a one-dimension conception of the human form. In many cases, attention to the function of a building is forfeited in exchange for ornamental and decorative design. One way to deal with these disablist attitudes is to include individuals with disabilities in the design process and request feedback after the project is competed (Butler, 1994). Consulting with them prior to building or making modification can provide important insights regarding the costs and benefits of a project.

2.4.1 Blindness, low-vision and the built environment

Vision plays a crucial role in the acquisition and development of spatial knowledge. It allows for the quick and accurate coordination of action and movement in relation to what is being directly perceived or what is mentally stored. It is for this reason that Golledge (1993) notes that the congenitally blind can only know "impoverished environments." Impoverished relates to the incompleteness or the distorted experiences of these individuals. This is not about the blind being socialized into an inferior category of society (Imrie, 1996) but the undeniable fact that the total or partial absence of vision can impose several restrictions to activity and movement patterns. Sensory limitation affects the decision making process during navigation as more time is required for the absorption, comprehension, storage and retrieval of environmental information.

The blind move about in routes. Anyone who has worked with the blind can attest for this, as it comprises part of the basic teaching of orientation and mobility. Movement is limited as navigation is highly dependent on prior experience and practice. In this manner, disability can be said to shrink the space/time prisms of individuals as a disabled person's experience, awareness and overall knowledge of the built environment is more constrained (Jacobson, 1999; Golledge, 1993). The ability to build accurate mental representations of space, and more important the ability to operate based on these representations will depend on the spatial abilities of the individual but also on quality and form of the environment in question. Shortcutting for example something that is often regarded as challenging for the blind as it requires a configurational knowledge of the environment, is a factor of both the accuracy of mental representation (and the ability to perform mental operations) and the fact that shortcutting requires navigating through unknown and potentially unfriendly environments.

One of the major problems associated with mobility in the total or partial absence of vision are the difficulties that blind and visually impaired individuals have previewing and pre-processing spatial information (Golledge, 1993). Vision allows for previewing which facilitates the development and implementation of a variety of heuristics for navigation such as choosing the appropriate path and avoiding obstacles. The urban environment is filled with obstacles and barriers that can limit movement and *impoverish* the knowledge of disabled individuals. Curves, and in particular slight angled curves, can be hard to detect and seriously disorienting. Hutchinson (1998) notes that the blind and visually impaired may have an easier time negotiating environments that are angular rather than curved. Yet, the downtown of most European cities is characterized by a non-grid complex set of pathways and dead-ends. Navigation in such environments will for the most part depend on prior experience, training and the help of others. A gridded pattern or a repetitious design style can also be disorienting. This is the case in hospitals or large offices where the design of each ward or area is similar. Long corridors, high ceilings, carpets and other situations where sounds or echoes cannot bounce back can also be problematic.

Table 2.3 - Barriers faced when navigating the urban environment

Physical barriers	Human/socio interaction barriers
Urban furniture (i.e., benches, water fountains, telephone booths, mailboxes, benches, signposts, plants, trees, terraces,)	Unprotected natural/man made hazards (i.e., bodies of water, street construction, cliffs)
Lack of railings	Traffic
Badly placed ramps	Travel access
Non-standard fixtures	Lack of signage or badly placed signs
Gradient	Crowding
Large-irregular open areas	Lack of communication
Unprotected construction/repair	
Bollards	
Transparent surfaces (glass doors)	

Adapted from Golledge (1996; 1993)

The blind and visually impaired are also disadvantaged regarding their access to information (Passini & Proulx, 1988). Typical urban signage is often unavailable in a medium that caters to their needs. Considerable work is being conducted on the development of clear, functional and informative tactile maps but their implementation is yet to become common practice. Any form of tactile aid, whether is Braille on a wall or toilet door or a tactile map of a shopping centre, must also be strategically positioned for quick and easy detection. It makes no sense in putting up a state of the art tactile map at a shopping centre if the actual map cannot be found by blind and visually impaired patrons. To this we must add that issue of sensitivity threshold for the discrimination of audio and tactile information. Audio and tactile cues must be provided in a format that can be easily discriminated from other environmental cacophony and must cater to widest range of visual impairments and conditions. Figure 2.2 illustrates some of these barriers and the dangers they can impose. Table 2.3 presents a list of physical and human/socio interaction barriers that are found in most urban areas.

Architects, planners and designer have come up with several intelligent solutions to aid navigation in open urban environment and buildings. Below is a short list of these easily to administer interventions. Figure 2.3 provides a few concrete examples of how these have been implemented:

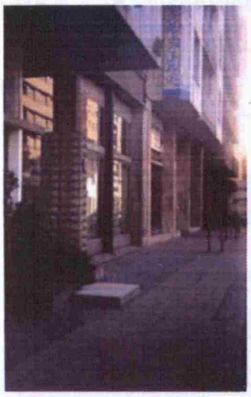
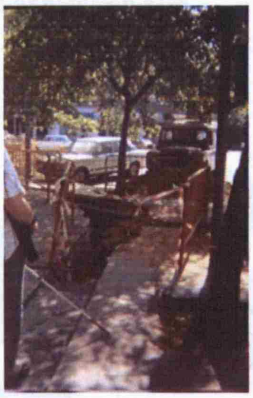
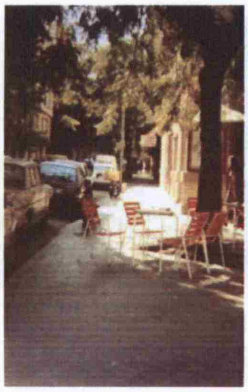
1. Colour contrast: Colour contrast is a simple and effective way to increase the responsiveness of an environment. Contrasting facilitates recognition and can help individuals find and avoid objects as well as their general navigation.

2. Tactile maps: Maps are excellent tools for communicating information regarding the overall relationship between different objects in space. Unfortunately, the majority of maps have been designed for the sighted. The conventional graphic map rather difficult to interpret by someone who has low-vision and of absolute no use for someone who is blind. Tactual maps have been shown to be considerable aids to navigation (see chapter 7). It is up to planners, designers, architects, real estate developers and owners to include them in public spaces along with those designed for the sighted.

3. Lighting: Lighting is the essence of vision[12] and appropriate lighting levels can be a powerful aid to mobility. This however, can be difficult to implement as different individuals have varying lighting needs. Designers should aim at creating spaces where lighting levels can easily be adjusted to suit the individual. In general, environments should be evenly lit without any abrupt light changes. Designers should also take into consideration the reflective characteristic of surfaces as these can also be highly disorienting. This is usually the case with glass, bright steel and other glossy surfaces. In some situations surfaces that are not necessarily reflective can become because of a change in weather i.e., asphalt after rain.

[12] A small anecdote on lighting and the inanity of society: The Royal London Society for the Blind is located at the end of Wildernesse Avenue in Sevenoaks, Kent. Wildernesse Avenue is a private road of mansions that has one of the highest real state values in all of the United Kingdom. In an "effort" to stick to countryside living, some residents of these houses are presently in a legal battle against the college because they want the college to turn off their campus lights during night time. Students from Dorton College are forced to navigate in the dark until the issue is solved. This is particularly distressful in the winter months when lighting levels rapidly decrease in the evening. In many cases, students are forced to be escorted by sighted staff who themselves have problems navigating.

Figure 2.2 - Urban barriers

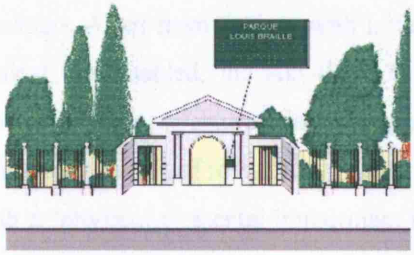
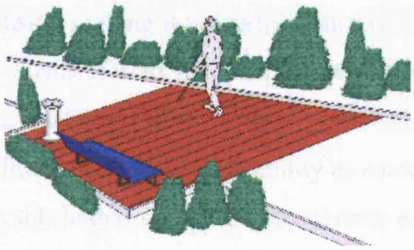
(a) Protruding façade	(b) Unattended construction	(c) Unprotected scaffolding
		
(d) Poorly placed containers	(e) Street cafe	(f) Diagonal crossing
		
(g) Crossing barrier	(h) Driving obstacles	
		

Source: ONCE, 2003

4. Surfaces & pathways: Contrasting surfaces can act as useful navigation guides and indicate particular features in the environment. Surfaces should be non-slip and even. A distinct surface can be used as a pathway to a particular place (see figure 2.3e). Individuals can follow the path by keeping track of the surface in the bottom of their shoes or with their cane. Navigation seems to be easier in flat surfaces. When the environment is not flat, level changes such as steps and ramps should be clearly marked (different surface can be used to identify the approach) and complemented by

handrails. There are many examples of tactile surfaces. A modified blister pattern (fig. 2.3d) is used to indicate the limit in sidewalks, the edge of stairs, ramps or escalators. In some cases, surfaces are raised (fig 2.3c) to indicate a street crossing.

Figure 2.3 - Environment based navigation aids

(a) Well placed signage	(b) Different textures
	

(c) Raised crossing	(d) Limit guide	(e) Textured pathway
		

Source: ONCE, 2003

5. Technical aids: A variety of technical aids have been developed with the purpose of helping navigation by providing spatial information to senses other than vision. The *Sonic Guide* (Kay, 1973) and the *Nottingham Obstacle Avoider* (Dodds et al., 1981) use ultrasound to provide information about objects in the environment and serve as hazard identifiers. Other technological aids such as the laser cane or *Mowat* sensor use the intensity of sound vibrations to provide distance information to nearby objects. Since the late sixties, Paul Bach y Rita has worked on a series of sensory substitution devices, the most famous known as the *Tongue Display Unit* (TDU) where environmental information is captured through a camera and reproduced to a device that is placed on the tongue. The device consists of gold-platted copper electrodes that are organized a 10 X 10 pixel matrix that reacts to contrast picked up by the camera identifying the location objects in space (Bach-y-Rita, 1972; 1967). These devices however, only provide useful information in terms of obstacle location and avoidance. They do not provide a frame of reference or contextual information. Researchers at the University of California Santa at Santa Barbara have been working for over a decade on technological devices designed to provide pre-view information using Global Positioning Systems (GPS), Geographic Information Systems (GIS) as well as audio cues and verbal descriptions (Golledge et al., 1991b).

2.5 Summary and discussion

In April of 2005 a new version of the Disability and Discrimination Act (DDA) was passed by the English parliament amending many of the provisions set forth by the 1995 DDA (DDA, 2005; 1995). The purpose of the DDA was to provide disabled individuals with rights regarding employment, education, and access to goods, facilities and services including the buying or renting of land and property and minimum access for public transport. Apart from dealing with issues of inclusion making it unlawful to discriminate against the disabled, the Act (Part 3) required businesses to take *reasonable steps* to correct or replace features that act as barriers to disability (DDA, 1995).[13] Interestingly (and despite years of revision) the 2005 DDA defined a person with disability as someone with a "physical or mental impairment that has a substantial and long-term adverse effect on his or her ability to carry out normal day-to-day activities" (DDA, 1995).

In England and Wales the mechanism for securing access to public buildings is found in *Part M* of the Building Regulations. The goal of the Building Regulations was to set performance standards for the design and construction of buildings. This included the workmanship, safety, energy conservation and accessibility and applies to all new buildings, building extensions and material alterations. The success of *Part M* will depend on the effectiveness of policies and guidance that stem out of the DDA. It is in this arena that the guidance inherit in the social model of disability must be enforced. The over preoccupation with aesthetic qualities to the demise of function and access, the inclusion of disabled individuals in the design and decision making process and even the correction of vague and slippery terminology such as "reasonable steps" or "minimum standards" that is commonly employed in legislative documents must all be taken into account if changes are to occur.

Disability is a complex phenomenon and as we have seen neither model can account for it on its own. Disability is a functional limitation imposed by impairment and it is also a pervasive social construct demeaning the competence of individuals. The medical model failed to take into consideration social factors that can have a disabling effect, it tended to be value loaded and imposed a false belief about normality. The social model redefined disability in terms of a disabling environment and relations. Disability was socially and culturally constructed. It put the onus on society and refocused society's responsibilities towards the disabled. However, striving for change many proponents of the social model

[13] For further information on the Disability Discrimination Act please refer to: http://www.direct.gov.uk/en/DisabledPeople/RightsAndObligations/DisabilityRights/DG_4001068

lost track of the reality of functional limitations that result from impairment.[14] It seems that in the attempt to separate the "oppressive social experience of disability" (Gleeson, 1996, pp. 391) from the functional limitations imposed by impairment, the historical materialistic view presented in the social model has in itself reified the concept of disability. It is one thing to believe that the abilities of the disabled are culturally and historically conditioned. It is another to deny the relationship between impairment and disability. This reification, as mentioned in the opening lines of this chapter, is a product of the repudiation that we live and will continue to live in an able-bodied society and that we can achieve concrete results only by talking about disability and not giving any concrete examples of the abilities and differences of the disabled.

The biosocial model accepts the fact that impairment can actually cause limitations but that many problems also arise due to social attitudes and prejudices. The model is grounded in reality as it acknowledges the difficulties of some disabled people to function in society but it also recognizes that many social changes can take place that will help fulfil their potential. Environmental modification is clearly not the "principal, or only tactic available for combating disability" (Gleeson, 1996, pp. 392). Education still remains the most important tool for change. Let us shift the disability debate to focus on educating society regarding the potential and abilities of the disabled. Through concrete examples, let us make evident the reality of an able-bodied society and give the disabled the confidence to cope and feel recognized and accepted as individuals in their own right (Lowenfeld, 1981). As remarked by Shakespeare (2006), the way forward relies on the adoption of an alternative and relational view where disability is neither reduced to an individual medical problem "nor regrets the predicament of bodily limitation" (Shakespeare, 2006, p.2). Finally, this interplay between individual and contextual factors (individuals are disabled by their bodies and society) has important implications for the discipline of geography and the advancement and proliferation of research on the *geographies of disability*. Research that goes beyond the problems associated with physical barriers, which often regards disability as something that can be treated by recourse to a technical solution (Imrie & Edwards, 2007), and incorporates the significance of social-political and environmental contexts and their role in the production of disabling spatialities (Imrie & Edwards, 2007). This includes the actual

[14] Here it is important that we differentiate between what Oliver (1992) meant by the social model. Oliver (1992) stated, that the way forward in the disability debate is to determine "which aspects of disabled people's lives need medical or therapeutic interventions, which aspects require policy developments and which require political action" (p. 33).

production of disabling environments (not only by architects, planners and designers either through institutional or political processes), the relationship between identity and space, space technology and the body as well as the actual opinions of disabled people about social research (see Imrie & Edwards, 2007 for more examples of emerging research).

Chapter 3
Blindness and visual impairment

> "Face your deficiencies and acknowledge them; but do not let them master you. Let them teach you patience, sweetness, insight." – Helen Keller (1920, p. 112)

3.1 Introduction

In the previous chapter we discussed disability in relation to geography, planning and design. In this chapter we consider in more detail the concepts of blindness and visual impairment. Special attention is given to the terminology where a functional approach to the definition of blindness and visual impairment is proposed in order to complement past definitions that focus on medical and clinical measures. Data on the prevalence and incidence of visual impairment is also presented with a focus on the United Kingdom. The chapter concludes with a discussion of several issues related to psychosocial adjustment noting that there is a general lack of knowledge when it comes to blindness and visual impairment. This lack of understanding is often responsible for the propagation and perpetuation of many myths and misconceptions, "some innocuous but others inimical" and responsible for many blatant discriminatory practices (Barasch, 2001).

Only a limited number of studies in geography have considered the social and psychological impacts of visual impairment. For the most part, these questions are treated separately and no real link is made between psychosocial adjustment, mental representation and spatial ability. Some researchers are careful to consider different aspects of development and maturation in the total and partial absence of vision (see chapter 4) but this is usually limited to a discussion of norms or stages and conclusions are often drawn solely based on comparisons between the sighted and the visually impaired. In addition, developmental research is by essence longitudinal, blurring the direct relationship between the individual, the environment and society. The overall analysis can lack coherence as different groups are studied at different periods. To focus on specific social and psychological issues is to study in real-time the impact of visual impairment, to single out the problem and consider the appropriate intervention. This chapter draws heavily from the author's experience living and working with the students at the RLSB, and is an essential contribution to the debate about the abilities of the blind and visually impaired. After all, performance and competence are fundamentally related to psychosocial adjustment and wellbeing.

3.2 Terminology and implications

Language is a paradox. It is vulnerable, forgetful and ambiguous but it is also resilient, impervious and consequential. Words are but abstract concepts. Their interpretation however, is susceptible to time, society and culture. Knowledge cultivates and experience endows it with meaning, recognition, approval or dismissal. These variations are a manifestation of the social temperament, a reflection of education, awareness and most certainly the political agenda[15]. Myths are often perpetuated because of the misuse or misunderstanding of terminology. Labelling is a slippery slope as individuals may actually become *blinded by definition.* Labelling can have significant psychological impacts and tremendous implications on self-image, personality and beliefs. The purpose of this section is to clarify a variety of terms in relation to blindness and visual impairment that will be used throughout this thesis. It will begin with an explanation of the terms congenital and adventitious and the importance of specifying the age of onset when discussing visual impairment. This will be followed by a definition of partial sight, legal blindness, low-vision and blindness. Definitions can sometimes vary depending on the country. This discussion will focus on definitions provided by the World Health Organisation (WHO) and those accepted and used in the United Kingdom.

3.2.1 Congenital and adventitious visual impairment

The age of onset impairment can have an important effect on the life of individuals who are blind or visually impaired. The total or partial absence of vision at birth and infancy can affect the manner individuals will access information and the strategies they will use to control and react to it. The age of onset impairment will also have considerable implications on the academic and mobility strategies that will be used educate these individuals. Individuals who are born blind must rely on their other senses and will

[15] In many cases labelling (the use of a specific term to describe an individual or group) was specifically used to demonstrate eligibility for government-funded services.

require a different style of teaching. Two terms are usually employed when describing the period when individuals have lost their vision:

1. Adventitious: The term *adventitious* is used when the condition was acquired after birth as a result of genetical, infectious or accidental reasons. The term implies that vision was lost after individuals had a certain amount of experience with it. Huebner (2000) characterizes an individual as adventitious when vision is lost after visual memory is established. The age in which visual imagery is established has long been an issue of debate. Nowadays, it is often considered to be around the age of five (Corn & Koenig, 1996a; Lowenfeld, 1981).

2. Congenital: The term *congenital* is used to describe a disease or condition that exists at or from birth. In many cases however, the term congenital blindness or visual impairment is extended to include those individuals who lost their vision before visual memory was established.

3.2.2 Legal blindness & partial sight

Up until the 20th century individuals without sight were usually referred to as "blind" even if they had some form of functional or residual vision. In time, organizations such as the WHO began to use the term *legal blindness* to characterize a variety of visual impairments that left the individual with some vision. Individuals were considered legally blind either in regard to their visual acuity when their central visual acuity of the better eye was 20/200[16] or less (6/60 metric) or had a constriction of their peripheral vision[17] such that their central acuity was more than 20/200 but their peripheral field was constricted to twenty degrees in the better eye.

The "diagnosis" of legal blindness does not take into consideration any aspect of light or contrast sensitivity (Jose, 1983). Photophobia, a condition in which the eyes are very sensitive to light, can affect the use of vision under normal lighting conditions and will almost certainly influence the general behaviour of the inflicted individual. Another problem associated with the concept of legal blindness is the mismatch between the clinical diagnosis and the actual potential behaviour of individuals. As observed by Corn and Koenig (1996b) the fact that a person has a 20/200 visual acuity or a severely

[16] Normal visual acuity is 20/20 (metric 6/6). A person with a visual acuity of 20/60 sees at 20 feet what a fully sighted person sees at 60 feet.

[17] Normal field of vision for both eyes usually extends to 180° (ninety degrees to either side from the centre).

constricted visual field "does not imply that a person will or will not be able to catch a ball, visually recognize a friend... or use vision when clearing dishes off a table" (p. 6).

Finally, the concept of legal blindness is a dangerous one as it can have negative psychological implications. As mentioned in the introduction to this chapter, individuals labelled as legally blind can actually become *blinded by definition*. By this we mean the manner in which the labelling or the categorization of the physical characteristics of individuals by society influences their social, legal and personal identity (Corn & Koenig, 1996a). It is a form of reification[18] whereby individuals who still have some sort of residual functional vision but who are constantly classified as *blind* or *legally blind* actually begin to doubt the extent to which their vision is useful and begin believe and act as if their vision was completely impaired. Blindness in this manner is an emotional state, a logical fallacy - a hypostatisation of the terminology.

The term partial sight has been used to describe individuals with a best-corrected visual acuity of 20/70 to 20/200. In some cases, individuals are separated into high or low partials (Corn & Koenig, 1996b) depending on the extent of their residual vision. In this thesis we will avoid the use of the terms legal blindness and partial sight and use term low-vision or visually impaired instead. The author will also use the concepts "partial and total absence of vision" to differentiate between individuals who are visually impaired from those who are blind.

3.2.3 Low-vision

The term low-vision was developed by the *American Medical Association* as an attempt to isolate individuals who were in need of special care because of their visual impairment. To have low-vision entails the need to enhance or make adjustments in order to correct for poor vision. The term is in itself relatively value free as it pushes away from association with impairment, disability and handicap. Yet, there is no legal or universally accepted definition for the term. Many tend to be based on medical or clinical measures that downplay the extent to which individuals can actually use their residual vision in their daily lives. That is, the practical or functional use of vision is usually forfeited for clinical descriptions and classifications.

Interesting enough, the most widely used definition, that by the WHO, tends to be clinically biased focusing on the visual acuity or a particular constriction of the visual

[18] Reification should not be understood in a strictly Marxist fashion but instead as the notion of treating or regarding a concept (or an idea) as a distinct substance or reality.

field and not the extent to which a person can use the remaining acuity, or field of vision in order to function. People vary a great deal in terms of their ability to use their remaining vision. As early as the 1960's researchers such as Berthold Lowenfeld were already discussing the need to change the definition of low-vision to emphasize the functional characteristics of vision in the examination and classification of individuals. Definitions should incorporate both the medical/clinical and the functional aspects of vision. For the purpose of this thesis we will use the medical/clinical definition as a starting point in the classification but this classification will be fine-tuned with recorded and observed details on each subject regarding the functional aspects of their vision. In this manner, a person who is visually impaired can be defined as someone who in conjunction with a medical assessment " has difficulty accomplishing visual tasks, even with prescribed corrective lenses, but who can enhance his or her ability to accomplish these tasks with the use of compensatory visual strategies, low-vision or other devices and environmental modifications" (p.4).

3.2.3.1 Functional vision

There has been considerable progress in the understanding of low-vision. Lowenfeld (1963) notes that in the past ophthalmologists did not encourage the use of residual vision. This is no longer the case as professionals now seek to maximize the use of functional vision and recommend individuals to use their sight without any restriction. This new perspective allowed for the incorporation of an educational element in the definition. As observed by Ashcroft & Harley (1966) individuals with low-vision are many times impeded in their education if no interventions are made. The extent to which residual vision is used will vary from person to person. It is not uncommon to see two individuals with the same visual acuity or restricted peripheral vision who behave in a completely different fashion. Some individuals may rely to a greater extent on their residual vision while others will adopt strategies that will maximize the use of their other sensory modalities.

3.2.4 Blindness

The concept of blindness is both generic and imprecise. It is estimated that 75% of individuals that are considered blind have some remaining functional vision (Moore et al., 1997). There is still a significant amount of confusion between the social conception of blindness as the total absence of sight, legal blindness used to determine eligibility for government-funded services, and blindness based on a clinical analysis of minimal acuity level and field constriction as defined by the WHO. According to Huebner (2000) it is not uncommon for professionals to jot down "blind" when a person is severely visually impaired while even light perception can help individuals to locate objects, orient themselves and avoid obstacles. Similar to low-vision, there is a tendency to ignore the remaining functional vision of individuals that are classified as blind. Dodds (1988) notes that the majority of individual registered as blind have sufficient residual vision to benefit from low-vision training and that the legal definition can many times impede the development and teaching of low-vision strategies. For this reason it is critical that we define blindness and clarify the manner in which this term will be employed throughout the thesis and particularly in the experiments conducted at the RLSB.

The WHO defines blindness as visual acuity of less than 3/60, or a corresponding visual field loss to less then ten degrees in the better eye with the best possible correction. For the purpose of this thesis we will reserve the use of the term *blind* specifically to refer to individuals that have a total lack of vision and those with varying degrees of light perception. Light perception (LP) will usually be acknowledged in brackets. In this manner, visually impaired will be used to refer to the group of individuals whose sight is limited but who still have a certain amount of functional residual vision. Two visually impaired groups (mild to moderate & severe to profound) will be created based on the International Council for Ophthalmology multiple ranges of vision classification.

3.3 Myths and misconceptions

Progress depends on the replacement of fiction with factual information. Blindness and visual impairment have generated a variety of myths and legends that continue to be perpetuated in our society. The opinions and attitudes of the general public can have important implications not only on the education, socialization and employment but also on the manner in which individuals that are blind or visually impaired view themselves. In many cases, these myths are perpetuated by institutions that fail to adapt their names. This is the case with The Canadian National Institute for the Blind (CNIB), The Royal National Institute for the Blind (RNIB) or even The Royal London Society for the Blind (RLSB) among many others. These institutions continue to use the term *blind* when the majority of the people they treat, teach or work with are not blind but have various degrees of *low-vision.* This stubbornness is often the result of tradition, history and the unfortunate belief that these terms are interchangeable. Regrettably, it seems that in many situations the world *blind* is kept for marketing, public relations and funding purposes. After all, the word blind is more evocative, more symbolical and most of these institutions are charities. In the last few years, many institutions have adapted their names such as the Texas School for the Blind and Visually Impaired and The Association for the Blind and Visually Impaired (ABVI).

Below is a summary of some myths that have survived from antiquity and continue to be transmitted in mass media and culture.

1. The sixth sense: People who are blind or visually impaired do not have an extra sense. The lack of vision forces them to rely to a higher degree on information provided by the other senses. These individuals do not have a heightened sense of hearing or smell but simply pay more attention to information provided by these senses.
2. Myth of darkness: Blind people do not live in complete darkness. Darkness is a concept that requires vision and light in order to be understood. Many blind people still retain some form of light perception.
3. Braille literacy: Just because you are blind or visually impaired does not mean you can read Braille. Many individuals lose their sight later in life when it becomes harder and more time consuming to learn Braille. In addition, it is very hard to incorporate Braille into the public world.
4. Sadness & depression: The blind and visually impaired are not generally unhappy, envious and devoted to religion (Ashcroft & Harley, 1966). Visual impairment can have very strong psychosocial impacts but each person is an individual formed by a variety of experiences and an idiosyncratic personality.
5. Overuse of vision: Poor lighting, long periods of reading or writing, tasks that require fine visual acuity, long periods of watching television or computer use and wearing glasses of an incorrect prescription will not damage but fatigue the eye (Hutchinson et al., 1998).

3.4 Prevalence in the population

Calculating global and local rates of the prevalence of blindness and visual impairment is not an easy task (Warren, 1984; Ashcroft, 1959). There are two main reasons for this: First, the definition of blindness and visual impairment tends to vary from country to country making it hard for comparisons to be made. Second, estimates are based on information from individuals who are registered with the government or an independent association making it difficult to account for individuals who have not been diagnosed or registered. It is estimated that in the UK alone there are 74,000 blind and visually impaired individuals who are not receiving services, benefits and products they need simply because they are not registered. Nonetheless, the standardization and the improvement of testing equipment and techniques for the screening of conditions as well as recommendations on the definition and classification of impairment by organizations such as the WHO have helped create a certain amount of cohesion. With regard to incidence, it should be noted that the aetiology of the condition is also geographically variable. Such is the case for river blindness, a condition affecting over 17 million people (BBC Health Report, 2000) in Sub-Saharan Africa but almost non-existent in the United Kingdom.

In Great Britain[19] it is estimated that there are currently two million people with *sight problems*, the vast majority (85%) being sixty-five years of age or more (RNIB, 2007). Data from registered users reveals that around 100 people begin to lose their sight everyday and that this number is set to double over the next few years because of an ageing population and conditions such as diabetes and obesity (Ekstrom, 2006). The term *sight problems* encompasses various levels of impairment. Ekstrom (2006) notes that the term includes individuals that have a mild visual impairment that would prevent them from passing the sight test in a driving exam (VA of 6/12 → 6/18) to individuals that can be registered as partially sighted (VA of 6/18 → < 3/60) to those who can be registered as blind (VA < 3/60). Table 3.1 presents a simplified breakdown of prevalence by age of individuals with *sight problems.*[20]

Table 3.1 - Prevalence of visual impairment in the United Kingdom

Age group	Estimated population
Children (0 – 18)	25,000
Working age (18-59)[21]	43,000
Retired (65 and over)	1,900,000
Total	Approx: 2,000,000

Source: (Ekstrom, 2006)

Looking at the table we notice that the vast majority of individuals are retired and aged 65 and over although there is still considerable numbers in the working age group (43,000). While there has been a decline in sight problems that can be prevented and treated (i.e., congenital cataracts), there has been an increase in untreatable and hereditary disorders (i.e., retinal dystrophy, optic nerve atrophy). New advances in technology and medicine that allow for higher survival rates of premature babies may be behind such trends where sight problems are often accompanied by other disabilities. In fact, almost half of all children (12000) with *sight problems* have an additional disability (RNIB, 2007).

[19] These estimates do not include Northern Ireland.

[20] There is no data for individual between the ages of 60-64.

[21] Ekstrom (2006) notes that prevalence data from the working age population may be inaccurate and estimates that the real figure to be much higher than 43,000.

There are only 378,000 people who are registered as blind or partially sighted in the UK (315,000 in England; 38,000 in Scotland; 20,000 in Wales and 5,000 in Northern Ireland). It is estimated that at least another 74,000 should be registered. Out of these 180,400 are registered as partially sighted and 190,100 registered as blind. Both prevalence and incidence is highest among the elderly as they make up 95% of all people with sight problems. The report also found that older women are more likely to develop sight problems than older men although this is mainly due to the fact that women tend to live longer. Among the elderly (aged 75+), the most common cause for visual impairment is age related macular degeneration (376,000). This is followed by short-sightedness (myopia), long-sightedness (hyperopia), astigmatism and cataracts. Most of these conditions can be treated by prescribing glasses, lenses or through surgery. Furthermore it is estimated that around 25000 people in the UK have glaucoma but are not able to detect it during its early stages.

3.5 Psychosocial implications of blindness and visual impairment

Individuals who are blind or visually impaired must face the constant challenge of psychologically and socially adjusting to their disability. Tuttle (1987) defines adjustment as the process of responding to life's demands and stresses. While there is no direct relationship between impairment and psychopathological disorders (Harrington & McDermott, 1993), the heterogeneous nature of eye-conditions and the possible differences in family life, education, social and economic status suggest that adjustment is idiosyncratic – it is personalised, peculiar and dependent on the individual and his/her experience. In the paragraphs that follow, several aspects of psychosocial adjustment to blindness and visual impairment will be presented and the role of the family, peers and the society in general will be discussed in relation to the formation of a positive self-concept and the development of high self-esteem. Throughout the discussion examples will be provided from the author's research with students from Dorton College at the Royal London Society for the Blind (RLSB).

3.5.1 Age of onset impairment

The age of onset blindness or impairment can have a significant effect on the affective development of individuals (Rosa, 1993). During the years the author spent working as a life-skills tutor at the RLSB some students who were congenitally blind observed that they considered themselves lucky to be born blind instead of losing their vision later in life. These students felt that they were not missing anything because they had no idea what it actually meant to see. Jill, a blind student went as far to remark that she preferred being blind than visually impaired. For her, the total loss of a sense was more comforting than having "something that did not function properly." The view that being congenitally impaired (usually congenitally blind) is easier to come to terms with is often mentioned in the literature (Warren, 1984; Morse, 1983) but should not be over generalized. Affective development is individual and context dependent. Clearly there will be differences in the adaptation of the congenitally and adventitious impaired. Time is an important variable to consider. First, a congenital impairment forces an almost automatic acceptance of the condition. An adventitious impairment on the other hand, is often accompanied by an element of surprise, trauma and depression that requires a certain accommodation period. The shock usually affects the individual and the family and communication between both parties is essential. Training or experience should also be considered, as functional and positive self-development will depend on the individual's mastery of the other senses and/or residual vision for the organization of information and active participation in society.

3.5.2 Social classifications

Man is a social being and a person's sense of identity is dependent on the manner it is perceived by others. We adapt and live based on constant feedback from the family, the community and friends. Feedback allows for the control and organization of actions and provides checks on behaviour. The delivery of feedback is crucial and can have an important effect on one's sense of identity, self-concept and esteem. Individuals who are blind or visually impaired must rely to a greater extent on auditory and tactile cues. While this type of information still allows for the discerning of moods, emotions and can help the individual make inferences about a person's character and emotional state; it lacks the visual complement afforded by facial expressions. Morse (1983) observed that the blind are not very accurate at deducting and judging personal characteristics by voice alone. For this reason, communication must be clear, reliable and as redundant as possible.

In some individuals who are blind or visually impaired the normal appearance of the eyes can lead to a certain amount of confusion and in some cases lead to mistrust, suspicion or doubts about the degree of impairment. Roger, one of the author's most extreme cases lived through his early teen years under scorn, disrespect and was often taken for a lazy, unmotivated and careless man. In his early teens, Roger complained to his mother that he could not see very well. Together they visited a series of ophthalmologists who failed to diagnose his condition, many of them saying that they could not find anything wrong with Roger's sight. Roger's performance at school declined and some of the teachers went as far as to say that he was lying about his vision to make up for his lack of interest in school activities and his low grades. In reality Roger could barely read from the blackboard! Roger was finally diagnosed with *macular dystrophy* but the absence of any blindisms, mannerisms and the fact the he was not required to use glasses perpetuated some of the prejudice from both his teachers and classmates. Roger went on to complete school and university with minimal assistance. He developed a series of techniques that in time included the use of low-vision aids such CCTV and other type of magnification tools. He now has a successful post at the Department of Transport.

Roger's story is both shocking and a true example his mother's trust and indefatigable persistence, staying by her son's side until his condition was diagnosed and cared for. It also a reflection of Roger's own character – his courageous and hardworking nature. Despite his impairment and years of shunning, Roger never gave up on his education and eventually was able to secure a good working post. Such stories are the exception rather than the rule. These days, ophthalmologists are quite efficient in detecting visual conditions and introducing technical aids. Nonetheless, low-vision continues to be filled with contradictions. The fact that an individual is not wearing eyeglasses, carrying a symbol or white cane or the fact that the eyes appear to be unimpaired from the outside can lead to some confusion.

The way we are perceived however only partly reflects who we are. The visually impaired population is extremely heterogeneous. There are a variety of impairments each limiting different aspects of vision. The word limiting should not be taken lightly. Limit is related to vision not to behaviour in general. Morse (1983) notes that loss to the lower half of the visual field usually implies difficulties in mobility but does not mean that the individual cannot watch television, do a crossword puzzle or work with a computer. Similarly, loss to the right field is associated with difficulties in reading (reading print in western countries requires a left to right eye scanning) but does not imply a lack of independence in terms of mobility or spatial awareness. Low-vision manifests itself in contradictory behaviours. It is not uncommon to see the student with low-vision who cannot read from a blackboard but is able to comfortably ride a bicycle or the individual who can watch television from a distance but continuously stumbles on a step or curve. This lack of understanding often balloons low-vision to total vision loss or at least leads to assumptions about general ability disproportionately discrediting the individual. We must seek to understand these limits and refrain from making false assumptions and generalizations that can have disabling effects. The same is true for blindness where the uninformed assumes that those who are blind have more acute senses or that because of their loss there are incapable of independently coping with life in society. It is important to note that there are several strategies used by educators and orientation and mobility specialists that can be used to compensate for different types of conditions.

The manner in which people are labelled and classified can have important implications in their social and personal lives. At the heart of Durkheim's sociology of knowledge (Durkheim & Mauss, 1963) is the notion that classification is social in origin and a categorization and extension of reality. Low-vision has often been described as a *neither fish nor fowl* phenomenon. Visual loss is many times perceived as an all or nothing occurrence. For some reason, blindness seems like an easier concept to grasp than low-vision. We can close our eyes; walk about the room and to a certain extent place ourselves in a situation of total visual absence and try to imagine some of the difficulties associated with it. It is much harder to conceive of a situation of partial visual loss – and even more so of the different conditions and types of visual loss. Blindness in this sense is understood and classified by contrast to seeing. Low-vision on the other hand falls in a sort "grey" and uncertain area.

An incorrect classification imposes an inaccurate reality. Classifying a person with low-vision as blind can have serious limiting effects as individuals become uncertain of the extent of their residual vision and overall abilities. People with residual vision are usually labelled as blind and many times act or convince themselves that they are blind. The inaccurate labelling of low-vision can also lead to wrong decisions on the part of parents and educators. Lack of knowledge regarding the condition can force parents of children with low-vision to adopt educational strategies that do not take advantage of residual/functional vision. It can also lead to a type of over caring where the parent spoils the development of the child hampering his/her independence. Sometimes children are placed in specialist schools solely based on their acuity level while their functional vision would still make them competent candidates for mainstream education.

3.5.3 Passing

Passing occurs when an individual with low-vision pretends to be blind or sighted in order to take advantage or cope with a situation. During his years at the RLSB the author had the opportunity to watch two cases of such theatrics whose relevance to this section make it worth reporting. The first case is that of Alex, a teenager who enrolled as a registered blind student. When asked about his visual condition, Alex replied that he was blind and had no vision. He moved around with a white cane, used speech software in the computer and was learning Braille. He considered himself and was considered by others a blind student. Alex was eventually asked to participate in the author's study and was screened to be part of the blind group. During one of the tasks, when the subject was asked to construct a tactile model of the RSLB campus using scaled cardboard pieces, the author noticed that instead of asking for the pieces to be handed to him Alex was actually grabbing them from their location on the table. This behaviour was very odd considering it was impossible for Alex to reach directly with such dexterity.

Alex was not blind. After inspection of his personal file, the author discovered that he was diagnosed with *Leber's optic neuropathy* when he was fifteen. Many believed that Alex was passing as blind in order to claim a higher disability/incapacity living allowance. Free loading is not our primary concern especially if we consider that the actual claim difference is neither substantial nor extravagant. What is particularly upsetting is the fact that when passing as blind, Alex was being educated as a blind person surrendering the functional aspect of his vision. Before the sudden onset of his condition Alex was a talented cartoonist but passing as blind forced him to give up almost completely his sketching. Alex was not discarded from the research but re-classified as severely visually impaired. His overall high performance in spatial tasks is further evidence of his ability to functionally use his residual vision. He is no longer viewed or considers himself a blind person and is currently working on strategies to make the best of his residual vision.

The transition from education to the workforce is perhaps one of the biggest challenges faced by individuals who are blind or visually impaired. That society discriminates should not come as a surprise especially in the labour market where the order of the day is the maximization of utility. Although the government intervenes and labour laws are constantly being updated (most recently laws on ageism); preconceptions, presuppositions, biases and prejudices still have their way in the work domain. It is in such situations that passing may be beneficial. David a former RLSB student spent almost six months applying for a variety of jobs. The only replies came from fast food joints and cleaning services. David automatically turned these down. Taking a job meant that he would have to give up his disability/incapacity allowance and as it turned out the wages offered were lower or on par with what he was already receiving. Although the author does not condone this type of action, it is at least demonstrative of the difficulties in transition and to some extent the cult of poverty that many times surrounds disability.

David was upset. Not a single company, office or factory replied and he began to doubt his skills. At that moment he decided to pass as sighted. The author would be lying if he said that the situation really improved. What did happen was that David was at least able to secure two or three interviews, one of these with British Telecom (BT). Unfortunately, after passing most aptitude tests with BT and at the verge of being offered a job as a repairman, David was turned down because he did not have a driver's licence and could not travel independently to meet the customers. While it will never be known if passing is what secured the interviews it is at least clear from his experience with BT that as long as he was fully sighted and had a valid driver's licence he was able to secure a job. Presently David is working as cook at a school's canteen. The irony lies in that during his unemployed days the author hired David as his research assistant. He was trained, to interpret video data and to enter it in Geographic Information Systems (GIS) software, a somewhat advanced skill for a college graduate and something that would surely afford him a decent wage in the job market.

3.5.4 Psychosocial adjustment, self-concept, identity & self-esteem

The overall psychosocial adjustment of individuals with disabilities has been a topic of much interest but of considerable disagreement. The adjustment to life in a world that is essentially visual is a complex feat. Adjustment is inevitably tied in with issues of independence, sufficiency and control and will vary from person to person influenced by their character, previous experiences and support network. Research on psychosocial adjustment has incorporated a variety of questions ranging from the impact of progressive or immediate visual loss, anxiety, the inability to work, avoidance and bullying to the role of support networks such as friends, families and charities. Morse (1983) reviewed several studies on the psychosocial adjustment of children with low-vision. He concluded that children with low-vision tend to be more unsettled by the limits of their vision, when compared to those whose handicaps are more severe. In addition, parents of children with low-vision seem to be less understanding of the disability than those of blind children (Bateman, 1962). These results were echoed by Peadboy and Birch (1967) who found that children with low-vision tend to exhibit with more frequency underachieving behaviours and fatigue and are more prone to emotional problems.

More recently a study by Kef (2002) on the psychosocial adjustment and the meaning of social support for Dutch teenagers (aged 14 to 24) with visual impairments revealed that majority of these teenagers had high-self-esteem, were generally happy, did not feel lonely and that most had accepted the implications of their impairment. No significant differences were found between blind and individuals with low-vision (both severe and mild), although the scores for the severely visually impaired tended to be more negative. Interestingly, no significant differences were found between these groups and sighted adolescents. Sighted adolescents tended to have a larger network of family and friends although individuals who were blind or visually impaired were satisfied and believed they received enough support from parents and peers.

An important aspect of psychosocial adjustment is the development of a positive self-concept. Self-concept can be defined as a set of attitudes individuals hold about themselves that help shape their identity, self-image, and esteem. Self-concept is what conditions our expectations and motivates behaviour, and has important implications on our personal, professional and social lives. A positive self-concept is usually associated with the ability to cope and overcome the consequences of a disability. It gives an individual a positive outlook on life, satisfaction and commitment. Jake, another student who participated in the research, was diagnosed at birth with *retinopathy of prematurity* and lost his sight at the age of three. His parents were divorced, and he lived with his mother who was unemployed and for the most part absent. It seemed as if Jake's future was determined; his ability to flourish and overcome his disability hampered by his socioeconomic situation and his family's lackadaisical neglect. Fortunately the opposite occurred. Jake's situation forced him to become independent at a very early age. The lack of support meant that he had to learn how to fend for himself and quickly develop life-skills to cope with life in a sighted world. With a remarkable hunger for achievement, and a constant strive for superiority Jake attended mainstream education and was able to properly integrate. As it turned out Jake was one of the best performers in the author's experiment. His ability to represent space and ease of movement was a true reflection of his audacity and confidence. His mobility officer having more than once remarked that "watching Jake move is like watching poetry in the making." Jake left the RLSB two years ago and now lives with his partner and future wife who happens to be sighted.

Individuals differ in how they accept their disability. In some cases, the inability to cope leaves the individual feeling detached from the general society. In other situations, individuals detach themselves because they feel they cannot fit in or are being pitied by others. Negative self-concepts are usually associated with isolation, depression and mental and health problems (López-Justicia, 2006). The author had the unfortunate experience of dealing with two separate cases of students whose emotional state was so low that they were contemplating suicide. Details are omitted in order to preserve teacher/student confidentiality. However, and without chancing any conclusion these individuals held several characteristics in common that were reflective of their negative self-concept. They were both blind from birth (retinopathy of prematurity), had few friends, preferred life at college than at home and tended to spend most of the time by themselves. They usually felt that they were not good enough and that the teachers and the "sighted society" communicated with them because they pitied them.

There is no general agreement as to whether the self-concept of individuals who are blind or have low-vision differs from that of the sighted. Results from several studies summarized in Morse (1983) vary as to the positive and negative attitudes the blind and visually impaired children and teenagers have towards themselves. Jervis (1959) concluded that there were no significant differences between the blind and the sighted, while Meighan (1971) found that the blind tend to view themselves extremely negatively and Bauman (1964) that the partially sighted have a greater degree of anxiety, insecurity and loneliness. More recently, Sacks (1996) found that individuals with low-vision perceive themselves more negatively, expressing feelings of isolation and unjust fault when compared to the blind or sighted and Freeman et al. (1991) found that in many cases individuals with low-vision tended to reject services that would be beneficial because they did not want to be labelled as blind. Here it is worth noting that all these experiments used different scales in their assessment of self-concept.

López-Justicia et al. (2001) conducted several studies to determine whether Spanish children and adolescents with congenital low-vision had lower self-concepts than did their sighted peers. They found that children between 4-11 years of age with low-vision tended to score lower on all dimensions of self-concept when compared to the sighted children. Interestingly, differences were not significant in terms of family, physical appearance, self-worth and security. This lack of significance appears to be an indicator that these children are receiving and value the support from their family, classroom and peer networks. For children aged between 8-11 years, significant differences with the sighted were found in regard to the relationship with classmates and parents. While the relationship with classmates was viewed as more negative (difficulty in making new friends or feel valued by their friends) the relationship with parents was regarded as strong and empowering. Finally, results for the adolescent (aged 12-17) group revealed significant difference with the sighted only in terms of physical self-concept with individuals with low-vision scoring considerably lower than their sighted counterparts. These results are somewhat expected as it is during this age that individuals begin to pay more attention to their physical appearance.

Love is not blind, at least for most part of the time. Our exterior appearance and the body language that usually accompanies it are responsible for many of the first impressions others have about us, and unfortunately first impressions tend to last. It is not uncommon to find among blind and visually impaired teenagers those who think of themselves as unattractive, because of their weight or a physical deformity. The author was faced with many situations where he had to counsel many of his students regarding their exterior appearance in an effort to boost their self-esteem. Self-esteem is one of the key components of self-concept as it relates to the value that individuals place on their own characteristics, qualities, abilities and actions (Griffin-Shirley & Nes, 2005).

Here again, results from past research on the self-esteem with the visually impaired and blind are contradictory. In a longitudinal study with visually impaired children, Shapiro et al. (2005) found significant gender differences on the perception of self-competence. Males were found to be more positive at the beginning of summer camp when compared to females. These difference however, tended to disappear across time with female perception of competence increasing at the end of camp. The improvement in the perception of competence, for both males and females, across times emphasizes the role of friendship and participation in the development of positive self-esteem. The fact that these children were at a summer camp and constantly interacting with camp counsellors is also further evidence that teachers and counsellors through their instruction, verbal praise and ongoing feedback can function as guides and role models. Rosenblum (2000) found that although many teenagers had negative feelings about their visual impairment, the extent of this negativity varied among individuals with some deliberately hiding their visual impairment while others expressing unhappiness but understanding it as a part of life. A study by Huurre et al. (1999) on the social support and self-esteem among Finnish adolescents with visual impairments found similar results. In addition, Griffin-Shirley and Nes (2005) found no significant differences in the level of self-esteem and empathy between sighted and visually impaired preadolescents. These authors argue that the lack of difference may be related to recent trends in education and inclusion as well as greater awareness of the disability by the family. Sacks (1996) observers that in many cases low-vision devices can be used to help individuals use their functional vision and enhance their self-esteem. He notes however, that these should be carefully instituted as they are highly conspicuous and may draw unnecessary attention to the individual.

3.6 Summary

In the final chapter of his book Blindness and early childhood development, David Warren (1984) expresses his disappointment regarding the quality of past research on visual impairment. His dissatisfaction stems from the failure of researchers to account for the heterogeneous nature of the population. To understand behaviour we must be open to the idiosyncrasies of personality. There is much to learn by focusing on the individual and the specificities of self-adjustment. During the last few years, researchers in psychology and geography have started to pay more attention to individual differences. This is evident from recent topics featured in specialized conferences (e.g. the Spatial Cognition 2006 conference held in Bremen, Germany) and academic journals. It remains however for this knowledge to be mainstreamed – for society to be educated. This chapter reviewed many issues associated with the definition of blindness and visual impairment. This was complemented by data on the prevalence and in-depth discussion of the psychosocial implications of blindness and visual impairment in an effort to complement the debate of geography and disability and set the ground for the two experiments conducted at the RLSB.

Chapter 4
The development of spatial thought

> "Perhaps there is nothing so difficult for the imagination as to teach it to feel about space as modern science compels us to think" – Bertrand Russell (1927, p. 108)

4.1 Introduction

In this chapter we bring together the discussion of disability and visual impairment with the acquisition and development of spatial knowledge. The chapter opens with a discussion of different characteristics and definitions of space. A functional definition that focuses on the nature of experimental space and spatial tasks is then proposed as a matter of conciliating this debate and moving it from a philosophical to a scientific arena where specific hypotheses can be tested. The work of Jean Piaget and his critics is also considered and special attention is given to his now challenged idea of egocentric to allocentric shift in spatial coding and the failure of his stage theory to account for individual differences. Domain specific, multiple intelligence and information processing theories are presented as complements to Piaget's work. The chapter ends by setting the ground for an investigation of the role vision plays in the acquisition of spatial knowledge and the developmental differences that exist between the sighted, the visually impaired and the blind.

4.2 Space: Historical and philosophical perspectives

It is hard to begin a discussion of space and the role of the different sensory modalities in spatial coding without recurring in one way or another to some of the philosophical debates that have been going on since antiquity. Philosophical questions whether space is absolute or relative, innate or acquired, Euclidean or non-Euclidean or the differences between physical and psychological space have now found their way into psychology and geography and are at centre of many academic debates on the development, accuracy and content of mental representations. In the paragraphs that follow we consider, only briefly, some of these views. The reader is encouraged to consult Nick Huggett's book Space from Zeno to Einstein as well as Donna Peuquet's Representations of Space and Time for further reference. O'Keefe and Nadel's (1978) chapter on the history of theories of space, also offers a quick and stimulating discussion on the topic.

4.2.1 Physical and psychological space

Before we begin our discussion on absolute and relative space it is worth differentiating between physical and psychological space. Psychological space can be said to be the product "of the normal operation of the mind" (O'Keefe & Nadel, 1978, p. 6). It is the product of an intrinsic quality of the mind and the result of reflection and experience as well as *reflection on experience*. In other words, it is the result of perception and cognition. Kuipers (1982) goes as far as to say that psychological spaces do not exist *sui generis* but that it is constructed on the spot with their nature and contents being context specific. Physical space on the other hand is the space that exists outside and independent of the mind.[22] It is the space that is perceived and to a large extent the basis of what is psychologically constructed. In this thesis we are concerned with the role of physical space in the construction of psychological space: How does the content and accuracy of mental representations actually reflect the reality of the physical world? Here we are cautious to note that psychological space is not necessarily determined by physical space, as mental representations can also be the product of inference and reflection.

4.2.2 Absolute and relative space

Isaac Newton (1642/1727) defined absolute space as space "in its own nature, without relation to anything external [and something that] remains always similar and immovable" (Newton, 1999). O'Keefe and Nadel (1978) propose a similar interpretation where absolute space is a container where elements[23] can exist but do so independently of other objects. Absolute space is both "immovable and continuous, the connected place where everything occurs or the basic framework that ties the "universe together into a coherent whole" (O'Keefe & Nadel, 1978, p. 8). In relative space objects are located in relation to other objects. These relationships are mediated by the different sensory

[22] Here we will avoid discussion as to whether something really exists if it cannot be perceived.

[23] Elements are used here to describe the material objects, smells and sounds that may exist in space.

modalities in the sense that relative space cannot exist without the existence of objects or at least their perception and cognition. Location in relative space is identified in relation to a reference and this can either be the body or other objects. Psychological space, our primary concern in this thesis, is relative. In his Critique of Pure Reason Emanuel Kant combined these two ideas concluding that space was not something to be perceived but *a way of perceiving*. By adopting this position, Kant allowed for the existence of absolute space but removed any association with the physical world (Kant, 1999). A *way* of perceiving meant that the mind in itself has an innate organizing principle to make sense of the sensations derived from the physical world (Peuquet, 2002; Huggett, 1999). As we shall see, the notion of a very basic mental structure that imposes regularity on sensory information forms the basis of Piagetian theory.

Newcombe and Huttenlocher (2000) argued against the existence of an absolute *empty* space. For them a discussion of spatial coding is "inherently relational" (p. 30). The locations and the eventual representation of objects in space are always encoded with respect to another referent. They avoid the infinite regress problem[24] by noting that certain geographic features and even features of the built environment change at such a slow pace (if at all) that their positions can be regarded as fixed. They adopt a functional view by arguing that if space is hierarchically organized, the infinite regress for contained situations will eventually come to an end. Finally, they note that even if one attempts to imagine an absolute empty space, the thinker is usually forced to become an observer or a "relational defining entity."

4.2.3 Innate vs. acquired: Empiricism and rationalism

Are spatial concepts innate or acquired? Is the knowledge of space or spatial concepts derived from the structure and function of different parts of the brain *a priori* coded in the organism's genes or is it the product of experience - a construction of perception and cognition (this may also include reflection)?[25] Let us state from the start that there is nothing wrong with a middle position or theories that hold that structures in the brain are specialized (i.e., the hippocampus, PPA), genetically specified and determined to deal with spatial concepts that function as a result of experience. It would be naïve to discuss psychological space in terms of strict, environmental deterministic theories, as there is

[24] The notion that defining location in relational terms to other referent leads to an infinite regress of references.

[25] O'Keefe and Nadel (1978) note that a posteriori theories of learned or constructed space also encompass those that view space as a concept generated by non-spatial (reflection based) operations of the brain.

clear evidence of distortions in mental representations. To these we can also add theories that view space as a concept generated on the basis of non-spatial aspects of the physical world. However, what holds true no matter if one is an empiricist or a rationalist/nativist is that the *content* of these representations is the product of experience or the product of reflection on past experience (O'Keefe & Nadel, 1978). This thesis deals with the content and accuracy of mental representation acquired in the total or partial absence of vision. For this reason, instead of discussing space in terms of dichotomies, something that Millar (1997) deemed as dangerously simplistic, we will discuss it in relation to the role the different sensory modalities play in the construction of spatial knowledge.

4.3 Towards a functional definition of space

Space is an abstract noun (Millar, 1994) with too many definitions and meanings to be useful. Definitions vary depending on the field of study and application. In mathematics, space can be defined as the set of points and elements that satisfy specific geometrical postulates. Euclidean space for example is isotropic and characterized by a set of specific rules expressed in terms of distance and angles in two dimensions (on a flat surface). In physics or astronomy space can be said to be the infinite extension of the three dimensional region where all matter exists. In psychology space has been defined as blank or empty area, an area created for a specific purpose or as Lowenfeld (1981) interpreted it as "everything extending into three dimensions" (p.65).

We will now attempt to come up with a functional definition that can be applied to the discussion of mental representations in this thesis. Two points should be observed: First as Heft (1996) argued, the everyday use of the terms *space* and *spatial* has in some ways confused the notion of space in environmental cognition by assigning connotations of emptiness or of empty containers. Space, or at least the space that is perceived and cognized is not empty. Environments are filled with elements and characterized by an array of features. Second, it is important to account and differentiate between (a) elements *of* space, (b) elements *in* space and (c) the processes of space (Golledge, 1990a).

Space in this thesis will be defined as a container of human activity. Here it is important to observe that the word *container* does not necessarily assign boundaries to space. Boundaries are relative and individually created (Ittelson, 1973). In defining space as a container for activity we simultaneously account for elements *of* space (the objects, sounds or smells that are present and characterize the environment), elements *in* space (when the individual is engaged with the environment as opposed to being just an observer) and processes of space (the relationship between time and space as activities occur at a specific time and place). As Golledge (1990a) notes, these distinctions are not absolute but bonded by *occurrences*, which are both temporal and spatial by nature. Occurrences are critical to the character of space. Their dynamicity is what allows us to speak of changes and to categorize phenomena into events and behaviour.

Occurrences provide structure to space. They allow for space to be partitioned and for phenomena of different sizes to be distributed. The partitioning of space automatically introduces two concepts that are crucial to this thesis. First and in accordance to a fundamental axiom in geography, that two discrete things cannot occupy the same point in space at the same time (Tobler, 1976) comes the notion of *separation* and *distance*. As Anselin (1988) observed *separation* or the notion of *degrees of separation* automatically introduces the concepts of proximity, similarity or dissimilarity, clustering, spatial variation and spatial heterogeneity (Golledge, 1990a). Second is the concept of orientation and direction that results from the partitioning of space in relation to a referent. A referent can be an element in space or the individual's own body. Together distance and direction allow us to talk about regions and the concepts of inclusion, exclusion, and spatial grouping.[26]

4.3.1 Experimental space and performance in spatial tasks

Millar (1994) argues that instead of dabbling on the complexity of the term space, it is easier to consider space as "a label for performance on a number of spatial tasks" (p.11). Spatial tasks in this manner are tasks that involve the knowledge of where *something* is located. These include locating objects (can also be smells or sounds) in relation to oneself or to other referent stimuli, to navigate from one location to another, to explore a specific environment and to represent the relationship between elements in terms of distance, direction and angles (Millar, 1994). The notion of space as a container for human activity fits well into this description. *Container* being the experimental space where the subject is tested and *activity* the actual task to be completed and the resulting behaviour. Experimental spaces are purposefully defined and vary in scale, complexity and familiarity depending on the task. It can be a tabletop, a specifically constructed room, maze, route, city block, university campus, etc. In this manner, to speak of mental

[26] This is invariably linked to Tobler's first law of geography or the notion that ""Everything is related to everything else, but near things are more related than distant things" (Tobler, 1970, p.236).

representations of space is to speak of the information that is coded by the different sensory modalities (in relation to a referent) in a specifically defined space.

4.4 The work of Jean Piaget

The development of spatial thought is a topic that has occupied academics of a variety of disciplines and something that has been extensively researched and documented (Flavell 1971; Piaget and Inhelder 1967; Bruner et al., 1966; Piaget, 1954). This section is centred on the work of Jean Piaget (and collaborators) while considering many of his critics and modern followers. Piaget's theories are at once the most criticized and the most respected. The sheer scope and detail of his work is enough to set it as the starting point for any discussion on the ontogenesis of spatial thought and mental representations. In regard to this thesis, we are interested in three particular aspects of this theory: First, the notion that spatial concepts are generated through actions directed at objects. That knowledge, and in particular spatial knowledge is the result of individual action on the environment, action that becomes internalised into mental representations as cognitive structures mature. In this manner, the acquisition of spatial knowledge is a result of acting in space rather than just simple "perceptual copying" (Hart & Moore, 1973). Second, there is sequential development of spatial concepts from topological relationships, to projective and later Euclidean or metric relationships that result from the *assimilation* and *accommodation* of knowledge. Third, there is the concept of schemes as a specific set of actions that are either physical or mental that can be applied to different situations and combined for more sophisticated action. Schemes are the basic building blocks of thinking

Piaget's theory was a reaction to behaviourism. It was a rejection of the notion that knowledge is accumulated and developed quantitatively and that learning is a function of extrinsic rewards.[27] Behaviourism is primarily concerned with the external factors that lead to behaviour paying little attention to what goes on inside the mind. Piaget was interested in the acquisition of all types of knowledge (language, space, number, morality) and the specific changes that occur as the individual develops. He was neither an empiricist nor a nativist. In his genetic epistemology (the study of the growth of knowledge), mental representations of space are a result of experience but something that is mediated or *organized* by the individual. Development depends on the relationship

[27] B.F. Skinner one of the fathers of behaviourism later acknowledge that learning in humans also depended on the "want to learn".

between the individual that acts upon the environment and the cognitive structures that organize and make sense of this information. For Piaget, all thinking is a kind of action but as the individual develops, action is *thought about* rather than *carried out* (Sutherland, 1992). Piaget's nativism relates strictly to the action system' s sensorimotor articulations, coordinations and movements (reflexes, reaching, grasping, mouthing) that control action and are embedded in the organism structure.[28] His theory is constructivist in the sense that the genetically inherited structure of the organism and the actions performed in the environment interact with each other producing an increasingly refined version of reality (O'Keefe & Nadel, 1978).

Crucial to this relationship are the concepts of *assimilation, accommodation and equilibration.* Assimilation is the process by which individuals incorporate new information from the environment into an existing body of knowledge or schema. Accommodation is the changing of this schema in order to better fit the environment (altering and old schema for information that is inconsistent with the existing schema). Assimilation and accommodation are the two sides of adaptation. Humans are continually trying to make sense of the world through assimilating new information into pre-existing mental schemas and accommodating (changing) these schemas to incorporate new information or adapt to a new situation (Hoy, 1987). Equilibration is a biological drive to produce a state of equilibrium between the cognitive structures and the environment.

Piagetian theory argues that knowledge develops through a series of invariant, sequential, biologically limited, and qualitatively different stages (Piaget et al., 1960; Piaget 1954). Piaget noticed there were periods when assimilation dominated, periods when accommodation was dominant but there were also periods of relative equilibrium. More important was the fact these periods tended to be similar for all children. Piaget identified 4 stages (with many subdivisions), each characterized by a more sophisticated cognitive structure rather than just a quantitative increase in knowledge. The child moves about and performs action on objects in the environment. This interaction is progressively internalized in the sense that instead of solely manipulating objects in the real world the individual begins to manipulate representations of these objects and actions within a more sophisticated cognitive structure. Infants, children and adolescents have to progress systematically through the same stages. The importance of the environment is clear as

[28] Here it is worth noting that Piaget was trained as a zoologist and it is not hard to detect a biological bias in his "genetic epistemology" or the notion that logical ideas develop within biological constraints.

Piaget notes that if individuals who are not appropriately stimulated may regress back to a lower stage. Table 4.1 below is a summary of these stages.

Table 4.1 - Summary of Piaget's stages

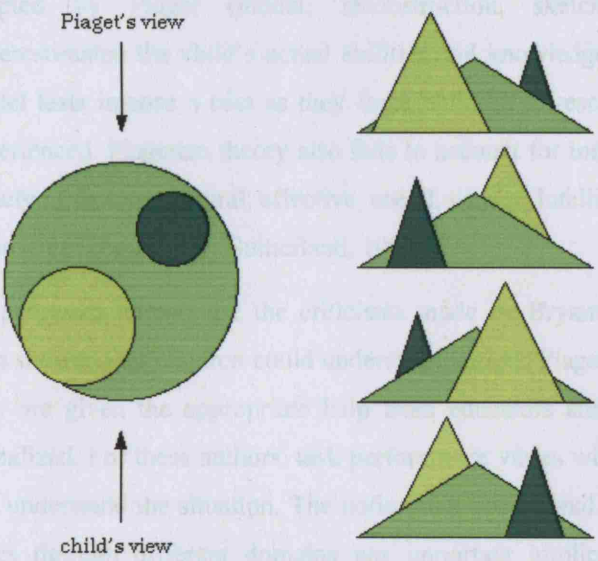
Stage	Characteristics
Sensorimotor (birth to 2 years)	-Reflex based (coordination of reflexes) -Development of action schemata with regards to objects and the world
Preoperational or representational (2 to 7 years)	-Action schemata are internalized. -Thinking is pre-logical (pre-operational) -Action schemata not divorced from actions in space and time -Child egocentric, action are self-oriented
Concrete operational or mid-stage of reversibility (7 to 11 years)	-Action schemata become reversible -Various viewpoints -Begins to consider goals, outcomes
Formal operational (7 to 11 years)	-Abstract logical thinking can take place -Theoretical reasoning

Adapter from Millar (1994)

4.4.1 Space and Piagetian thought

The acquisition of spatial knowledge occupies a central place in Piagetian theory and has been an important influence on modern theories of the acquisition and development of spatial thought in both children and adults (Siegel and White, 1975; Hart & Moore, 1973). For Piaget, spatial knowledge like any other form of knowledge develops through a series of stages and is linked to advancement in cognitive reasoning. The child progresses from encoding topological relationships to encoding projective and Euclidean properties of space. As noted above, the sensorimotor stage and preoperational stages are characterized by a high degree of egocentrism. This logical, linguistic, social and emotional egocentrism also applies to the spatial domain. The spatially egocentric child understands only one level of projection – that which pertains to its own body. Piaget demonstrated this with the *three-mountain task* where children were asked to adopt another person's perspective (see fig 4.1). In the task children were asked to sit on one side of the model and select from four drawings the one that represented what someone sitting on another side of the model would see. Piaget found that the preoperational child chose the drawings that represented their own perspective. Older children were able to recognize and understand other perspectives and showed this by selecting the correct drawing. Piaget also demonstrated this form of object coding preoperational egocentrism through the *A - B error* task (Butterworth, 1981) where children consistently looked for a hidden object in the same place. As we shall see in the following chapter some of Piaget's conclusions regarding the extent and uniqueness of egocentrism have been criticized as researchers have shown that familiarity and the presence of salient landmarks can often correct egocentric coding (Newcombe & Huttenlocher, 2000; Huttenlocher et al., 1994).

Figure 4.1 - Piaget's three mountain task



Source: http://webspace.ship.edu/cgboer/genpsypiaget.html

Given that the egocentric child cannot simultaneously represent different perspectives, spatial behaviour (i.e., navigation) is based on memory for movement. In order to move around, the egocentric child reproduces a set of sensorimotor responses that eventually become internalized as feedback from a sequence of cues. Route navigation is an example of such behaviour. The egocentric child can also only understand the topological relationship between objects. In a topological representation, the basic layout of objects in the environment is encoded in terms of continuities or discontinuities. The position of objects is coded as whether or not they are touching, enclosed or separated from each other (Newcombe & Huttenlocher, 2000). By the end of the concrete operational stage, at the onset of the formal operations stage, the child begins to code objects in terms of projective (different lines of projection extended from one object or another) or ordinal relationships. When individuals reach formal operations, they can finally understand and represent Euclidean properties of space. Locations in the physical world are metrically represented in terms of distance, direction in regard to vertical and horizontal reference lines. The body of the child is no longer at the centre of spatial coding as the metric relationship of the objects *between themselves* is understood.

4.5 Critics and alternatives to Piaget: Individual differences?

The literature on critics and alternatives to Piaget is vast. Many suggest that the methods adopted by Piaget (model, reconstruction, sketching or reproduction tasks) underestimated the child's actual abilities and knowledge. Liben (1982) has shown that model tests impose a bias as they force children to rescale the environment previously experienced. Piagetian theory also fails to account for individual differences. There are a variety of factors, cultural, affective, social, gender, intelligence that will affect the ability to progress cognitively (Sutherland, 1992).

Of particular interest are the criticisms made by Bryant (1972) and Donaldson (1978) who showed that children could understand various Piagetian concepts at an earlier age if they are given the appropriate help from educators and if the tasks are appropriately verbalized. For these authors, task performance varies with the manner children perceive and understand the situation. The notion that operational thought is achieved at different times through different domains has important implications in the study of mental representations by individuals who are blind and visually impaired as the ability to represent and manipulate information is strongly dependent on the access these individuals have to information. At this point it is important to mention that that majority of experiments conducted by Piaget and his associates were conducted in small-scale spaces. Most of these were tabletop experiments that took place inside a room or the laboratory. In this manner, one should be extremely careful when generalizing Piagetian theories of cognitive development to situations where the individual is faced with real world and large-scale environments. Different tasks require different abilities, and the inability to perform a specific task does not necessarily translate into a lack of knowledge.

4.5.1 The Vygotskyans and others

Vygotsky believed that social interaction plays a fundamental role in the development of cognition (Vygotsky, 1978). Contrary to Piaget, Vygotsky argued that learning (social learning) was a necessary and universal aspect of the developmental process. There are two basic elements to Vygotskyan theory. First is the concept of *more knowledge other* (MKO) or the idea that there is a learner and someone or something that has better knowledge, higher understanding and higher ability. Second and related to the concept of

MKO is the idea of the zone *of proximal development* (ZPD). Vygotsky defined the ZPD as "the distance between the actual developmental level as determined by independent problem-solving and the level of potential development as determined through problem-solving under adult guidance, or in collaboration with more capable peers" (Vygotsky, 1978, p.86): in other words, the difference between what children can do with help and what cannot be achieved without help. Social interaction *scaffolds* learning and this is what allows for development. Development depends on social interaction and collaboration (not on the individual processes of assimilation and accommodation) mediated by a variety of cultural tools such as symbols and language (Sutherland, 1992). Learning is the process of internalization of external and social activities and interactions and of making them part of mental structures. Unlike Piaget, Vygotsky does not focus on biological inheritance. Instead attention is given to culture, cultural objects or tools for interaction.

The influence of Vygotskyan theory is clearly noted in other modern theories of learning. The theory of *situated learning* for example is a clear shift from traditional developmental theories that view learning as something mechanical or individual. The theory argues that learning is a function of the activity, context and culture in which it occurs (Lave & Wenger, 1991). Much like Vygotsky, the theory holds that social interaction is critical to learning (Brown et al., 1989) but that learning should take place in contexts that reflect situations where it will be used in real life. Learners should be immersed in an environment that approximates as closely as possible the environment they will eventually apply their knowledge.

Earlier in this chapter we classified Piaget's theory as constructivist in the sense that humans construct knowledge (their own schemata) from their unique experience – an active process where experiences are internalized and allow the individual to deal with new situations. However, Piaget accorded some space for the innate structures of the mind and their interaction with what is picked up from the environment. Modern constructivist theory focuses more intimately in the relationship between the individual, the environment and the unique concepts that are created in order to cope with this environment. A key element in modern constructivist theory are the personal strategies that humans construct in order to problem solve – strategies that are individual and context dependent. There are no defined stages, rather the *construction* of knowledge being a gradual learning processes whereby existing concepts are modified by new ones.

Many researchers have attempted to account for development in terms of information processing. Here it is worth noting that information processing is not really a theory of development. Information processing focuses on learning but at a specific time. Intelligence is defined as the ability to efficiently process information and is made up of various factors one of them being *spatial ability* or the ability to "visualize" a problem spatially in all its details (Sutherland, 1992; Sternberg, 1977). Contrary to Piaget, it regards the process of learning as quantitative. This allows for a more scientific rigour and controlled experiments that provide precise and detailed accounts of specific learning experiences. Much like constructivism and situated learning, it takes into account the context or the place where learning occurs allowing for individual differences to be explained in terms of memory, intelligence, attention, strategies and mental representations. Many information-processing (IP) theorists (Johnson Laird, 1988; 1983) believe that the development of intelligence is based on the construction of mental models where assumptions about reality are continuously being tested. These models rely heavily on memory and language. In fact these two concepts are critical elements of most IP theories. Language (abstraction of reality) and memory (familiarity) enrich mental models facilitating the processing of information and the selection of appropriate behaviour. Some neo-Piagetian theorists have incorporated many of the tenets of IP in their theories. Pascual-Leone (1976) for example argues that development is an improvement in the ability to process information rather structural changes.

Domain specific theorists have used IP in order to criticize Piaget's notion of developmental stages. For these theorists, knowledge is specific. There are no universals in cognitive development, as knowledge cannot be generalized to different contexts (Brown & Desforges, 1979). This idea is well supported by the multiple intelligence approach (Gardner, 1983). This theory holds that humans possess, in varying degrees, a number of distinct forms of intelligence (linguistic, musical, logical-mathematical, spatial, body kinaesthetic, intrapersonal and interpersonal). It is a nativist theory that sees people having different penchants for different types of knowledge. Howard Gardner, one of the fathers of this theory, argued that culture and the cultural context affect the development of different types of intelligence and uses the example of the navigational/spatial abilities of the Puluwat islanders who were able to sail over hundred of miles without the aid of any instrument (Gardner, 1983; Kuipers, 1977).

4.6 Summary and discussion

In this chapter we have attempted to come up with a functional definition of space that will be used throughout the thesis. For this it was necessary to differentiate between physical and psychological and between absolute and relative concepts of space. Following Millar's (1994) argument, space was considered as a label of performance on spatial tasks and defined as a container for human activity. The chapter also considered the work of Jean Piaget on the acquisition of knowledge and the development of spatial thought and used it to contrast nativist and behaviourist theories of cognitive development. Despite the variety of criticism and alternatives, the work of Piaget and collaborators is still an essential contribution to developmental psychology and an important basis for research conducted in this thesis. Piaget's genetic epistemology connected the biological and behavioural while highlighting the importance of interaction. The notion that spatial concepts are generated through actions directed at objects as well as movement in space will also be considered when we look at development in the total and partial absence of vision. Piaget's argument that spatial thought develops in a series of stages from egocentric behaviour to projective and finally Euclidean or metric conceptions was also presented and will be a recurring theme as we discuss other Feuersteinian critiques on the notion that intelligence can be improved at any age depending on the access, type and context where the information is provided. The notion that development should not be considered in a social vacuum was also adopted by theories of situational learning where learning is seen as a function of the activity, context and culture in which it occurs and should take place in contexts that reflect real life situations.

Chapter 5

Blindness, visual impairment, growth and development

> "Who is there who would not wish to lose the senses of hearing, smell, and touch before losing sight? For he who loses sight is like one expelled from the world, when he does not see it any more, nor anything in it. And such a life is a sister to death" – Leonardo da Vinci (1452/1519)

5.1 Introduction: The advantages of vision

Leonardo da Vinci's words were carefully chosen. They are extreme and not factual. They represent the feelings of an artist that had an in depth knowledge of optics, who had written substantially on the topic of perspective (linear perspective), and for whom vision was indispensable. Vision is often considered the spatial sense *par excellence* (Foulke, 1983) and essential for development. This chapter begins by looking at some of the advantages vision holds over the other sensory modalities while considering the type and quality of information that can be gathered through touch, sound and proprioception. It then goes on to consider growth and development in the total or partial absence of vision where some of the theories presented in the previous chapter are critically discussed in relation to specific studies conducted with the blind and visually impaired. The chapter concludes with a discussion of frames of reference and Newcombe and Huttenlocher's *re-weighting* theory (2000) as well as Millar's CAPIN model (2000; 1994) and their application to the perception and cognition of space by the blind and visually impaired.

Thinus-Blanc & Gaunet (1997) identify four main reasons why the visual sense can be both quantitatively (greater detail, quicker precision of information) and qualitatively (the type of encoding and representation) superior to the other senses when dealing with spatial information.

1. Simultaneous perception (Foulke 1983; Millar, 1982): One of the primary principles of Gestalt psychology (Köhler, 1940; Koffka, 1935) is the idea that the whole is more

important than the sum of its parts.[29] Vision allows for the simultaneous perception of different objects (or the different parts of the same objects) in the environment. Eye movements between objects are quick and can convey detailed and accurate information. Different types of information can be processed at the same time as some information can be maintained in peripheral vision while other information is foveated. Of course there are limits and this will depend on the size of the environment. Nonetheless, this is a considerable advantage over touch where objects for the most part must be handled individually and information can only be collected serially. Serial processing is slower and imposes a stronger cognitive burden, as it requires the individual to integrate information into a coherent whole.

2. Amount, quality and detail of information available: Vision provides precise and detailed information on the features and objects that make up the environment. It has an advantage over touch in that it can provide information on the shape and size of distal objects. Some researchers (Middlebrooks & Green, 1991) hold that although estimations of direction and distance by sound alone is possible, accuracy is limited when compared to estimates made by sight.
3. Level of extraction of spatial invariants: As noted in Gibson's (1979) theory of ecological perception, important visual information can be directly collected through motion in the environment. Vision stabilizes the surrounding layout during movement allowing for the separation and identification of invariant structures in the environment. Visual information gained through locomotion presents the individual with different vistas and information about displacement through transitions. It provides quick and precise feedback (Tobin et al., 1997) on the consequences of displacement by relating the external environment (and the objects contained within it) with individual motion.
4. Level of mental imagery: Vision facilitates the production of mental images quickly condensing information into a single and meaningful snapshot (Thinus-Blanc & Gaunet, 1997). Mental imagery is also possible by touch. However, spatial tasks that require individuals to mentally rotate images (Heller & Kennedy, 1990; Marmor & Zaback, 1976) have shown that for the most part the blind (particularly the congenitally blind) make more errors and have longer rotation reaction times when compared to the sighted.

5.1.1 Auditory perception

Language and sounds can convey information about the identity as well as the distance and direction of places, objects and people. Mental representations of objects or places in space can be achieved when sounds are clear and isolated. Schlaegel (1953) argues that auditory cues can help in the formation of mental images for individuals who have light perception or less allowing these individuals to coordinate their movements during

[29] Gestalt theory recognized the importance of context in the study of human behaviour (Ittelson, 1973). Behaviour is localized and this plays a role in the representation and eventual behaviour. The theory differentiates between the *geographical field* or the physical, objective and stimulating environment and the *behavioural field*, the subjective and unique environment perceived by the individual (O'Keefe and Nadel, 1978). Gestalt was a reaction to the nativist notion by refocusing the debate of mental representations in relation to the geometry of the physical world and the organizing capacity of the mind. The concept of organization is crucial to the theory as evident from its main tenet that the *whole is more important than the sum of the parts.*

navigation. However, in many everyday scenarios (urban settings, crowded spaces) auditory information is incomplete and hard to isolate. The cacophony of everyday city life imposes several restrictions as to what can be discerned through sounds. The sounds of cars for example can convey to the individual the approximate location of a crossing or intersection. At the same time, traffic can prevent the blind individual from hearing the cues (traffic light signal) that will allow for the coordination of appropriate action. Some individuals use sound shadowing, the ability to identify and locate objects and places from the difference in sound between the individual, the sound source and any other intervening variable. Others use sound signatures or unique sounds that surfaces make when touched or walked on. No matter what technique is involved, making sense of the cacophony of daily life is a skill that must be developed with practice.

Human echolocation[30] has been defined as the ability to sense objects in an environment by hearing the echoes that bounce off these objects. Its efficiency for navigation is evident from the sonar and animal echolocation ability of bats and dauphins. In humans, the ability to interpret the sound waves reflected by objects in order to identity their location (and to some extent their size) is harder and requires a certain amount of training. Echolocation allows for the collection of information about the space and the objects within it far beyond the reach of the long-cane. This allows a blind individual to plan in advance and adjust their actions and movements. According to Kish and Bleier (2006), an individual who has mastered echolocation will not only be able to know the overall arrangement of objects in space but also their shape, size and texture. There are some examples of individuals who are able to use this technique in order to guide their movements but these are the exception rather than the rule. In most cases, blind and visually impaired individuals use auditory information as complimentary to tactual and other vestibular/proprioceptive information. Daniel Kish who was born blind (now a blind psychologist and a leading researcher in echolocation) developed a technique of clicking his tongue and guiding his movements according to the echoes as they bounce

[30] Echolocation is sometimes confused with the concept of facial vision. Facial vision is defined as the experience some blind individuals report of perceiving an object through the skin (nerves) on their faces. Sometimes facial vision is incorrectly understood as an extra sense permitting an almost unconscious awareness of the location of different environmental features. The existence of facial vision has been contested (Ono et al., 1986). In the 1940's a series of studies known as the Cornell studies concluded that the blind are able to detect object not by a visual type of skin sensation but through an echolocation process (Cotzin & Dallenbach, 1950). For the purpose of this thesis it will suffice to say that if it is a real phenomenon facial vision is not by any means a paranormal experience or a sixth sense developed in the absence of vision and that our understanding of this phenomenon is incomplete, and needs to be thoroughly researched before any conclusions can be made. There seems to be contradictory reports regarding its existence. Some of the author's students have reported this ability to facially sense the presence of environmental features. Many of these descriptions being very similar to the ones found in the literature. The author however believes that these sensations resulted from sound wave localization.

off the surfaces around him. Daniel's ability to interpret these echoes allows him to navigate safely and independently. Similarly, Ben Underwood who lost his vision at the age of three due to retinal cancer is able to use echolocation to ride a skateboard, rollerblade and play basketball by judging distance from the strength of the echo (Tresniowski & Arias, 2006).

Ashmead et al. (1989) found that congenitally blind children were able to use echolocation to detect and avoid obstacles in the form of small boxes during a navigation exercise. The ability of the blind to use echolocation is further defended by Boehm (1986) who found significant differences in the ability of the blind and blindfolded sighted subjects to identify objects along a hallway by echolocation produced by a handheld clicker. In this case, the blind group had lower levels of incorrect responses and reported three times as many reference points when compared to their sighted peers. Morrongiello et al. (1995) also found that the presence of auditory landmarks during trials significantly enhanced performance of both blind and blindfolded sighted subjects when making inferences about the location of different objects inside a medium sized room. These results are at odds with those from a study conducted by Rieser et al. (1982) on how auditory cues can facilitate the ability of blind individuals to update their position relative to other locations during navigation. These researchers asked subjects to make a series of pointing judgements and results revealed no effects of audio cues on pointing performance. The authors conclude that the congenitally blind are deficient in perceptual updating during locomotion even in situations where sound cues are available. This inaccuracy in locating audio landmarks may be related to a later finding by Guth et al. (1989) who note that blind individuals are more accurate in locating the position of sounds but only when the sound source is directly in front of them.

Miller (1992) separates structural and strategic auditory compensation. Structural compensation involves a restructuring or reorganization of cortical functions to accommodate for an impaired sense. Strategic compensation suggests that in the absence of a sensory modality, information is processed in an equivalent fashion and that differences in performance are a result of attention and/or practice. Results from a series of studies that compared the ability of the blind and visually impaired to detect and discriminate sounds are inconclusive. The blind and visually impaired tended to perform better in complex auditory tasks (complex non-linguistic sounds) but were less sensitive in the detection, discrimination of sounds (auditory threshold) or the discrimination of verbal material when compared to their sighted peers. Ashmead et al. (1998) found similar results when comparing the spatial hearing of the blind and sighted. In their experiment, blind subjects were able to discriminate between direction and distance of a sound source and their performance was slightly higher when compared to the sighted groups. The authors argue however, that higher performance is not necessarily evidence for compensation but simply that the blind make a more efficient use of their hearing ability.

5.1.2 Touch

Apart from vision, touch is the only sensory modality that allows an individual to grasp the spatial qualities of an object such as size and shape. Touch however, differs from vision in that it requires the direct contact and the integration of successive movements. Its extent is smaller than vision and for this reason may be considered a slower modality.[31] Objects that are either too large or too small may be difficult to grasp. Even if a person manages to tactually manipulate them, precision may be hard to infer. This is the case with planets or stars or small animals and insects.[32] This is also true for objects in motion that depend on quick and snapshot-like perception. Nevertheless, touch can convey important information on the temperature, weight and resilience of objects.

Lewis (2003) reports on several studies on tactual perception conducted with the blind and sighted individuals. Landau (1991) showed that blind children as young as three years are able to identify textures and shapes but that performance varied with size and whether or not the object was fixed. Larger objects that required the condensation of various movements often lead to confusion. Smaller objects on the other hand were easier to manipulate. These results were confirmed by Catherwood (1998) who showed that young and old children alike are able to discriminate between shapes and textures. Morrongiello et al. (1994) found no differences between the sighted and the blind in their ability to identify everyday objects as well as miniaturized and oversized versions of these objects. Differences exist in the pattern of movement or exploratory procedure used when exploring an object affecting the type information that is obtained about the object (Lederman & Klatzky, 1987). Schellingerhout et al. (1998) found age-related differences in haptic exploration by blind infants and argue that visual information is not necessary for a variety of exploratory activities such as mouthing and grasping. It is possible that the blind and the sighted do not differ in their ability to tactually recognize shapes

[31] There are always exceptions such as the case of able Braille readers who can reach reading speeds close to that of a sighted reading text.

[32] Here it is worth noting that individuals who are blind or visually impaired can still represent very small or very large objects on the basis of their function or purpose they serve. The sun is a large "ball of fire", a bee has a sting like the tip of a pencil.

although D'Angiuli et al. (1998) have shown that blind children eventually develop better manipulatory strategies but that the development of these strategies is greatly aided by teaching and guidance.

5.1.3 Proprioception

Humans can use allothetic and idiothetic information in order to navigate. Optic flow, acoustic flow, light and heat are different types of allothetic information that can help guide movement during wayfinding. Idiothetic information, also known as proprioception (and thereafter referred as proprioception), arises from the individual's body during travel. This information is derived from the muscles, tendons, joints and the vestibular sense (Klatzky et al., 2002). In other words, proprioception is the conscious awareness of the position of the body in space brought about by movement and muscular activity. Waller et al. (2004) distinguish between three different types of body-based information: (a) The vestibular system which senses linear and angular accelerations of the head; (b) Proprioceptive or information about movement of one's body parts and; (c) Efferent copy "represents the commands to the musculature issued by the central nervous system." They note that the vestibular system alone may be good enough for simple tasks such as maintaining direction and determining position (Israel et al., 1993) but that proprioceptive information enhances accuracy of mental representation of perceived space (Telford et al., 1995). As noted in our discussion of development, movement and interaction play a major role in perception and cognition and the overall development of spatial knowledge. It is through proprioceptive awareness that the reciprocal relationship between perceptual and motor activities develops.

Waller et al. (2003; 2004) conducted two experiments on the role of inertial cues on the acquisition or development of environmental knowledge of a large-scale environment. In the first study, participants were divided into four groups and tested on their knowledge of a large-scale environment learned from a car trip through an unknown area. The first group learned the environment as passengers in the front seat of a car (full-cue group). The second group received only inertial information by traversing the route on the backseat of the car wearing a Head Mounted Display (HMD). The third group viewed the video while travelling a different route (non-matching) and the fourth group watched the video while sitting in the lab (video). Results from a pointing estimation, a distance estimation and a map construction task, revealed no significant differences between the inertial, non-matching and video groups. The authors conclude that valid inertial cues have only a minimal effect and do not actually facilitate the acquisition of environmental knowledge. They note however, that the value of inertial cues may have been reduced by the amount of "noise" collected during travel in a large-scale environment. Significant differences were found between these three groups and the full cue group for pointing and distance estimates suggesting that field of view, visual fidelity and the ability to actively look around contribute to the acquisition of large-scale environmental knowledge further emphasizing the role of vision in spatial cognition. Finally, the presence of invalid inertial cues did not seem to interfere with such acquisition. These results are consistent with Goldin and Thorndyke (1982) who found that inertial cues only had a minimal effect on the estimation of relative directions. These authors showed that subjects that travelled along a bus route were on average 10 degrees more accurate than those who viewed a video of the road (Waller et al., 2003).

In the second experiment, Waller et al. (2004) tested whether body-based cues that result from actual movement (difference between active and passive movement –Waller's previous experiment was passive transport - riding in a car) can facilitate the acquisition of environmental knowledge. Participants were separated in different groups. The first group (walk) walked a route with full access to body-based cues (vestibular, proprioceptive and efferent). The second group learned the route by sitting in a lab and watching captured videos form the first group (video). The third (smooth) group also watched a video but a simplified version of the route where the optic flow from head rotations was controlled and noise was eliminated. Results from a pointing test revealed small but significant differences between groups. Subjects in the walk group were approximately 10 to 15 degrees more accurate than those in the other groups. The authors conclude that inertial cues from body-based information can improve accuracy in directional knowledge. These results are consistent with Klatzky et al. (1998) who argued that the visual field alone is not sufficient for updating one's orientation in space. These authors demonstrated that additional vestibular information could enhance the acquisition of environmental knowledge. In their study participants that received visual information through a head mounted display were also passively guided. Results revealed that subjects that were passively guided, performed better in a pointing task when compared to those that stood still while viewing the information in the head mounted display.

5.2 Blindness, visual impairment growth and development

The role vision plays in development is undeniable. The formation of concepts and the coordination of action and movement are all greatly facilitated by sight. Vision allows us to look and imitate,[33] to quickly transfer what we see and what others do into action. Foulke and Hatlen (1992) argue that vision dominates nearly all the early stages of development and helps to lay the necessary foundations for further intellectual growth. For this reason it is no surprise that when compared to the sighted, blind and visually impaired infants (blind to a larger extent) differ in the course of their development. Their motor abilities and some aspects of their cognitive development, in particular the development of abstract thought, something which is crucial to the formation of and manipulation of mental representations of space, is usually delayed when compared to their sighted peers (Hatton et al., 1997; Reynell, 1978; Hatwell, 1966). Vision is indeed an important differentiating factor but it by no means a determining or a predicting variable. According to Warren (1984) there are three critical periods when vision is of major assistance to development:

1. During infancy when the child begins to integrate touch and sight. This is the period of the acquisition of hand-eye coordination.
2. When the child begins to crawl and walk as vision allows for a reference in motor behaviour and the integration of locomotor activity with perceptual information.
3. During the development of language used to relate objects and the relation between these objects in space.

Some researchers (Nielsen, 1991; O'Donnell & Livingston, 1991; Olson, 1981; Cowen et al., 1961) believe that visually impaired and even congenitally blind infants are able to develop an awareness of spatial relations without very much delay as long as they are nurtured in an appropriate and stimulating environment where they will be able to learn key concepts such as object permanence with accessible and redundant tactile and auditory cues. Early intervention that promotes active exploration is also crucial for the development of gross motor skills and other spatial concepts. In her book Piagetian Reasoning and the Blind, Hatwell (1966) concluded that in comparison to the sighted, blind children proceed along the same Piagetian stages of cognitive development, but that this progression was slower. Delays are particularly evident (two or more years) in the acquisition of conservation and classification skills (Stephens & Grube, 1982) such as the conservation of substance weight and volume (Tobin, 1972) and the classification and seriation of concepts (Friedman & Pasnak, 1973). Brambring (2006) also found clear

[33] Much of development relies on imitation and this is greatly facilitated by vision. Imitation could be achieved by touch but it is slower and more difficult. The lack of vision places the blind children at a disadvantage as their feedback such as facial expressions and body language is incomplete.

developmental delays in the acquisition of motor skills but notes that a high degree of variability exists within the blind population with many congenitally blind having similar acquisition ages when compared to their sighted peers. He argues that the incentive role of vision (to engage in movement) especially visual feedback for activity is particularly important for development (Tobin et al., 1997). The lack of feedback forces blind children to find alternative strategies from compensation. Hatwell (2003) attributed many of these delays to the fact that blind individuals learn their environment through a succession of experiences. Simultaneous perception places the sighted at an advantage as it allows for a more complete type of interaction. The lack of vision leads to a curtailment of interaction with both objects and people in the environment. It reduces the quantity and quality of data reaching the individual and eventually leads to problems in logical reasoning (Hatwell, 2003; 1966). Some researchers (Fraiberg, 1977) have suggested that the blind and visually impaired child becomes more passive and self-centred.[34]

In a series of Piagetian reasoning assessments, Stephens & Grube (1982) compared the ability of 75 blind and 75 sighted children matched in age and intelligence. The tasks included conservation, logic classification, mental imagery, spatial relationships and formal abstract operations. Results revealed that although there was sufficient evidence of development, the blind group still had considerable problems engaging in abstract thought particularly in tests that required mental rotation and mental imagery. In relation to the sighted children, the congenitally blind experienced significant delays in their cognitive development - this lag extending to almost eight years for the conservation of volume and class inclusion. However, after the implementation of a training program that catered to the individual needs of each of the congenitally blind children, the authors were able to demonstrate that these lags and deficits are remediable. After training, the performance of a sample (18) of the blind children was equivalent to that of the sighted on the majority of tasks.

Rosa and Ochaíta (1993) report on several studies (Birns, 1986; Ochaíta, 1982; 1984) that have used Piagetian theory to interpret and compare the development of children who are blind. Most studies converge on the idea that blind children are delayed when compared to their sighted counterparts with the blind experiencing on average a four-year delay in the development of topological concepts. This delay is even longer, usually between five

[34] Although there is no real conclusive evidence for the reason behind blindisms (repetitive self stimulation, turning and tilting the head, swinging the body, eye rubbing and poking) some researchers (Cutsforth, 1951; Burlingham, 1965) suspect that they are the result of a lack of social and sensorial stimulation. They argue that the lack of stimulation from the outside forces some individuals to turn to their own body as a source of stimulation and satisfaction (Lowenfeld, 1987).

and six years, for the understanding of Euclidean or metric relations.[35] Most studies however, agree that blind children after the age of 14 or 15 can develop a fairly accurate knowledge of Euclidean concepts and successfully perform Piagetian-like perspective tasks (i.e., three-mountain task) that require the manipulation of these concepts. They note however, that their performance depends on the complexity and scale of the task. Rosa and Ochaíta (1993) further report on a study that looked at the development of mental representations in blind children between 8 and 18 years of age. Subjects were asked to walk a route either inside a small room or a larger space, and learn the position of different objects. They were then asked to verbally estimate distances and build a model of the environment. They concluded that there is indeed a progression but that only around 13 and 14 years of age, the blind begin to have a proper knowledge of the spatial relation between objects. Moreover, they note that it is only around the age of 18 that it becomes apparent that these individuals are capable of abstract thought - their mental representations showing evidence of Euclidean knowledge.

Gottesman (1976) argued that vision and visual imagery are not necessary for the successful performance of Piagetian-like tasks. More important is the finding by Dulin and Hatwell (2006) that expertise and familiarity with the context and tasks can compensate for the lack of visual representations and should be controlled in all types of research evaluation. Warren (1978) among others (Lewis, 2003; Holbrook et al., 2000; Tobin et al., 1997) note that particular care should be given when comparing the development of the sighted with that of the blind and visually impaired considering many of the tasks designed to test knowledge and assess intelligence tend to rely heavily on vision. The elimination of tasks that emphasize the role of vision can also confound results given that the overall score depends on a composite contribution of various items. Van der Kolk (1977) studied the relationship between intelligence and various types and characteristics of visual impairment (congenital, adventitious, degree of vision, attendance to private or public school, level of education, family and social status). He found that the sighted and the blind were similar in IQ scores. More interesting is the fact that within the blind group differences existed in terms of age, etymology, length of education and damage to central nervous system.

No matter how different blind and visually impaired individuals may be, they still maintain many characteristics in common with the rest of the population. Their growth and development, although affected by their disability, is still dependent on a genetical

[35] Sighted children usually have an understanding of topological concepts by the age of seven.

past (both physical and mental) that is common for the entire species. Differences in development exist and these will depend on the type, severity of impairment and a variety of other variables present in the course of a lifetime.

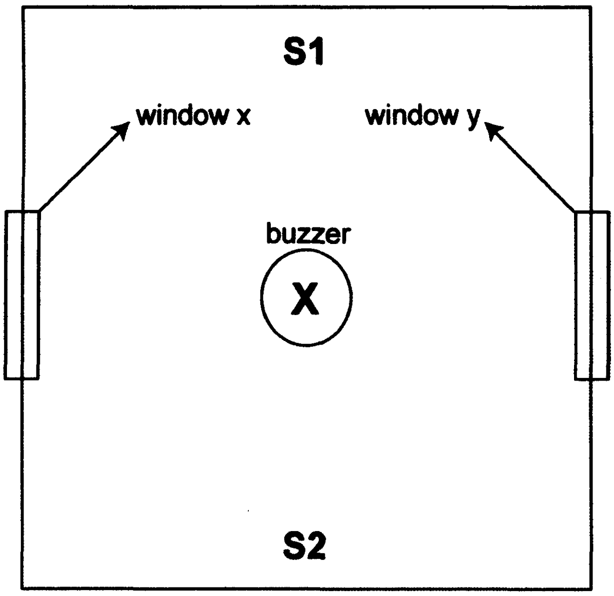
5.3 Piagetian egocentrism: Myth or reality?

Piaget did not spend much time discussing development in the total or partial absence of vision but it was clear to him that sight played a major role in the coordination of actions and their integration into more complex cognitive structures. In the paragraphs that follow, we will look at some studies that have used techniques similar to those used by Piaget in an effort to assess the relationship between egocentrism and the development of spatial concepts. We are particularly interested in research that has shown that children are not necessarily egocentric and that the body reference frame is one of the alternatives and one that is often chosen considering the amount, quality and type of information present during spatial coding.

Millar (1994) argues that poor results of blind children in some spatial tasks are not related to their ability to perform the task or a delay in development. The absence of vision results in (a) a lack of information about the external environment and (b) a loss in the redundancy of reference cues usually provided by the overlap of different sensory inputs. This in turn favours the use of an egocentric reference frame. In other words, without sight there is not enough direct and reliable external information on the relationship between different objects in the environment relative to an external reference frame. Under these circumstances, individuals have no alternative but to use information serially apprehended as a result of body movements.

There is considerable evidence that development does not necessarily consist of a strict shift between egocentrism to the use of allocentric reference frames to code space (Millar, 1994). In a seminal study, Acredolo and Evans (1980) tested the ability of infants to objectively code the location of an event (figure 5.1). Infants were seated (S1) in a room and trained to turn at the sound of a buzzer to one of two identical windows. After the training phase the subjects were moved to a new location (S2) at the opposite end of the room and their behaviour at the sound of the buzzer was recorded. The rationale of the experiment was simple. Once in the new location, if the infants coded the space allocentrically it would be expected that, at the sound of the buzzer, they would look in anticipation at the correct location (opposite to where they were trained to look). If the infants coded the location egocentrically they would turn towards the same window as in the training phase, now the non-target window. If unsure of the position of the correct location they would look in hesitation at both windows. In order to test for the facilitative or saliency effect of landmarks in the formation of allocentric relationships, subjects were divided into four landmark conditions: 1- No landmark: Subjects were given no information differentiating the two windows; 2- Star landmark: Had a yellow star around the target window; 3- Direct lights and stripes: A panel flashed lights around the target window and stripes on the wall; 4- Indirect lights and stripes: Lights and stripes appeared around the non-target window[36].

Figure 5.1 - Experimental space used by Acredolo and Evans (1980)



Source: Acredolo, 1981

In general results indicated that when there was no information differentiating the two windows infants tended to egocentrically code the location where an event occurred. For the "no landmark" condition all subjects, irrespective of age, responded egocentrically. Age differences were present in the star condition with a small decrease in egocentric responding by the eleven month-olds, followed by the nine and the six-month group. More interesting is the fact that in the presence of very salient landmarks such as the direct light and stripes, egocentric responding was almost nonexistent for all three groups.

The idea that people are not necessarily egocentric in their infancy and early childhood is backed by several other studies on children's ability to use large-scale spatial information

[36] The fourth condition is concerned with the idea that some subjects may use landmark information relationally.

while performing a task in a small-scale space (Bremner & Bryant, 1977; Smothergill, 1975). Responses that may seem egocentric may be nothing more than a learned motor response or a repetition of a learned behaviour. In order to test for this, and still keeping in mind the effect of external information, Acredolo (1981) used a simplified version of Piaget's "A not B" error test where children sitting at a table were shown an object being hidden in one of two identical pockets and immediately rotated to the opposite side of the table. By eliminating the training trials the author was able to remove the possibility of a learned motor response and focus only the reference frame used. Results indicated that when the task was performed at home only 15% of the infants behaved in an egocentric fashion choosing the wrong pocket when on the opposite side of the table. However, when the test was conducted in the lab, (a relative unfamiliar and landmark free environment) 77% of the children tended to behave in an egocentric manner.

In a study more in line with the current research, Herman and Siegel (1978) created 4.9 X 6.1 meter miniature village inside a classroom that consisted of different cardboard buildings. After a learning period the buildings were removed and children were asked to replace them in their correct location. Results indicated that the youngest group (5 year olds) was able to accurately replace the buildings, even those isolated from other landmarks within the village. Furthermore, they noted that continuous exposure to the village eliminated any age differences between the groups. The same experiment was then conducted inside a very large gymnasium. Performance by all groups was significantly lower especially that of the youngest groups. The authors assign this discrepancy in results to the fact that unlike in the first experiment where the miniature village was "bounded" by the classroom furniture, the size of the gymnasium did not provide any type of topological clues or external landmarks to aid in the coding of space.

Young children are not necessarily egocentric but rely on the condensation of competing information either from the body or from an external referent. The unbounded space of the gymnasium did not provide the information necessary for allocentric coding and children were forced to use a less efficient strategy, in this case an egocentric strategy, in order to complete the task. Here it is important to emphasize that egocentric responses are not always necessarily less efficient strategies (see Millar, 1994).

5.3.1 The CAPIN model

It is surprising given the elegance of Millar's model (2000; 1994) that only a few researchers have adopted it in their theories on the development and acquisition of spatial knowledge. The root of the CAPIN (Convergent Active Processing in Interrelated

Networks) model can be traced to connectionist models that take into account the neuropsychological and behavioural components, the constant changes that take place during development and the ongoing interplay between perception, acquired information and context. The model assumes that in a given situation, different parts of a network will have particular levels of involvement. These parts however, have "dedicated connections" with each other. Learning, development and the acquisition of information is a result of the constant interaction between these parts. The convergent section of the model refers to the idea that each of the different sensory modalities provides specialized but complimentary and overlapping inputs. It is the convergence of inputs that provides the redundancy that is necessary for the organization of collected information (Heller, 2000). Spatial coding in the absence of vision will depend not only on the substitution of inputs but the restoration of the redundancy of a variety of converging inputs from external and internal sources mediated by the access and type of information present.

The model implies that redundancy is crucial during childhood but it also emphasises the value of practice and repetition in later stages of life. Maturation is not uniform and is affected by past and present patterns of stimulation (Millar, 1997). Good performance in spatial tasks that involve rotation and reorganization of different elements not only depends on cue saliency, long and short-term memory but also on the presence of reference frames and an understanding of their alignment and possible discrepancies. The absence of vision does not preclude the understanding and potential coding of spatial concepts but makes it harder for the individual to seize the information necessary for the coordination of external frames. The performance of the blind child will depend on how sensory cue redundancy can correct for the discrepant, hard to code and visually biased information (Tobin, 1998).

As Millar (1997) accurately describes:

> "Performance [in spatial tasks] depends on what information people have and use, and how it is coded. Visual conditions do, of course, afford constant updating cues for moving through geographic space, as well as reference cues in small-scale spatial layouts. How spatial information is coded in memory by children as well as by adults depends, among other things, on how the information was acquired in the first place. Thus, moving along a route through an environment favours sequential coding of landmarks; while spaces that have prominent surrounding frames favour spatial coding of locations in relation to these reference frames" (Millar, 1997, p. 419).

In the introduction to his seminal book Brain Mechanisms in Sensory Substitution, Paul Bach-y-Rita (1972) asks whether the eyes are really essential for vision. His argument throughout the book (and through much of his later research) being that images captured through the eyes never really leave our retinas but travel to our brain in the form of electrical and chemical pulses. In this manner, we do not really see with our eyes but with our brain (Chebat, 2006). Millar's CAPIN model is able to account for the growing evidence that developmental time frames are influenced by experience and stimulation. The discrepancy found in the Piagetian model between task performance and developmental stages can be explained by the control, the coding and the type of information supplied. The growing evidence of brain plasticity (Ptito & Kupers, 2005; Ptito et al., 2005; Pollok et al., 2005) in blind (or blindfolded) individuals, and findings regarding the multimodal aspects of cortical areas specialized in spatial coding (Passini et al., 2000; Stark et al., 1996)[37] further validates the idea that constant stimulation with the correct type of information can provide alternative modes of development. Perception in this sense is highly dependent on memory, learning and the ability of the brain to reorganise its functions. Braille reading can be seen as a form of sensory substitution – the ability of the brain to reorganize itself, interpret and transform fine tactile sensations into letters, words and coherent sentences. The fact that parts of the visual cortex are activated during Braille reading (Ptito & Kupers, 2005) is further evidence on the plastic characteristic of brain's functional organization where tactile stimuli is able to fire regions in the brain once thought to be solely dedicated to vision.

The key aspect of the CAPIN model is the notion that differences in task performance between the sighted, visually impaired and the blind are related to differences in the manner space is coded. The model holds that differences in spatial coding can be explained by the need for greater information redundancy. Redundancy in this case encompasses various concepts such as familiarity, repetition of inputs and the presence of salient cues. The degree of residual vision and the type of impairment will interact differently with the amount and type of information that is provided. Performance in spatial tasks will depend to a great extent on the quality, mode and type of information that is available. Differences between children and adults or between the blind and sighted that are usually attributed strictly to age or developmental stage tend to disappear when the appropriate information is provided and captured. This does not undermine the role mental structures play in the acquisition of spatial information. There is a

[37] Using imaging and single cell recording techniques these authors have shown that damage to specific parts of the brain can result in different types of spatial deficit.

considerable amount of neuropsychological evidence (Millar, 1994) regarding the development (maturity) of areas in the brain (posterior parietal, prefrontal and hippocampus) specialized in spatial coding (Mackintosh, 2002). But it is exactly during their development that these structures are susceptible to pick up competing and erroneous information. It is in such situations that redundancy is important (as these structures mature, much of this being determined by practice, memory and familiarity, redundant information although helpful is no longer seen as absolutely necessary). When adults perform better than children or when a sighted group outperforms a blind group in spatial task it is because the information that is being provided for successful task completion is not redundant enough. The nature of spatial coding is not strictly dependent on age (children versus adults) or sight (sighted versus blind and visually impaired) but on the combination of maturity, the demands of the task, salience, redundancy, reliability and format of the reference information. As we shall see, this view is shared in Newcombe and Huttenlocher's (2000) re-weighting theory and Montello's (1998) continuous framework (see chapter 6).

5.3.2 The re-weighting theory

Newcombe and Huttenlocher (2000) argue that Piaget was wrong in suggesting that (1) many spatial achievements are reached at a late age in childhood and (2) adults are very accurate in spatial tasks. For them infants and children are capable of *advanced spatial thinking*, as they are able to reason about distances and perspective. At the same time large biases also exist in adult spatial coding (McNamara & Diwadkar, 1997; Tversky, 1981) and reasoning many of which can be attributed to the fact that adults used an egocentric type of spatial coding. Following Acredolo's (1977) rationale that incorrect spatial reasoning is the result of *competing reference systems*, they argue that humans have the ability to use different reference systems to code space but given a specific situation, differ regarding the frame they choose. For them infants are not egocentric but equipped with mature spatial coding (this includes hierarchical organization) abilities. Their experience with the environment is what provides them with knowledge and practice of when and where to use the appropriate frame of reference. Newcombe and Huttenlocher (2000) note that there are four possible systems that can be used for spatial coding. *Cue learning* (the association of locations with landmarks) and *place learning* (coding in terms of distance and direction from specific landmarks or landmark-like regions) are based on external references. *Response learning* (memory for particular motor/muscular movements or pattern of movements associated with a goal) and *dead* *reckoning* (also known path integration or the ability to adjust and infer distance and direction from information from vestibular, kinaesthetic and visual sources) are body or person centred. They argue that both *place learning* and *dead reckoning* are more powerful and widely used coding systems.

Consider Acredolo and Evans' (1980) experiment reported above. In such situation the child may use one of the four different systems in order to code the location of an event at a window. However when landmarks are removed or their saliency reduced children can no longer use cue learning and place learning given that these reference systems are landmark based. Instead, the child has a greater propensity for using response learning or dead reckoning. Given that the child may not be familiar with the experimental task and layout, cannot find other possible cues and that coding was based on a motor response; the child may, at the sound of the buzzer misplace her gaze and look at the wrong window. In the same manner, it may be said differences in performance in spatial tasks by the blind and visually impaired can be attributed to incomplete spatial knowledge as the direct result of the absence of sight and the presence of mature but conflicting systems for spatial coding that will remain error free as long as information is properly conveyed. Biases in their performance, much like the biases of sighted adults are evidence that this system is not safe-proof. Depending on the situation reference frames will conflict, a conflict that may eventually be settled by experience. Blind and sighted humans alike go through a *re-weighting* process (in a computational sense) when systems conflict and they must decide which will be used. Much of this weighting depending on practice/reinforcement, noise removal/attention, the presence of information and the level of emotional stress. Development in this sense can be understood as the changes in "importance that is attached to the different types of spatial information as they come into conflict" (Newcombe and Huttenlocher, 2000, p. 49). The propensity to weigh in favour of a correct coding is influenced by a variety of factors the most important being motor coordination, visual experience and cortical maturation.

5.4 Conclusion

Sight organizes, integrates and unifies experience. Vision acts as an incentive to action and movement and allows for quick and simultaneous perception. In this chapter, we have shown that while it cannot be denied that sight plays an important role in the acquisition and development of spatial knowledge, it is by no means the only sense that can provide spatial information. It is often believed that the absence of vision results in egocentric behaviour. As we shall see, this has led to the common belief that the blind they can only develop knowledge for routes and are unable to represent space in a configurational manner using Euclidean or metric concepts. We have shown however, that the difficulties children have in performing spatial tasks are not entirely related to an underdeveloped cognitive structure that is unable to deal with advanced spatial coding but to the difficulties these children have obtaining/capturing the relevant information from the environment. Here it is important to note that *accurate* does not necessarily mean allocentric, as the appropriate reference frame will depend on the environment and task requirements. It follows, that in the absence of vision the information that is sometimes necessary for accurate spatial coding cannot be attained. Blindness and visual impairment do not result in egocentric behaviour but encourage it.

Chapter 6
Spatial representation, navigation and wayfinding

> "We believe that in the course of learning something like a field map of the environment gets established in the rat's brain..." – Edward Tolman (1948, p. 31)

6.1 Introduction: Representational theories of perception

Representational theories of perception have to a large extent dominated research on environment and behaviour (Glotzbach & Heft, 1982). For the most part, these theories tend to focus on the relation between visual stimuli and the resulting actions. Perception is made up of a series of mental processes that make sense of retinal images through the transformation and enrichment of stimuli (Heft, 1997). The perceiver is usually the starting point and perception is seen as a process of relating acquired visual information with what has been previously stored. In this chapter we consider different theories on acquisition of spatial thought. The chapter begins with a review of classic cognitive mapping theory that argues for a *stage like* development of spatial knowledge characterized by discrete or qualitative differences. This is followed by a discussion of Montello's (1998) framework where the development of spatial knowledge, particularly the manipulation of metric or Euclidean concepts is seen as continuous. The chapter concludes with a discussion of the concept of hierarchy and distortions in mental representations.

6.2 Tolman and the cartographic metaphor

The term *cognitive map* was coined by the psychologist Edward Tolman (1948) in order to explain the behaviour of "hungry" rats in a variety of mazes. For Tolman, learning did not consist of series of "stimulus-response connections but in the building up in the nervous system of sets which function like cognitive maps" (Tolman, 1948, p. 32)[38]. The term *cognitive map* is perhaps the most widely used metaphor to describe our knowledge of the environment and the elements that comprise it. It has been used by researchers in variety of disciplines and stems from the notion of the map as a cartographic medium for storing and communication environmental knowledge. While it may seem obvious that we do not literally store information in a cartographic form, Tolman (1948) was describing a process; the metaphor suggests that no structural differences exist between mental and cartographic representations (Peuquet, 1998). Perhaps the main issue is that the term *cognitive map* falsely implies knowledge in a unitary spatial format (Montello, 1992) isomorphic to the information stored in a graphical map (Kuipers, 1982). The cartographic map is not the only yardstick for comparison (Downs, 1981). Environmental knowledge is not necessarily stored in a singular unified fashion and retrieved by "mentally reading" a holistic and image-like representation.

Mental representation of space should be regarded as a conglomeration of multiple representations stored in long-term memory. These representations are not necessarily coordinated or consistent (Tversky 2005; Montello, 1992) but fragmented, schematized, incomplete - multimodal mental constructs of reality. Sholl (1987) argued that cognitive maps act as orienting schemata with no preferred orientation with respect to the local environment while mental representation of large geographical regions acquired through a map tended to be more like *pictures in the head* that favour a specific orientation.[39] In fact, Evans and Pezdek (1980) found that map-reading experience produced orientation specific representations while representations built on the basis of navigation produced orientation free representations. Tversky (1993) has suggested the term *cognitive collage* instead of *cognitive maps* as a more realistic metaphor for mental representations of space. From a constructionist perspective she argues that mental representations of space are made of "disparate pieces of knowledge" (Tversky, 1993, p. 14) in a variety of formats (verbal, visual, motor) that although stored in long term memory will only be selectively retrieved. Many times and particularly in unknown environments this knowledge will not be organized into a coherent maplike structure but will resemble a

[38] Tolman's 1948 article is also found in: Image and environment. The quote was taken directly from this book.

[39] This last view supports the Levin et al., (1982) equiavailability principle where information in mental representations is equally available and with a specific orientation where the relationship between different objects in the environment that may have been acquired sequentially is simultaneously integrated.

collage. The term collage implies a series of "thematic overlays" (p. 15), information in various formats and from a variety of sources. Information in a collage will not be as complete as one from a map but will include different perspectives, images, verbal and proprioceptive information. As we shall see, this lack of coherence and incompleteness of information is consistent with some of the systematic errors committed when these representations are externalized.

6.3 Microgenesis of spatial representations

In this section we will review some of the most important theories in the acquisition of spatial knowledge during navigation. Here it is important to distinguish between knowledge that is acquired through navigation and knowledge that is acquired through a cartographic map. Lloyd (1989) has argued that navigation usually provides procedural knowledge that can also be verbally encoded while map reading is often associated with imagery and survey knowledge. These however, are not mutually exclusive (McNamara, 1992) as survey or configurational knowledge can also be developed during navigation through the integration of discrete chunks into a whole and coherent representation. In this thesis we are particularly interested in the development and accuracy of representations that are exclusively built through navigation. As we shall see, many of these theories follow the Piagetian notion of discrete developmental stages and egocentric/topological to allocentric/metric shifts.

Before we begin, it is imperative that we differentiate between *route* and *map* learning. Route learning involves the encoding of the sequential relationship among objects and depends on the integration of a series of movements that connect perceptual information about different elements in the environment (Allen et al., 1979). Route learning is often characterized as egocentric, serial and organized on the basis of body referents. Routes are made up of different segments that are *temporospatially* connected to each other. For this reason routes tend to be static and not prone to reorganization. The ability to shortcut or to make spatial inferences on the basis of route knowledge can be difficult as each segment has a specific represented relationship with the other. Map learning on the other hand, implies an overall knowledge of the relationships among the different objects in the environment. These relationships can be simultaneously encoded and do not have to be directly perceived. Map learning allows for the automatic encoding of both distance and direction providing a more comprehensive knowledge of the relationship between the various paths that make up a network. Maps are characterized by a high degree of plasticity as spatial inferences can be made on the basis of allocentric information irrespective of body position. Given that the construction of mental representation tends to rely to a great extent on the perception and encoding of distal cues, and the fact that the total or partial absence of sight greatly reduces the access to such information, Millar (1994) argues that the first stage in the acquisition of spatial knowledge by blind and visually impaired is usually route-based as it is constructed on the basis of body-centred, proprioceptive and kinaesthetic information.

6.3.1 Hart and Moore (1973)

Coming from a Piagetian constructivist stand, Hart and Moore (1973) argued that the development of spatial representations can be separated into three stages that are marked by a change in the reference system used to code space. In the undifferentiated egocentric stage (usually between 4 and 7 years of age), the child tends to code the location of objects in space in relation to the body. Representations are topological and usually centred around familiar places such as the house and school. After seven years of age, children begin to organize their representation in terms of differentiated, partially coordinated but fixed subgroups. Finally, around eleven years (at the end of the concrete operations stage and beginning of the development of abstract thought) the child begins to integrate and coordinate different representations as well as elements within representations in a projective and Euclidean format. This type of progression from egocentric to progressive Euclidean representations also takes place when an individual learns a new environment.

6.3.1.1 The role of landmarks in mental representations

For Hart and Moore (1973) landmarks are the basis of the reference system that "supersedes" the child's egocentric tendencies. In fact, landmarks play a crucial role in many representational theories of space as they facilitate the coordination of action and the integration information. They provide individuals with a reference (Presson & Montello, 1988) allowing space to be cognitively partitioned and for inferences to be made accordingly.

A landmark can be any salient feature in the environment. Kevin Lynch (1960) considered a landmark any element that can potentially serve as a point of reference. Landmarks are usually distinctive (shape, colour, size) or have some form of symbolic meaning (historic, religious, socio-cultural) that makes them stand out (Couclelis et al., 1987). They could be a building, road, sign, river or pretty much anything - the saliency of a landmark relating directly to the individual and the experience in the environment. A landmark may also be regarded as a point of correspondence between the actual spatial experience and the representation of a previous experience, and can be extremely valuable in situations when a person is lost. Landmarks are also context and task dependent. What may be considered as a landmark in a particular place or situation may not be salient enough to act as a reference in a different situation. It is the nature of the task that will determine what will be considered as a landmark. As noted by Presson & Montello (1998) "a campus library may serve as a reference point for other campus buildings, but not for the larger city in which the campus is located." Landmarks also do not necessarily have to be spatial as reference can also be made in relation to a smell or sound – although these tend to be more dynamic and inconsistent.

Sorrows and Hirtle (1999) have put forward a tripartite theory of the characteristics of landmarks. They define a *visual landmark* as an object that contains high informative value for the navigation and orientation in an unfamiliar environment. A *semantic landmark* is an object whose meaning stands out and contrasts with the surrounding. The meaning may be historical or cultural and usually develops from past experience. *Structural landmarks* are those that hold a prominent place in the structure of a space (i.e., Big Ben in London).

6.3.2 Siegel and White (1975)

Siegel and White's (1975) theory holds that spatial knowledge is acquired through a series of qualitatively different stages. Individuals first acquire knowledge of landmarks (points of high saliency such as buildings, junctions, signs) without specific information about the spatial relations between them. Experience allows for the development of a sequential ordering of these landmarks along a route. This eventually leads to knowledge of the spatial relations among these landmarks and an understanding of the layout of the route. Route knowledge is initially *nonmetric* and develops into *minimaps* or clusters of connected by landmarks (Siegel & White, 1975). The continuous integration of different routes (or route schemata) leads to the creation of an allocentric and holistic (global) knowledge of the environment. Repeated experience allows for mental representations to become more flexible. It is in essence a process of scaling and metricizing of distances and directions between landmarks that are later integrated into more complete and accurate configuration such that "routes or linear maps are superordinate to landmarks, and subordinate to configurations" (Siegel, 1981, p. 170). Configurational knowledge (or survey knowledge) is the most sophisticated stage and is characterized by a Euclidean or metric understanding of relationships (both distance and direction). Configurational knowledge allows for inferences to be made regarding the spatial relationships among previously unrelated locations and is crucial for shortcutting (Kirasic et al., 1984).

Unlike Piaget, this theory does not make any strict association between age and type of mental representation although age has been found to have an important effect on the accuracy and utility of mental representations (Herman, 1980; Herman & Siegel, 1979; Siegel, 1978). Siegel and White's (1975) theory actually emphasizes the similarities between children's developmental stages and those faced by adults when learning a new environment. The essence of spatial knowledge depends on the level of experience or familiarity with the environment. What is important to highlight here, is that delays in the acquisition of spatial knowledge are not developmentally invariant or mandatory but depend to a large extent on the ability of the individual to pick up and organize environmental information. In the total or partial absence of vision, when individuals are forced to deal with less reliable information, experience in the environment will have an important effect on the ability to develop configurational knowledge.

6.3.3 Anchor point theory

Landmarks are the basis of Golledge's (1978) anchor point theory. As the name itself implies, landmarks or anchor points provide structure to representations and allow for different segments (routes) to be connected into areas. Couclelis et al. (1987) note however, that anchor points and landmarks are not the same considering landmarks are usually concrete cues whereas anchor points may be more abstract. Anchor points are better understood as nodes in the *Lynchian* sense of strategic spots. The theory holds that when in a novel environment, individuals find and select major anchor points (or nodes) from which they begin to build their spatial knowledge. These nodes are eventually connected by major paths and spill over effects around these paths provide the individual with areal knowledge. In most cases, locations associated with the home, work and shopping become known and are associated with paths that connect them. There are also some spread effects and sets of secondary paths begin to develop in the vicinity of anchors with some becoming major decision points. Finally, sets of spatially primary and secondary paths as well as nodes are integrated and generalized (neighbourhood, community area).

Anchor point theory is hierarchical in the sense that there is an ordering of spatial information – the connections between nodes and paths follow a skeletal structure for representing cognitive information. Hierarchy implies that accuracy of externalization will vary as a function of importance or encoding order. In most cases, distortions in recall will vary in terms of proximity to anchor points and the number of paths that connect such nodes (Couclelis et al., 1987). Golledge (1978) argues that the anchor point theory is not a developmental theory tied in with age but an organizational/structural theory that could exist at any developmental stage.

6.3.4 The continuous framework (Montello, 1998)

The notion that configurational knowledge develops from the sequential association of routes has been subject to criticism. A study by Moar and Carlton (1982) on the development of mental representations of two intersecting routes in an urban area found that subjects used a network type of schemata in which both routes were combined from the start rather than being separately integrated. These authors argue that although knowledge of individual routes can be combined to produce a more complete representation, it is also possible that given a situation in which routes integrate in an obvious manner, individuals can automatically develop knowledge of a "network of interconnected routes." These results suggest that the theory developed by Siegel and White's (1975)[40] tends oversimplify the process of acquisition of spatial knowledge. Route knowledge can also develop through more complex process where information from junctions, connections and associations between different routes can be simultaneously (and automatically) encoded and represented as nodes (Byrne, 1979). Similar results have also been found by Slator (1982 – see Millar, 1994) who has shown that children are capable of acquiring a configurational knowledge of the environment when task information about the area is simultaneously provided along with the location of prominent landmarks. When the children were shown the same information but in a sequential manner, they tended to respond in a sequential or route-like form. The authors argue, that spatial coding is not only dependent on the context but on the manner in which the information is presented. At the same time Golledge et al. (1993) showed that the development of procedural knowledge for navigating a series of routes that connect specific locations does not always guarantee the ability to integrate these different routes into a configurational knowledge of the larger environment. They argue that contextual and frame of reference information is crucial for the integration of piecemeal knowledge.

Blades (1991) disputes the stage development by arguing that the concepts of landmark and route are hard to define and distinguish in a representation given that "for an environmental feature to function as an effective landmark it must already be fully or [at least] partially integrated into the route sequence of which it is part" (p. 142). In this case, Golledge's (1978) concept of anchor point as a node may be a more appropriate definition. Blades (1991) goes on to argue that although researchers have tried to study the microgenesis of mental representations, results often contradict the hypothesis of discrete developmental stages or the strict separation of landmark and route knowledge (see Spencer & Weetman, 1980). In most cases, stage development is confounded with issues of familiarity, the adopted methodology and the fact that subjects can develop route knowledge with minimal experience. For Blades (1991) the development of spatial abilities depends on mnemonic (rehearsal, grouping), wayfinding and encoding strategies used by individuals. This is the case where in the absence of landmarks a variety of other encoding and wayfinding strategies could be used in the construction of mental representations.

More recently, Montello (1998) challenged the strict Piagetian style of stage like development as proposed by Hart and Moore (1973) and Siegel and White's (1975). Montello's continuous framework argues that minimal exposure to a new environment is enough to provide people with Euclidean or metric knowledge allowing individuals to perform with accuracy in a variety of tasks that involve shortcutting, returning back to a home location and estimating distances and directions (Ishikawa & Montello, 2006). This is in direct contrast with classic stage theories such as Siegel and White (1975) where this kind of knowledge can only develop after significant experience with the environment. The framework posits a continuous and quantitative theory of the development of spatial knowledge building on several ideas put forward in Blades (1991) and Liben's (1981) work regarding the problems of separating landmarks from route knowledge. More important, the theory can account for individual differences in spatial abilities. Differences between subjects are regarded as evidence that individuals are not constrained to develop in a strict *stage like* manner. Individuals vary in terms of their spatial abilities and this includes their knowledge of the Euclidean relationships among objects in an environment.

Support for the continuous framework is found in Ishikawa and Montello's (2006) longitudinal study on the ability to estimate various spatial properties of two unfamiliar routes. They found that the spatial abilities of their subjects did improve continuously across trials but that the majority of subjects either showed good signs of Euclidean (metric) knowledge in the first session or did not manifest this knowledge at all across the

[40] Also an earlier theory developed by Shemyakin (1962).

different trials. They argued that if configurational knowledge develops in a series of stages then performance in the first trials should be considerably lower when compared to later sessions. The fact that performance was better than chance in the first trial but continuously improved is evidence that people can quickly develop Euclidean knowledge and that this knowledge continuously improves in terms of "quantity, accuracy and completeness" (Montello, 1998, p. 146). Individual differences are not only a factor of age or experience. Some individuals may actually have better spatial skills and this may be related to differences in encoding, wayfinding and exploratory strategies.

6.4 Distortions in mental representations

Cognitive distances can be influenced by the saliency of landmarks (Saddala et al., 1980), familiarity (Downs & Stea, 1973), the number of turns and intersections on routes (Saddala & Magel, 1980), whether two places are connected by a route (Klippel et al., 2004; McNamara & McKoon, 1984) as well as the presence of environmental barriers such as roads, railways and rivers (Lloyd, 1997). Barriers have consistently been shown to lead to an exaggeration of estimated distances (Lloyd & Heivly, 1987). Byrne (1979) has successfully demonstrated that intersections, bends and turns or the presence of landmarks in a route can lead to the overestimation of distances between two locations. In general, distances among paths with more segments are overestimated (Kahl et al., 1984). People also tend to overestimate the distances between places that are closer together and underestimate the distances between places that are further apart (Lloyd & Heivly, 1987; Moar & Bower, 1983). Distortions also exist in relation to major transportation axes and key reference points (landmarks). In experiments where subjects were asked to estimate distances and directions between 105 pairs of landmarks Lloyd and Heivly (1987) found that the home location had a strong effect on the distortion of the mental representation. There are also a series of individual factors that may lead to distortions in cognitive maps such as the length of residence (Downs & Stea, 1973) and the level of mobility (Golledge, 1993; 1978). Here it is important to note that there is a difference between length of residence and familiarity as individuals that are long time locals may be used to only a particularly set of routes.

Tversky (1992) has shown that distortions in mental representations are related to errors during the encoding, storage and decoding of spatial information. Here it can be argued that if a group of people share a series of distortions than these individuals must have used similar cognitive processes to encode spatial information and are, to a certain extent, operating on similar mental representations. A typical form of systematic distortion is the categorization of spatial information (Lloyd, 1997) that is acquired through a variety of formats but related abstract categories. Mental representations are not identical copies of the environment but integrated and organized knowledge structures (Klippel et al., 2004) that are modified and enriched with previously stored information. Spatial information is stored with nonspatial and non-perceptual information and this can usually lead to distortions when these representations are externalized. Time is a typical variable that can lead to distortions in representations. The fact that something is located uphill or has to be reached through an indirect route that requires more time or effort can distort the metrics of a representation.

Distortions can also occur when spatial information is hierarchically encoded (McNamara, 1986). This relates to the famous San Diego/Reno error where subjects consistently responded that Reno is located east of San Diego when in reality it is located to the west (Stephens & Coupe, 1978). Tversky (1992) has argued that these distortions occur as a result of mnemonic strategies used to simplify the encoding and memorization of spatial information. She notes that there is a general tendency to rotate elements so they correspond to the accepted North/South frame of reference. Elements in a representation can also be distorted so they end up more aligned to each other than they actually are (Tversky, 1981). Alignment effects are usually the result of perceptual grouping where elements that are part of a larger configuration are organized closer to each other. This is supported by research (Hirtle and Mascolo, 1986; Allen 1981; Maki, 1981) that found that distances across clusters were consistently judged as being longer than identical distances between objects inside clusters.

6.5 Summary

In this chapter we reviewed several classical theories on the construction of mental representation that argue for a stage-like development of environmental knowledge where the individual progresses from simple egocentric route knowledge to configurational knowledge of the environment. Montello's (1998) continuous framework was presented as a reaction to these theories and it was argued that minimal exposure to environments was enough to provide individuals with accurate Euclidean knowledge. That is, Euclidean knowledge does not usually take long to develop having to progress from landmark to route to configurational knowledge. In the chapters that follow, it will be argued that this break from the classical approach was pivotal in the reassessment of the cognitive mapping abilities of the blind and visually impaired. Montello's continuous framework allows for an analysis of individual differences that moves away from the constraints imposed by strict developmental stages, either in terms of egocentric to allocentric shifts or the progression from route to configurational knowledge, while considering the variety of factors (personal or environmental) that are involved in the formation of mental representations. The chapter concluded with a discussion of distortions in mental representations where it was argued that similarities in distortions could be regarded as evidence that individuals are using similar cognitive process in the encoding of spatial information.

Chapter 7
The spatial abilities of the blind and visually impaired

> "The most pathetic person in the world is someone who has sight, but has no vision" – Helen Keller (1880 /1968)

7.1 Introduction: The three theories

Fletcher (1980) proposed three theories as a way to categorize the long history of research on the spatial abilities of the blind and visually impaired. The deficiency theory holds that vision is essential to the formation of mental representations. The inefficiency theory states that the blind and visually impaired are able to understand and manipulate spatial concepts but that their spatial knowledge is inferior. The difference theory believes that blind and visually impaired are functionally equivalent to the sighted in their ability to process spatial information but that this is carried out in a different and slower manner. These theories have served as a useful framework in the discussion of past research (Jacobson, 1998). They have allowed for the classification of different experiments and have provided an overall structure where different hypotheses could be tested and results presented. However, these theories have also in some way restricted the types of questions that could be asked. Although the difference theory acknowledges that blind and visually impaired acquire spatial knowledge through different means, it does not provide any details regarding the role of the different sensory modalities in spatial coding. Carreiras and Codina (1992) have proposed an amodal interpretation that questions the central role of vision in the acquisition and manipulation of spatial knowledge. As we shall see this theory finds support in the work of Susanna Millar (see chapter 5) who notes that no sensory modality in itself is necessary or sufficient for spatial coding.

The chapter begins by considering these three theories in detail. This is followed by a review of a series of experiments regarding the spatial abilities by the blind and visually impaired. Navigation, curiosity and exploration in the absence of vision are considered and Hill et al. (1993) study on the exploratory strategies used by blind in an object location task is presented. The chapter concludes by looking at some of the different exploratory strategies taught in orientation and mobility and others developed through research with the blind and visually impaired. The strategies are classified in terms of egocentric or allocentric and their role in spatial coding is discussed.

7.1.1 Deficiency theory

The deficiency theory holds that vision is the spatial sense par excellence (Foulke, 1983) and essential to the formation of mental representations. This is an extreme view that has very few supporters and can be said to originate in the work of the German doctor Marius von Senden (1932; 1960). After reviewing a series of cases of individuals who had their vision restored after operation (in most cases corneal grafts for the removal of cataracts) von Senden concluded in his book Space and Sight that "...the blind can only grasp succession and relation [unable] to produce the completed whole" (von Senden, 1960, p. 288). That is, the early and congenital blind are not able to build overall impressions from fragmentary experiences of the environment collected by the other senses. They are incapable of spatial thought, as they have never experienced the perceptual process necessary to comprehend spatial arrangements. His extremism is well portrayed when he notes that "not one [case] has provided evidence to support the hypothesis of a space of touch; [but] have shown beyond doubt that the congenitally blind patient lacks everything that would entitle one to speak of a tactile awareness of space" (p. 279).

Von Senden's conclusions have been widely contested. Fletcher (1980) argues that the blind can form gestalts from sequentially perceived information and uses examples from photographs and sculptures by blind artists where different parts of their work are integrated to form a complete picture. Brambring (1976) argues that perception depends on learning and development. He notes that case reviews of individuals who have recovered their sight after surgery is in some way a futile exercise as these individuals cannot be directly compared to the sighted without considering the actual development of the visual system. It seems rather impossible that these individuals would make sense of visual stimuli directly after the operation without any previous learning.

We should not be so quick to dispense with von Senden's work. What von Senden did, examining almost every recorded case (until the 1930's) of visual restoration after surgery, was no simple task (he was also the first to do it). Von Senden's conclusions should be understood as his personal interpretation of the data. Unfortunately, this happened to be second-hand data from a variety of sources that varied in terms of the detail and intention. In fact, if one carefully looks through the case descriptions he was dealing with, it is hard to arrive at a very different conclusion. The merit in his work lies in the formulation of a theory that regardless of its veracity has generated and continues to generate *scientific* research.

7.1.2 Inefficiency theory

This theory holds that the other sensory modalities are inferior to vision; that the blind and visually impaired are able to manipulate spatial concepts but that their mental representations are substandard or incomplete when compared to the sighted. Auditory, kinaesthetic and haptic cues are less effective ways of encoding spatial information. Support for this theory is originally found in the work Worchel (1951). Worchel conducted two sets of experiments. In a reproduction experiment, congenitally blind (CB), adventitiously blind (AB) and blindfolded sighted (BS) subjects were asked to feel a series of geometrical forms and reproduce their shapes graphically (drawing using a pencil) and verbally (by describing the object). For all geometrical forms, the drawings and descriptions of the sighted were significantly superior to that of the blind. The blind performed better at the verbal description tasks and the author acknowledges that their performance in the previous task may have suffered due to a lack of experience in drawing. In terms of object recognition however, no significant differences were found between groups.

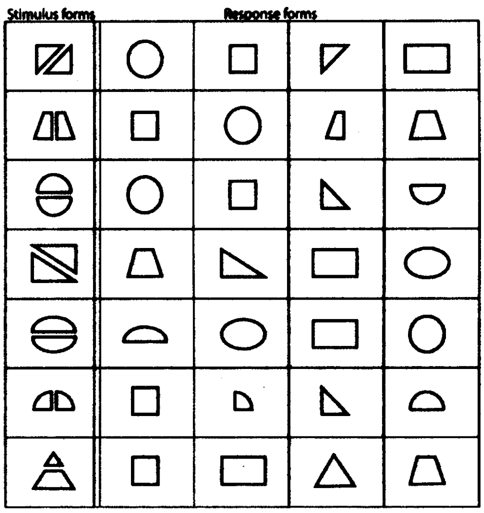
In the mental matching experiment, subjects were given two objects (one in each hand). After feeling the objects, subjects were asked to choose from a set of objects on a table which object represented a synthesis of the two forms (figure 7.1). Worchel found that the performance of the CB, although above chance, was inferior to that of the AB. Moreover, the performance of both blind groups was inferior to that of the sighted.[41] In the second experiment, Worchel led subjects along two short legs of a triangle (figure 7.2) and asked them to return along the hypotenuse. Similar to the previous experiment, the performance of the sighted was significantly better than the two blind groups. The blind were fairly accurate estimating distances but had considerable problems estimating direction.

In a haptic version of a triangle completion test where subjects were asked to give verbal and motor estimates to the shortest distance between two points, Brambring (1976) found that although the CB could represent the different vectors and produce new spatial

[41] The identification of objects does not necessarily involve a synthesis of tactile impressions. The fact that some CB individuals were able to accurately match the form may be due to a prominent feature of the object (sharp angle).

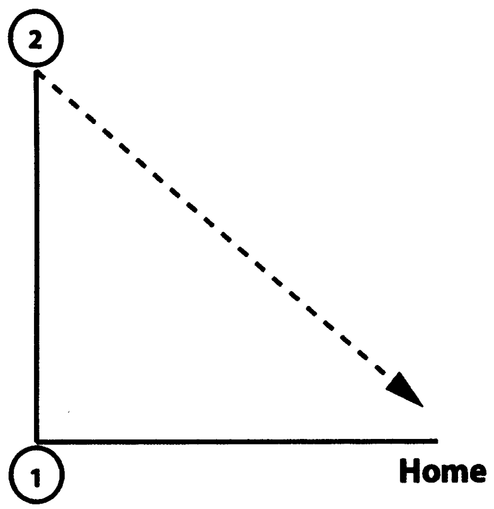
relationships, their response tended to be less stable when compared to people with prior visual experience. Here again, the performance of the sighted was better than the two blind groups. Both the CB and AB made more errors of distance and direction. Like Worchel, Revesz (1950) believed that unlike vision, which could provide simultaneous and distal information about how objects relate to each other, touch depended on the succession of information. As we shall see however, Revesz was a proponent of the difference theory noting that the ability of the blind and visually impaired to understand and represent space is different and not lacking when compared to that of the sighted.

Figure 7.1 - Mental synthesis task



Source: Worchel (1951)

Figure 7.2 - Triangle completion task



7.1.3 Difference theory

The difference theory holds that the spatial abilities of the blind and visually impaired are functionally equivalent to the sighted; that blind and visually impaired have the same abilities to process and understand spatial concepts but these are developed more slowly and by different means. Differences can be explained in terms of a developmental lag or intervening variables such as stress, experience and access to information (Jacobson, 1998; Passini & Proulx, 1988). Juurmaa (1973) argues that one should be careful when interpreting Worchel's (1951) conclusions as these may be flawed and the result of a testing artefact. He argues that subjects were dealing with material that was optically familiar and favoured vision. Differences between groups disappear when subjects are asked to synthesize irregular shapes or return to the starting point after being guided through an irregular shaped path (Juurmaa & Suonio, 1975).

Juurmaa's criticism is supported by several studies on path integration (Klatzky et al., 1997; Klatzky et al., 1990; Dodds et al., 1983). Path integration refers to the updating of one's position without reference to landmarks. Updating takes place through the processing of proprioceptive information as well as an internalization of velocity and acceleration. Most of these studies have focused on the calculation, accuracy and updating of the *homing vector*. Like Worchel's experiment, most subjects were asked to walk the two legs of a triangle and return to the origin along the hypotenuse. Apart from showing the ability to continuously update their position in space (either in increments or at specific salient areas) these studies also investigate the ability to shortcut – often considered an indicator of configurational knowledge

In general, most studies did not find any differences between the blind (CB & AB) and sighted in the calculation and completion of the homing vector. When paths are simple, reproduction was fairly accurate with turns being reproduced on average within five degrees of the correct response. Results in more complex paths support Juurmaa's conclusion that performance declines as the complexity and the size of the travelled path increases. Changes in performance are clearly seen when the travelled path increased from two to four segments (Loomis et al., 1993). Errors are said to accumulate, as more mental operations are necessary. Loomis's et al. (1993) conclusions support the notion that at least in path completion, the spatial abilities of the blind and visually impaired can be said to be functionally equivalent to that of the sighted. However, large individual differences were also found within the different groups.

7.1.3.1 An "amodal" interpretation

Carreiras and Codina (1992) have proposed an amodal interpretation as an explanation of the differences between the spatial abilities of the blind, sighted and visually impaired. This version of the difference theory questions the central role of vision in spatial cognition. It holds that the formation of spatial representations necessary for the successful completion of certain spatial tasks is not limited to any particular sensory modality although processing is probably faster with vision. They argue that the cognitive understanding of space in the absence of vision depends on the development of specific strategies for the capturing and processing of stimuli. At the same time, the formation of mental representations does not depend to the creation of visual images. Other senses (mainly touch) are well equipped to deal with environmental information as long as it is presented in an accessible format. The amodal interpretation is particularly at odds with the deficiency theory. While the deficiency theory holds that touch and sight are irreconcilable (Von Senden, 1932) the amodal interpretation believes that the formation of representations actually depends on the convergent information that is acquired by the different sensory modalities.

This idea finds support in work of Susana Millar (1994). She proposes a Convergent Active Processing in Interrelated Networks (CAPIN – see chapter 5) model whereby she argues that spatial coding depends on convergent, overlapping and complementary information from the different and specialized sensory modalities (Millar, 2000). She distinguishes between potential (the biological and genetic structure of an individual) and present competence and notes that the underperformance of the blind and visually impaired in spatial tasks is a function of the lack of redundancy and convergence of information resulting from the context, task requirement and access to visually biased information.

7.2 Research on space, visual impairment and blindness

This section reviews a series of studies that deal specifically with the spatial abilities of the blind and visually impaired. The experiments are divided into three categories depending on the scale of the space where they were conducted. Over twenty years ago, Warren et al. (1984) observed that the performance of blind and visually impaired on spatial tasks varied depending on the scale of the environment where the testing took place. They noted that the adventitiously blind tended to perform better in small-scale environments when compared to the congenitally blind but that these differences tended disappear in larger environments. This has lead some researchers (Rieser et al., 1992; 1980; Hollyfield & Foulke, 1983) to conclude that performance in large-scale environments often relies on information from motor and proprioceptive inputs that compensate for the lack of vision or prior visual experience.

It seems logical to separate research to conform to the characteristics of the space. However, the issue still remains on how exactly to distinguish between large, medium and small-scale spaces? Montello and Golledge (1999) remarked that *scale* is one of the "most fundamental yet confusing concepts underlying research involving geographic information" (p. 3). They propose a taxonomy of cognitive spatial scale classes:

1. Miniscule space: This encompasses all spaces that are too small to be apprehended without technological aid.
2. Figural space: Space that is large enough to be perceived without recourse to technological aid but is still smaller than the body.

3. Vista space: Space that is larger than the body but can be apprehended from a single vantage point.
4. Environmental space: Space that requires locomotion in order to be apprehended.
5. Gigantic space: Space that is too large to be apprehended without recourse to technology.

According to Siegel (1981) the scale of space is defined by the perceptual and motor mechanism by which the space is explored and eventually represented. Large-scale spaces can be regarded as spaces where the subject actually becomes a participant. A space that has multiple vantage points that can be viewed from many perspectives, deduced from a number of observations and that acts as a container of the actual individual. Large-scale spaces generally require movement and the integration of piecemeal mnemonic information over time (Montello, 1992) or as Ittelson (1973) cleverly observed, one does not observe a large-scale environment but explores it. Small-scale spaces on the other hand, are spaces where the individual can be considered as an outside observer, one that stands apart from the entire configuration. In the case of vision (and to some extent touch, as long as the space can be simultaneously explored with the hands), this allows for a quick overview and perception not only of the relationship between the individual and other objects within the space but also of the relationship between the objects themselves. It is also possible for a small-scale space to have multiple vantage points while only a large-scale space can surround the individual (Acredolo, 1981).

Completing a task in small and large-scale space requires different motor abilities. As mentioned earlier, small-scale spaces can be fully captured through fewer, more compact and less cognitive demanding vantage points. The sequential coordination of spatial learning necessary in large-scale spaces requires the coordination and condensation of a variety of vantage points and while motor action may serve to integrate information, it is possible that is also introduces a higher cognitive load.

The classification of space can be especially awkward when dealing with research on spatial representation in the total or partial absence of vision as many experiments are conducted in spaces that are neither large nor small. The need to control for extraneous and confounding variables has led researchers to design experiments inside laboratory settings, or rooms that share many characteristics in common with large-scale spaces but that given their size, layout and complexity can also sometimes be perceived and represented in a simultaneous fashion. Considering the previous discussion, the experiments reported below were classified as follows:

1. Micro-scale experiments: This will include tabletop and experiments conducted in manipulatory space where there is no locomotion involved. These are spaces where the relationship between objects contained within them can be simultaneously understood either through vision or a series of sequential hand movements or manipulations.

2. Meso-scale experiments: These are experiments conducted inside a lab, room gymnasium or any type of confined and/or specifically constructed environment (maze, model city or obstacle course) where the construction of mental representation requires locomotion. In many cases (but not all) the relationship between all objects within the space cannot be directly perceived. For the most part, the construction of mental representations requires the integration of piecemeal perception information collected through one or the various senses.

3. Macro-scale experiments: This is similar to medium-scale space but it deals specifically with experiments conducted at the level of the neighbourhood or city requiring locomotor movement and exploration for the integration of information and formulation of mental representations.

7.2.1 Micro-scale

Considering the two experiments reported in this thesis were conducted in locomotor space, it seems logical to ask whether a review of research in micro-scale space is really necessary. There are two reasons why such studies are relevant. First, many studies conducted in micro-scale space have focused on the heuristics and strategies used when coding space. This is related to the second experiment reported in this thesis that focuses on the relation between wayfinding strategies and the development, content and accuracy of mental representations. Although many of the strategies and heuristics used is small-scale space cannot be directly generalized[42], these studies are evidence that humans use a variety of strategies (proprioceptive, spatial imaging, temporal, linguistic) to account for the absence of vision. In fact, many aspects of the development of spatial knowledge may be similar for manipulatory and locomotor space. This is also true regarding the role of landmarks where researchers (Acredolo, 1981; 1977) have found that the presence of salient landmarks facilitates objective responding and allocentric coding. In addition, it is expected that some of the cognitive processes used when dealing with information will be similar independent of the scale (Thinus-Blanc & Gaunet, 1997). Second, many of the tests that require the externalization of mental representations (model building, sketch

[42] Siegel (1981) warns that one should be careful when generalizing between scales.

mapping, non-verbal distance estimations) are conducted in small-scale tabletop settings. In this manner, it is important to determine the ability of individuals to shift between these two scales.

7.2.1.1 Spatial memory vs. inferential tasks

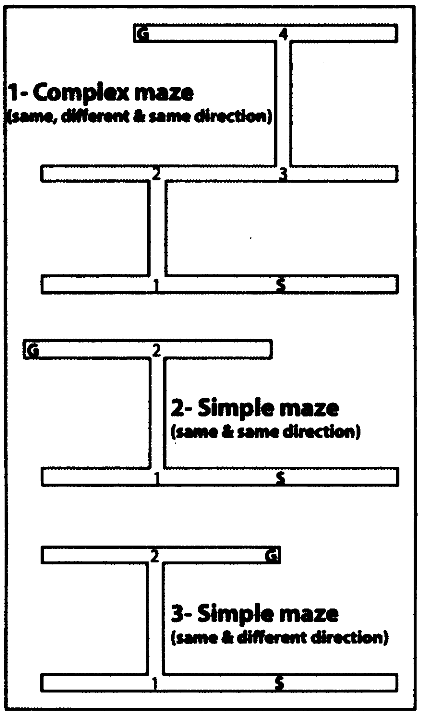
The majority of experiments conducted in manipulatory space suggest that the absence of vision, especially at an early age, can have important implications on the ability to accurately represent space in the sense of developing a Euclidean knowledge regarding the position of the different elements. As we shall see however, this pattern is by no means universal. Many studies have shown not only considerable competence but also an understanding of imagery by congenitally and adventitiously blind subjects. Before we begin to review the literature we must distinguish between two types of spatial processing that can occur when participants are asked to complete spatial tasks in either small, medium or large scale spaces. *Spatial memory* tests are concerned with the subject's knowledge of spatial relationships that are actually experienced. *Inferential tests* on the other hand, deal with the inferential abilities or the computation of spatial relationships that are not known but can be deduced from those previously experienced (Thinus-Blanc & Gaunet, 1997). Inferential tests are usually considered to be more challenging, as they require a higher level of cognitive processing in the reorganization and updating of representations.

Cleaves and Royal (1979) found that CB subjects commit more errors in both memory and imaginal[43] (inferential) tasks when compared to the AB and BS groups. In their experiment, participants had to learn six T-mazes of different difficulties[44] (figure 7.3) and then point from the start of the maze to different locations within it. The CB committed more errors in both the memory and imaginal conditions. The AB were the best performing group in the imaginal condition. This superior performance may be due to a combined experience in both the *sighted* and *blind world.* That is, the AB had the advantage of early visual experience but also a greater familiarity/sensitivity when dealing with haptic and proprioceptive information. For all groups, errors increased as the complexity of the maze increased.

[43] Imaginal: An inferential task that requires the participant to imagine being at a certain position when making the pointing estimates.

[44] The difficulty level is defined by the number of changes in direction from the start point to the goal point.

Figure 7.3 - Mazes used by Cleaves and Royal (1979)

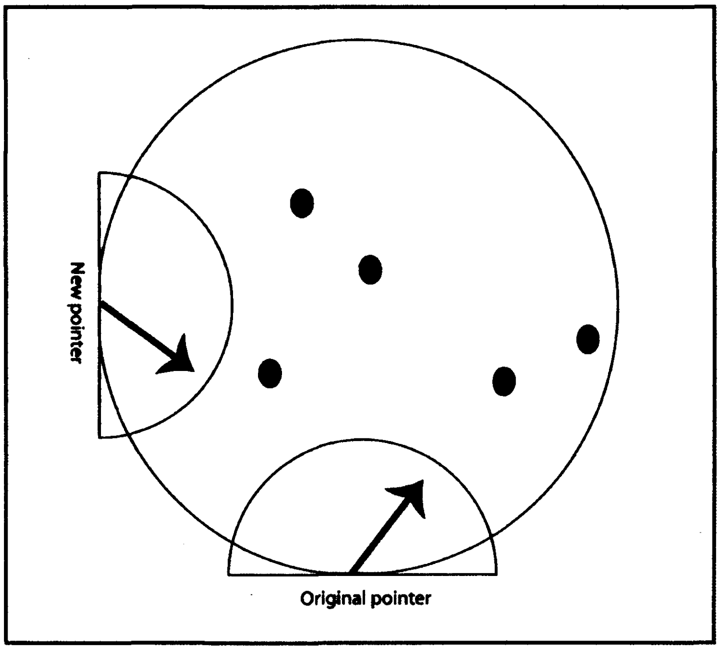


Source: Cleaves and Royal (1979)

Hollins and Kelley (1988) also found that blind subjects had more difficulties with tests that require mental inferences. They tested the spatial memory and updating abilities of five CB[45] and six BS subjects in four tabletop experiments. Subjects were seated behind a circular desk an asked to haptically explore and memorize the location of five separate objects (figure 7.4). They tested for their ability to make pointing judgements from their original sitting place and from a new pointing place located somewhere else on the table. In another task, the objects were removed from the table and subjects were asked to replace them on their original position. Results from the spatial memory tasks revealed that the blind group actually performed better than the sighted but this difference was not significant. The CB however, made significantly more errors in the inferential condition (consistently overestimating to the right). However their performance rose to match that of the sighted in the task that required them to replace the objects on the table. The fact that blind individuals could accurately replace the objects was evidence that contact with the table provided them with reference information necessary to restore the accurate relationship (correct for any distortions) between their bodies and the set of objects.

The idea that inferential tasks are harder to complete in the absence of vision is also evident from a study by Barber and Lederman (1988). In this study, CB, AB and BS subjects were asked to make a series of pointing judgements after exploring a series of locations with their index finger. There were no differences in performance between the three groups for both memory and inferential tasks but all subjects had more difficulties in the inferential condition.

Figure 7.4 - Hollins and Kelley (1988) experiment layout



Source: Hollins and Kelley (1988)

7.2.1.2 Visual imagery

The role of visual imagery in the formation and accuracy of mental representations has also been studied in manipulatory space. In general, it can be said that vision has a facilitating effect but is not necessary for mental imagery. Some researchers have studied the accuracy of mental representation that are constructed by touch using mental matching tasks where individuals are required to synthesize different shapes that are sequentially perceived. In a replication of Worchel (1951), Klatzky et al. (1995) did not find significant differences in the performance of the blind groups (CB & AB) and the BS group although differences were found regarding the time needed to recognize the

[45] Congenitally blind subjects had either prenatal glaucoma or retinopathy of prematurity.

different objects. As expected shapes that were more familiar were identified more quickly.

Spencer et al. (1989) argue that blind children are capable of imagery as they are able to match shapes that were tactually perceived to real world objects. Kerr (1983) showed that the mental images of the congenitally blind were not only "as mnemonically effective" (p.265) as those of the sighted but also preserved metric information about the relationship between different components given that a high degree of correlation was found between real distances and response latencies. The authors note however, that the CB had longer reaction times when compared to the sighted. In addition, both the blind and the sighted were quicker to assess mental representations of items that were more spatially contiguous (relatively closer in space) and larger in size. Similar results were found by Heller and Kennedy (1990) in a version of the Piagetian three-mountain task where participants were required to identify and draw raised-line pictures of objects from various vantage points. These authors found that although the accuracy of the CB was similar to that of the AB and BS, they were slower when making their inferences. It seems that the blind are capable of forming and accurately processing spatial images in a manner that is similar to the sighted, albeit more slowly.

7.2.1.3 Imagery and mental rotation

Researchers have used a variety of mental rotation tasks to show that vision and in particular visual imagery are not necessary for the formation and manipulation of mental representations. In a classic experiment, Marmor and Zabeck (1976) compared the ability of CB, AB and BS subjects to make *same/different* judgements of different pairs of tactile forms. Subjects were presented with sixty sets of two forms. One form was presented in the upright condition and the other rotated (either 0°, 30°, 60°, 120°, 150°). Subjects were asked to indicate whether the forms were identical but rotated or different. Results revealed significant differences in reaction times between groups with the BS group being the fastest. In addition, the CB group made significantly more errors than the two other groups (percentage of errors: CB = 8.7%; AB = 4.3% & BS = 2.9%).

At first these results seem to suggest that the congenitally blind have difficulties in forming and manipulating spatial images. However, if we take a closer look we see that: 1- Although the individuals who were blind did commit more mistakes, the actual percentage of error is actually low; 2-The range of errors (CB = 0% to 28%; AB 0% to 15% & SB 0% to 11.7%) points to the presence of good and bad performers with participants in each group having perfect scores; 3-The reaction times for both blind groups increased linearly as a function of angular discrepancy suggesting that these individuals were mentally manipulating some form of spatial representation (mentally rotating the form until congruent) before responding. Similar results were found by Dodds (1983) and Carpenter and Eisenberg (1978) where both latency and accuracy of response increased with angular deviation from the upright. Finally, in yet another mental rotation task, Klatzky et al. (1995) found that the blind outperformed the sighted group.[46] While these results are not conclusive as to whether blind individuals have an orientation specific type of representation they at least support the notion that they are able to form and use mental representations in order to solve spatial tasks. Finally, imagery does not necessarily have to be visual; it can also be spatial and can be formed either via haptic input or verbal descriptions. In a linguistic selective interference test where subjects listened to route descriptions and were asked to trace those routes on a tactile raised line matrix, Easton and Bentzen (1987) found that both the blind and sighted were capable of transforming verbal descriptions into spatial imagery to guide their actions.

7.2.1.4 Euclidean knowledge and tactile maps

Ungar (1996; 1994a; 1994b) and Ungar and Blades (1997; 1996) have conducted a series of experiments with tactile maps as either a tool for the development of mental representation or an aid to navigation. They have shown that tactile maps have specific benefits for blind children by providing important information about the orientation, spatial relationship (Ungar, 1994) and relative distances (Ungar & Blades, 1997) of different elements in the environment. They also found that children could use this information to orient, indicate and update their position as well as devise anticipatory and global strategies for large-scale spatial coding (Ungar & Blades, 1996). Arditi et al. (1999) found that blind (only light perception) individuals committed significantly fewer errors in a wayfinding task inside the interior of a building when using an interactive tactile map when compared to exploration based on bystander directions.

Landau (1986) took this notion a step further arguing that certain fundamental components of Euclidean knowledge are available to sighted and blind children without any recourse to prior map reading experience. In her study, a congenitally blind child (retinopathy of prematurity) demonstrated the ability to use a symbol map to navigate

[46] These researchers however, are careful to speculate on the basis of these results considering that the overall performance of all groups was considerably lower when compared to past experiments and probably due to a testing artefact as the shapes used were more complex and subjects were put through fewer trials.

inside a room and identify objects around her body as well as to perform mental rotations by aligning the map with the space. Figure 7.5 presents a schematic of the room with the subject "S" and the different objects (X1, X2, X3 & X4). Her results provide evidence in favour of Montello's (1998) continuous framework. Landau (1986) notes however, that although certain elements of map use may be present at birth, the fact the subject's performance increased across trials shows that the accuracy of mental representations is also dependent on experience.

Figure 7.5 - Landau (1986) map of room

		X2		
X1				X3
		S		
		X4		

Adapted from Landau (1986)

Several studies have looked specifically at the ability of blind and visually impaired to estimate distances under various manipulatory conditions. Blanco and Travieso (2003) used a tabletop test of a fictitious island to demonstrate that visual images preserve metric information. Blind, visually impaired and blindfolded sighted subjects were asked to explore a tactile map of an island. Objects in the tactile map were then removed and subjects were asked to replace them and make a series of distance estimations. Results revealed no differences between groups in distance estimation. Moreover, the blind groups were significantly quicker when exploring the island. Similar results were found by Klatzky et al. (1995) who compared the ability of the CB, AB blind and BS subjects to estimate distances (by positioning their hands at an equivalent distance along the table edge) after having their fingers guided along the vertices of four triangles. Although there were no significant differences between groups in terms of absolute error, both groups tended to overestimate short distances and underestimate longer distances. Hermelin and

O'Connor (1975) also found that the blind tend to underestimate longer distances but only in tasks that require the updating of position.

In a task that required subjects to reproduce movements (orientation and distance) by replacing a pair of magnets on their original positions in different triangular configurations, Dodds et al. (1983) found that the CB performed significantly worse than the AB and the BS although all groups were equally accurate when reproducing distances. The authors conclude that vision facilitates hand eye coordination but movement in relation to reference frames can also provide important information for the organization of mental representations. Lederman et al. (1985) however, found that in the absence of vision, CB and BS subjects tended to increasingly overestimate the length of Euclidean distances as the actual length of the explored path increased. The authors argue that the overestimation may be related to a form of parallel distortion from temporal and haptic inputs. In the absence of vision, time (temporal distance) can be an important variable in the estimation but one that can be easily distorted.

Carreiras and Codina (1992) compared the ability of blindfolded sighted and sighted individuals to estimate path (route) and straight line (Euclidean) distances between 12 different locations in a small-scale model that had either a regular grid pattern or an irregular configuration. Results revealed only small differences between groups in either the accuracy or latency of response in the estimation of Euclidean or route distances with the blind committing more errors in Euclidean estimates only for the irregular model. The authors argue that these results are consistent with past studies that suggest that environments that possess a certain degree of regularity (i.e., grid shaped, rectangular) may be more favourable for navigation (Lynch, 1960) and the construction of accurate mental representations in the total or partial absence of sight (Passini et al., 1986; 1985; Strelow, 1985).

7.2.2 Meso-scale space

Researchers have also investigated the spatial memory and inferential abilities of the blind and visually impaired in environments that are large enough for locomotion and proprioceptive coding but that can also be easily controlled.

7.2.2.1 Euclidean and route knowledge: Distance and direction estimates

In an experiment similar to that of Carreiras and Codina (1992) but conducted in locomotor space, Fletcher (1980) compared the development of route and Euclidean representations of blind and blindfolded sighted children. The subjects freely explored a room or a model of the room and were asked a series of questions about the position of the furniture in the room. Questions were considered *route questions* if they were about information acquired while traversing the route or *map questions* if they required the synthesis of information into a global representation. In general, the BS group performed better than the blind group. Blind subjects were more accurate when responding to *route questions* while the BS responded comparably well for both types of questions. Fletcher however, notes that some blind subjects performed as well as the BS in *map questions*.

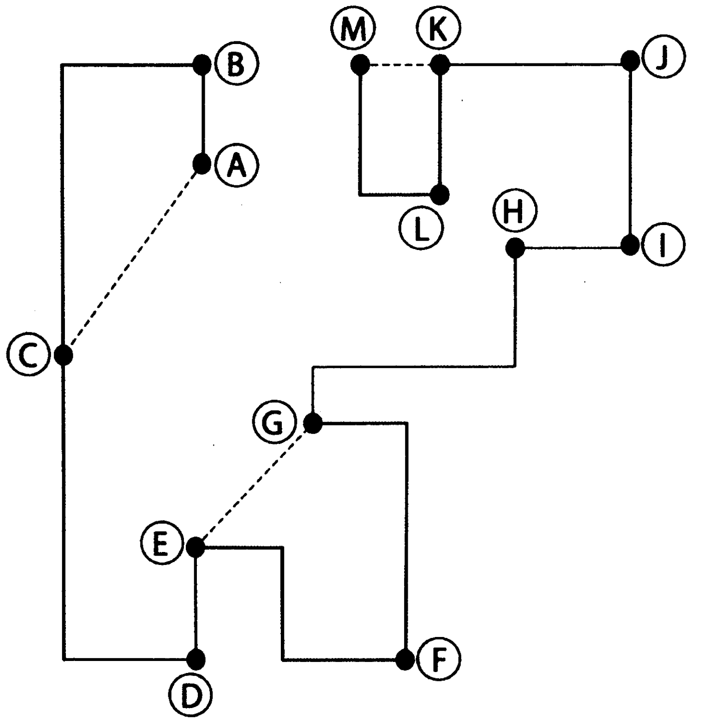
In an effort to account for these differences, Fletcher (1981b) conducted a subsequent study where she tried to relate different individual characteristics to the content and accuracy of mental representations. She found that intellectual ability was strongly related to performance in spatial tasks that required the synthesis of spatial information into a coherent whole (map questions). The age of onset blindness and the type of condition were also related to performance. Children with a visual acuity of better than light perception before the age of three were more accurate; while individuals with retinopathy of prematurity performed more poorly than those diagnosed with other conditions.

Veraart and Wanet-Defalque (1987) devised a clever experiment to test whether blind individuals can understand and manipulate Euclidean concepts. CB, AB and BS subjects were guided along six routes inside a 40-meter room with or without an echolocation prosthesis used to locate objects.[47] They were then asked to estimate the direction and distance between the different objects. There were two types of routes (see figure 7.6): Euclidean routes were those where the starting point was closer to the end point than to the intermediate landmark (ABC, EFG and KLM). Functional routes were those where the (temporal) sequence of the landmarks reflected their spatial remoteness from the starting point (CDE, GHI and IJK). Results revealed that CB made significantly more errors in both distance and direction when compared to the BS. When compared to the AB significant differences were found only for direction estimates. The blind groups performance was equally poor in relation to Euclidean and functional routes. Finally, the performance relative to the Euclidean baseline improved for both blind groups when the space was navigated with the prosthesis but this result was not significant.

[47] Echolocation prosthesis: The prosthesis provided information on the location of objects where distance to obstacles is proportional to pitch and direction coded by binaural intensity balance. All subjects were trained prior to testing.

Dodds et al. (1982) have also investigated the effects of early visual experience by asking CB and AB children to make pointing judgements between different locations and to draw a map of two simple but reversed routes over repeated trials. Figure 7.7 presents the layout of the two routes. Results revealed that the CB were significantly less accurate in estimating directions (Absolute error: CB = 106.05°; AB = 49.06°). Interestingly, the various locations along the routes offered different degrees of difficulty for both groups. Difficulty tended to increase (especially for the CB) as a function of the physical distance from the starting point. In the drawing task, while all the AB subjects were able to show clear changes in direction and the actual connection between the two routes, only one CB child showed some form of understanding of the spatial structure and connection between the routes. Like the previous studies in manipulatory space, the authors conclude that vision can have a facilitating effect for spatial memory and the ability to make inferences regarding the relative positions of objects within it but it is not a necessary precondition as evident from the performance of some of the congenitally blind subjects.

Figure 7.6 - Veraart and Wanet-Defalque (1987) experimental design

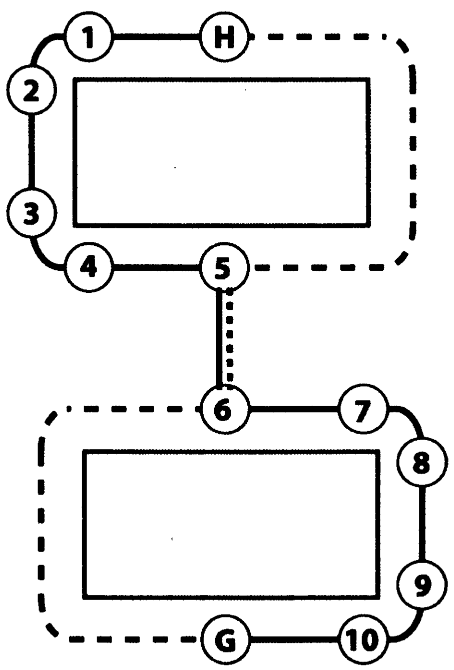


Source: Veraart and Wanet-Defalque (1987)

Herman et al. (1983a) argued that the accuracy in pointing to locations might be related to the complexity (in this case the number of turns or deviations from the starting point) of the space or the route. In their experiment they compared the ability of sighted, BS and CB adults to remember the position of four different objects along an unfamiliar Z-shaped route in a large room (figure 7.8). The route was specifically designed as to prevent sighted subjects from gathering additional cues from the experimental room (walls, ceiling) and from seeing any two objects simultaneously. After walking the route, subjects were taken to each object and asked to aim a pointer at the other objects. Significant differences were found between the blind and both sighted groups (mean error sighted = 35.61°; blindfolded = 38.77°) and the CB (mean error = 56.34°). All subjects were more accurate when pointing to locations that were only separated by a single turn.

The authors conclude that access to visual imagery or previous access to such information was a critical factor for the difference in performances as it allowed the sighted groups to integrate the position of the different objects into an overall configuration. It should be noted however, that the groups also differed in terms of IQ with subjects in the blind group having the lowest mean IQ.

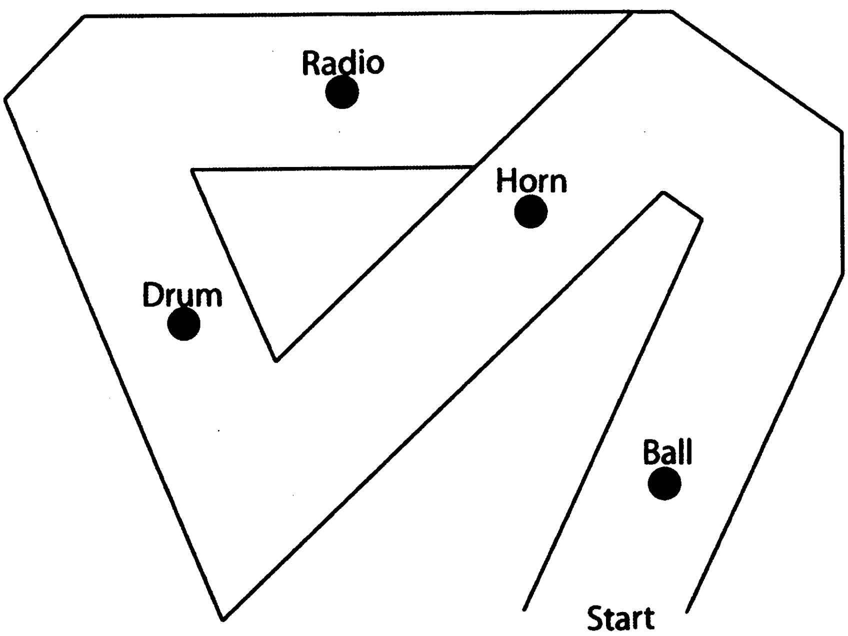
Figure 7.7 - Dodds et al. (1982) experimental layout



Source: Dodds et al. (1982)

Bigelow (1991) conducted a 15-month long study on the spatial knowledge of blind, visually impaired and sighted children by asking them to point to familiar locations around their homes. Children were asked to make pointing judgements to places located on the same floor, on a different floor, in their yard and their neighbourhood (figure 7.9). Children were specifically asked to point to the straight line (Euclidean condition) or the path (route condition) between the objects. All children except those in the blind group were able to make accurate pointing judgements and master all conditions during the 15-month period. The blind children exhibited particular difficulties in the Euclidean condition (the blind usually pointed to the route that they would take to reach an object) while the visually impaired, although able to master this condition, exhibited considerable delays when compared to the sighted group. Pointing to locations situated in a different floor and around the neighbourhood were the hardest to master. She concluded that the total and partial absence of vision interferes with the development of Euclidean knowledge especially when these are at a different plane or at a considerable distance from the individual. However, she is careful to note that while blind individuals may have an inaccurate representation of the straight-line relationship between the different objects it does not necessarily mean that they cannot navigate between locations.

Figure 7.8 - Route used in Herman et al. (1983a)



Source: Herman et al. (1983a)

That Euclidean concepts can also be understood and manipulated in total or partial absence of sight is also evident in an experiment by Rieser et al. (1980) that compared the ability of CB, AB and sighted adults to estimate familiar distances between 15 landmarks inside the Minneapolis Society for the Blind. Subjects estimated distances by triadic comparison (see chapter 8) under three conditions: 1- In the neutral condition, participants were not given any guidelines but simply told to estimate distances in the easiest and most efficient fashion. 2- In the Euclidean condition, subjects were asked to estimate the straight-line distance between locations; 3-In the functional condition, subjects were told to estimate the distance in terms of the route they would take to connect the two locations. Results revealed significant differences between the three groups with the sighted performing best followed by the AB and the CB. All groups performed with the same level of accuracy under the functional condition. Results from the neutral condition revealed that when subjects are not given any details as to the metric of estimation, they tend to respond in terms of functional distances regardless of their visual experience. The sighted and adventitiously blind however, were more flexible when asked to estimate in a specific metric. Haber et al. (1993b) also believe that the blind are capable of making distances estimations that preserve metric properties. In an experiment where seven blind subjects were asked to estimate distances between several objects from a central location in a familiar room or from memory outside the room they found that distance estimates were related to true distances (Jacobson, 1999).

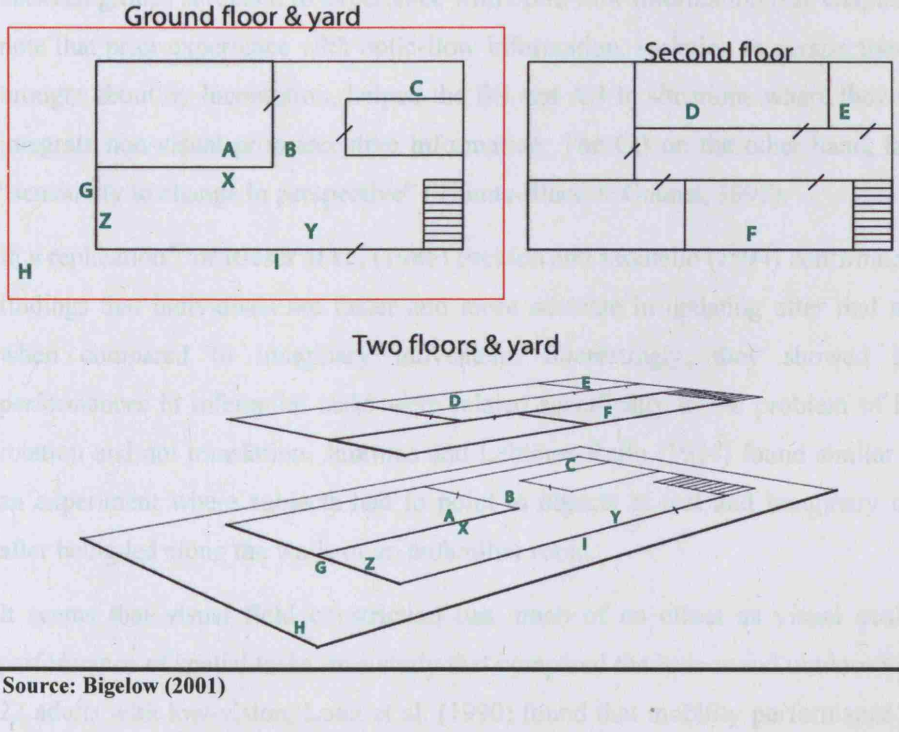
7.2.2.2 Visual imagery: Spatial memory and inferential tasks

Some researchers have argued that Euclidean knowledge can develop irrespective of visual experience and at a very early age. Landau et al. (1984; 1981) tested the ability of one 2-½ year old congenitally blind child (Kelli) and five 3-year old sighted (wearing opaque goggles) to infer the spatial relation of a series of objects in a room (see figure 7.5 above for an approximation of the experimental design – locations are marked with an "x"). The authors found that after being guided by several paths to the different objects in the room, all subjects were able to move between objects through paths that were not previously traversed. They concluded that Kelli had developed a Euclidean type of reasoning that served to organize her actions and generate novel routes between objects.

The fact that Landau et al. (1984; 1981) only used one subject in their experimental design makes these results hard to generalize. Millar (1988) and Liben (1988) have severely criticized this finding. They argue that it is almost impossible to conclude that Kelli had an innate knowledge of Euclidean concepts that she used during navigation.

They argue that the paths Kelli completed when moving from object to object were curved meaning Kelli was constantly updating her position instead of organizing her movement based on a straight-line representation of the objects. Millar (1988) also notes that Kelli was not completely blind but had light perception and that contrast information could have helped her in locating the target objects. Also it may be that Kelli was organizing her actions and guiding her movements on acoustic information such as breathing or other sounds emitted by her mother who happened to be one of the landmarks. In a replication of Landau et al. (1984; 1981) Morrongiello et al. (1995) argue that we should be careful to conclude that Euclidean knowledge is well developed and present in young children as the paths walked by their subjects (the youngest group being two years older than Kelli) showed no evidence of Euclidean knowledge. The majority of children walked circuitous paths when inferring new routes.

Figure 7.9 - Example of experimental layout (Bigelow, 1991)



Source: Bigelow (2001)

In two well-known experiments, Rieser et al. (1991; 1986) tested the spatial memory and inferential abilities of CB, AB and BS. Participants were guided, in an unfamiliar environment, from a start point to six different object locations returning to the start point after each *sortie*. When testing for spatial memory participants were (a) physically moved (locomotor condition) to one of the visited locations and asked to makes a series of pointing judgements towards the places they had previously visited or (b) were asked to make pointing judgements from the start point. In the inferential tasks subjects were asked to imagine as if they were at one of the visited locations and then asked to make the necessary estimations.

They found no differences between groups in pointing accuracy or response latency for memory tasks. In inferential tasks however, all subjects were slower to respond and committed more errors. Significant differences were found between the groups with the CB having particular difficulties with this task. These authors argue that in the memory condition, apart from having direct access to object-to-object relation in memory (Presson & Montello, 1994), participants were more accurate because they were able to integrate proprioceptive information and update their position relative to the different targets. More errors occurred in the *inferential* condition because participants were forced to use a more complex mental computational strategy to make sense of their position before pointing. Taking a Gibsonian approach, the authors concluded that the discrepancy of the results between groups is related to experience with optic-flow information (see chapter 6). They note that prior experience with optic-flow information, variation in perspective structure brought about by locomotion, helped the BS and AB in situations where they needed to integrate non-visual proprioceptive information. The CB on the other hand, lacked this "sensitivity to change in perspective" (Thinus-Blanc & Gaunet, 1997).

In a replication[48] of Rieser at al., (1986) Presson and Montello (1994) confirmed previous findings that individuals are faster and more accurate in updating after real movement when compared to imaginary movement. Interestingly, they showed that poor performances in inferential tasks were related specifically to the problem of imagining rotation and not translation. Juurmaa and Lehtinen-Railo (1994) found similar results in an experiment where subjects had to point to objects in real and imaginary conditions after being led along the walls of an unfamiliar room.

It seems that visual field constriction has much of an effect as visual acuity in the performance of spatial tasks. In a study that compared the indoor and outdoor mobility of 22 adults with low-vision, Long et al. (1990) found that mobility performance (assessed by the number of pauses and collision with objects) was not necessarily related to visual

[48] The study was replicated in somewhat more constrained conditions with only one target. Here we must remind ourselves that the main aim of their experiment was to establish whether imagined translation was the reason for an increase in errors in the imagined condition.

acuity but to differences in visual field and contrast sensitivity.[49] In fact, these authors found that if taken together, visual field and contrast sensitivity accounted for 39% in the variation of mobility performance. A previous study by Marron and Bailey (1982) found similar results. These results although somewhat obvious (you would expect for example that loss to the lower part of the visual field would lead to problems detecting objects on the ground) are not necessarily taken into consideration in the majority of research dealing with spatial cognition and visual impairment. For the most part, researchers continue to use visual acuity as the main criteria for the classification of subjects. Data on visual field and contrast sensitivity, although relatively easy to collect (by both the ophthalmologist and the researcher), is not usually available at the time of testing.[50]. At the same time, in a study that compared the accuracy of distance judgements (analysed via multidimensional scaling) of 23 individuals with visual field loss,[51] Turano and Schuchard (1991) found that poor spatial performance or knowledge is not particularly related to visual field loss as many of the visually impaired individuals performed as well as the sighted control. They conclude that although visual field constriction can have an effect, this effect cannot be easily generalized.

In what is perhaps one the most complete studies to date, Passini et al. (1990) asked CB, AB, visually impaired, sighted and BS subjects to complete eight[52] different wayfinding tasks inside a maze (figure 7.10). Performance was calculated in terms of (1) the subject's ability to complete the task error free, (2) the number of errors committed during each task and (3) the time taken to complete each task. In contrast to most research, results revealed that the CB performed better than the AB and the BS. Their performance however, was still inferior to that of the visually impaired and sighted groups. They also note that the performance of the CB varied according with the task requirement. The CB had the most difficulty with tasks that required rotating, shortcutting, inverting and

[49] Contrast can be defined as the amount of light reflected by the object divided by the amount of light reflected by its surroundings. Measures of contrast sensitivity are said to be more informative about real world conditions as they are descriptive of the ability to detect and discriminate objects in terms of their size (visual acuity) and contrast in relation to the background.

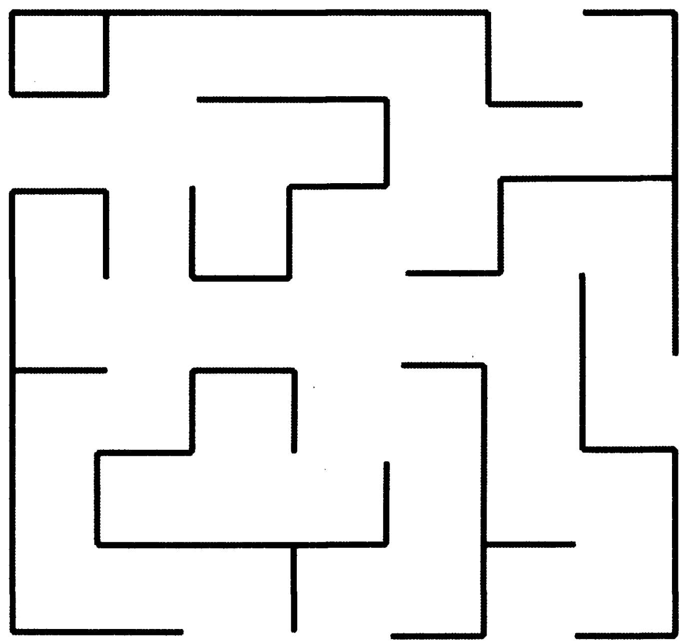
[50] In the author's experience the file of every subject that participated in the research contained information on visual acuity. This was not the case for peripheral vision, near vision and even less so for contrast sensitivity.

[51] Macular and extra-macular peripheral vision loss.

[52] Wayfinding tasks: 1-Learn a new route; 2-Returning from the destination to the point of origin; 3-Combining previously learned routes into new combinations; 4-Learining a route on a small scale model an executing it in a real setting; 5-Pointing to a series of locations visited during a journey; 6-Making shortcuts; 7-Making mental rotations or a route learned form a map; 8-Reproducing the overall layout by constructing a model of the maze.

joining routes. The better performance of the sighted and visually impaired groups also confirms the notion that even in somewhat sterile and highly complex environment such as a maze, vision can have a positive effect on performance.

Figure 7.10 - Layout of maze used in Passini et al., (1990)



Source: Passini et al., 1990

7.2.3 Macro-scale space

The majority of studies in large-scale space follow the same rationale and methodology as those in the meso-scale but differ in the sense that they are conducted at the neighbourhood, city, regional or global scale. Here again, the performance of the blind and visually impaired groups tends to vary depending on the individual and requirement of each spatial task. Byrne and Salter (1983) compared the ability of blind and sighted subjects to estimate the distance and direction between two familiar locations in their neighbourhood. No significant differences were found between groups in the distance estimation task. The sighted however, were significantly better when estimating directions. In a study by Hollyfield and Foulke (1983) sighted, BS, CB and AB[53] were taught how to walk a half-mile long route across a residential neighbourhood and asked to remember the position of different objects along the route. Participants walked the

[53] In this case subjects were classified as congenitally blind if they had less than one year of visual experience and adventitiously blind if they had more than 12 years of visual experience.

route a total of five times but were guided only on the first trial. Figure 7.11 presents the route traversed by the subjects. The stars represent different choice points along the route where subjects were told which way to turn.[54] The development of route knowledge was assessed by (a) asking participants to build a model representing the route and its elements and (b) by comparing their walking time after each trial.

Results indicated a learning effect for the blind groups with subjects traversing the route faster after each trial. In all trials their walking speed was slower than the sighted but faster than the BS. More important, is the fact that no differences were found between groups regarding memory of route structure. Data from the models showed that the blind groups were as accurate as sighted and blindfolded groups regarding the number of intersections on the route but not as accurate regarding the number of curves.[55] These findings suggest that the content of mental representations differs depending on the modality used to collect spatial information. While both the sighted and the blind can accurately collect and present information regarding the structure of an environment vision allows for the detection and inclusion of several other elements and details (i.e., slight curves).

7.2.3.1 Model building

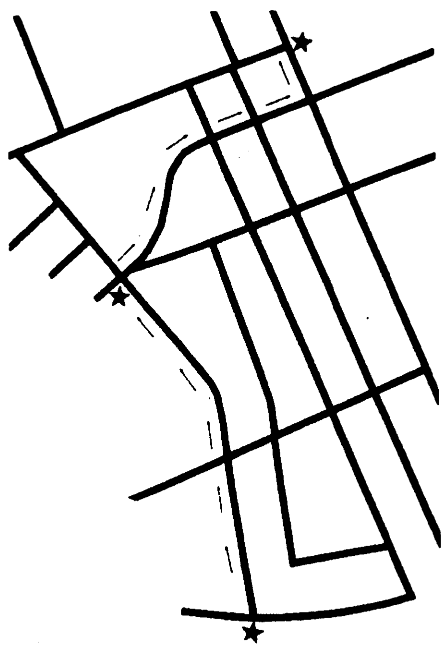
Model construction can be an effective means to study the content and form of mental representations. Casey (1978) compared the ability of CB, visually impaired and BS subjects (17 to 20 years of age) to build a model of their school campus (a well-known environment) using a set of miniature wooden buildings and strips of adhesive-cloth. The relative location of structures and overall organization of the models were assessed by two judges who compared them to an actual map and rated each model without knowledge of the visual condition of the subjects. Results revealed that although some CB subjects were able to construct well organised and accurate models, the majority of models built by this group were disorganized, poorly integrated, lacked curvature and contained significantly fewer elements (figure 7.12). The congenitally blind also tended to organize their buildings in a number of separate, discrete sets of objects – unable to grasp or at least re-represent the campus in a holistic format.

[54] Subjects were only told which direction to turn in the first trial. In the subsequent trials the subjects only received guidance if they deviated from the route.

[55] Although the authors claim that the curvature of all roads was above a threshold of detection, this result is somewhat expected considering the missing part of a curve during navigation did not lead the subject to go off course.

In a more recent experiment that also used model building along with a series of other externalization techniques, Jacobson et al. (2001) showed that individuals who are blind and visually impaired can learn how to navigate large-scale spaces quickly and successfully. Subjects learned a 1.6 km route around a suburban area in Belfast that included 16 choice points. Participants were first guided along the route where the position of salient landmarks was identified. They were then asked to walk the route another three times unaided and asked to make pointing estimates, verbally describe the route, estimate distances and construct a model of the route. Results revealed no differences among groups in terms of pointing accuracy and distance estimation with accuracy usually increasing across trials. These authors used bidimensional regression (see chapter 8) for the analysis of models, and did not find any differences in accuracy (degree of fit) between the different groups. Slight differences were found in the manner individuals from the different groups described the route but all descriptions tended to be accurate and representative. Similar results were found in another study (Jacobson et al., 2001) conducted by the same authors in a suburb of Santa Barbara.

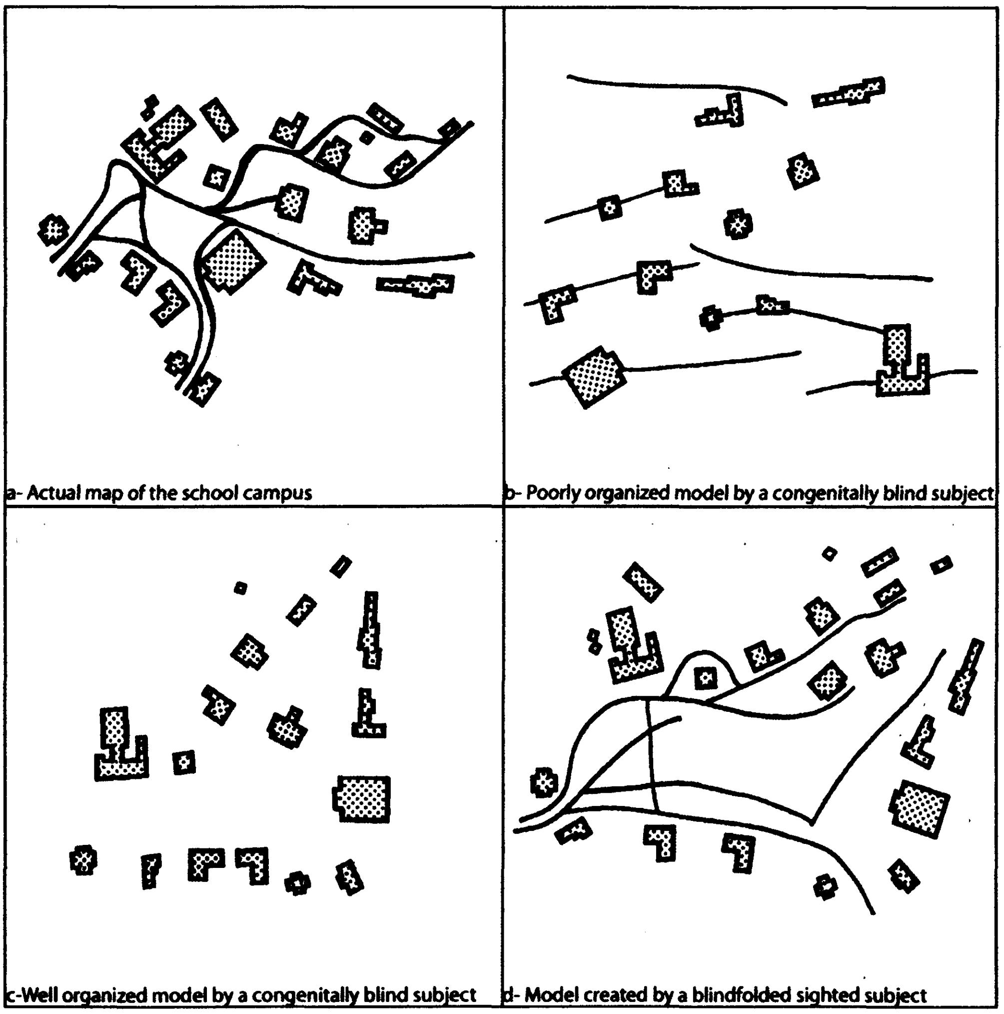
Figure 7.11 - Route traversed by subjects (Hollyfield & Foulke, 1983)



Source: Hollyfield and Foulke (1983)

Wanet-Defalque et al. (2001) compared the ability of congenitally blind, adventitiously blind, visually impaired and sighted individuals to accurately represent the position of objects inside a historic site. After a 90-minute guided tour that included both walking and verbal descriptions of a castle and its surrounding area, subjects were given different sized wooden blocks and asked to create a general map of the site as well as the different rooms inside a castle. All subjects had difficulties with the modelling task but the performance of the sighted tended to be better than the blind and visually impaired groups. The sighted were also more accurate and detailed in their verbal descriptions of the locale.

Figure 7.12 - Example of models (Casey, 1978)



Source: Casey (1978)

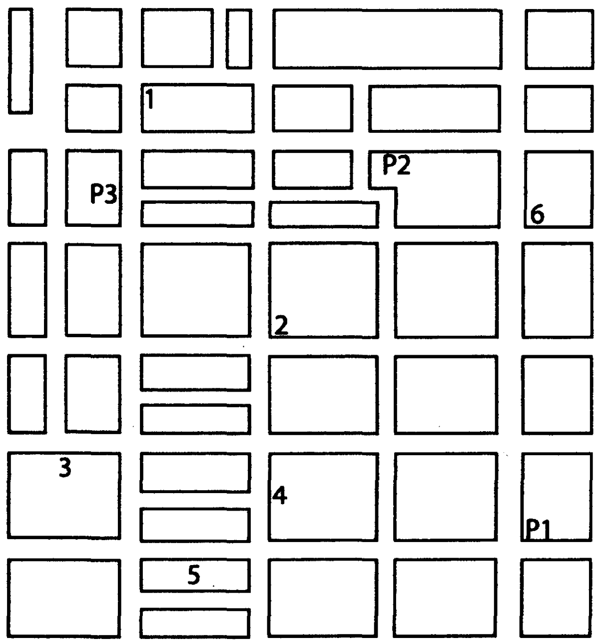
7.2.3.2 Tactile maps, scale transfer and direct experience

Siegel et al. (1979) argued that sighted children are able to translate their knowledge from small to large-scale space. They noted however, that although children possess this ability, the best way for them to learn about the spatial relations between objects is through active experience in the actual environment. Likewise, Hirtle and Hudson (1992) note that learning about space can be related to the instructional method used. Jacobson (1998) found that the sketch maps of a university campus of three congenitally blind subjects significantly improved in detail after experience with a tactile map. Herman et al. (1983b) conducted a simple experiment on the acquisition and scale transfer of spatial knowledge in the total absence of vision. Congenitally blind individuals explored the position and spatial relationship between four objects on a tabletop. They were then taken to a large-scale space where the objects were positioned in the same coordinates. The experimenter randomly guided the subjects to a specific object and asked them to find their way to the other three objects. The vast majority of subjects walked with considerable accuracy between objects regardless of the starting point.

Espinosa et al. (1998) conducted two experiments that compared the effectiveness of direct experience, tactile maps and a combination of direct experience and verbal descriptions of two unknown complex routes in the centre of Madrid (2.05 km) and Sheffield (1.2 km). Participants walked the route either (a) without any assistance, (b) while consulting a tactile map or (c) having previously consulted the tactile map or (d) with verbal descriptions by the researcher. They were assessed on the accuracy of their pointing judgements to different landmarks along the route as well as their ability to shortcut towards different locations. Results revealed that subjects who used the tactile map while learning the route walked fewer meters off the route, made significantly less pointing errors and were able to shortcut more efficiently. In the second experiment participants were asked to learn the route from the tactile map prior to any direct experience with the environment. In this case, performance was not as accurate. These authors attribute the higher accuracy in the first experiment to the fact that subjects were able to relate egocentric information collected to allocentric information provided by the map.

The role of optic-flow information in the sensitivity to change in perspective has also been studied in large-scale spaces. Rieser et al. (1992) showed that visual loss in either the peripheral or central field as well as the age of onset visual impairment can affect the ability to estimate distances (straight-line) and directions of places in a familiar neighbourhood.[56] Seventy-two participants with a variety of visual impairments were tested in their own communities in areas that ranged from 4 X 6 to 6 X 6 city blocks and which included nine "familiar" landmarks. Subjects were asked to "recall the experimental space in mind" and make pointing judgements from three of the landmarks to the other six as well as estimate distances by triadic comparison. Figure 7.12 is an example of a typical test area where the different numbers indicate the "possible" landmark locations and "P's" the locations from where subjects made their estimates. They found that individuals with early onset blindness or broad visual loss performed significantly worse when compared to those with early or late acuity loss and those with late field loss. They concluded that early experience with vision facilitates the development of sensitivity to nonvisual or visually reduced information.

Figure 7.13 - Typical experimental layout used in Rieser et al. (1992)



Source: Rieser et al. (1992)

Finally, Lockman et al. (1981) tested the spatial knowledge of ten adventitiously blind subjects by asking them to make distance judgements by triadic comparison between nine locations in a real city setting. All participants were receiving orientation and mobility courses and all locations were landmarks used by mobility instructors during classes. Sets

[56] The author is aware that this study was conducted in large-scale environment. The experiment is reported in this section as it bears particular relevance to discussion of prior visual experience and spatial updating.

of three locations were named and participants were asked to identify which two locations were the closest together and which two were the furthest apart. Data was analyzed with cluster analysis and multidimensional scaling. It was hypothesized that the maps generated by individuals with a better Euclidean knowledge would resemble more closely the actual city space. Results from cluster and scaling analysis revealed that the mental representation of distances was related to the person's mobility level. The best performer was a subject who had travelled extensively in the area and had previous visual experience of the space.

7.3 Navigation, curiosity and exploration

The study of spontaneous active search and exploratory behaviour can provide important insights regarding the development and integration of spatial knowledge particularly in large-scale environments (Cohen & Cohen, 1985). Wright and Vliestra (1975) distinguish between exploration and search and argue that exploratory behaviour is a "precursor to, and stimulator of, systematic search behaviour" (p.198). They consider exploration a simpler more spontaneous process that develops earlier and is motivated[57] by salient features of stimuli. This type of behaviour predominates in situations and tasks that are novel or less familiar. Search on the other hand, depends on more developed cognitive structures and is a more systematic, active[58] and goal-directed process where attention is focused on the logical features of the task. In other words, while exploration tends to be impulsive and perceptually organized, search is reflective and cognitively organized. Search behaviour is instrumental in the collection of environmental information and the development of mental representations that can be used to guide and direct behaviour. In this manner, the development of mental representations in a novel environment is the result of an increasing capacity and tendency of the individual to organize and systematize exploration into effective, logical and goal specific patterns. As we shall see, this distinction is crucial to the analysis of movement inside a maze where performance in a variety of spatial tasks will depend on the transformation of exploratory behaviour into logical and specific search patterns that will lead to the construction of accurate mental representations.

Caruso (1993) observes that exploration is an important means used by infants to gather information and develop cognitively. Contrary to experiments where subjects are

[57] Motivated: Many times determined by external stimuli.

[58] Many times search behaviour is not directly observed but inferred from patterns in behaviour.

provided with a controlled amount of information, research on spontaneous activity require subjects to collect the features that they consider to be relevant in order to solve a spatial task. Researchers have used reaction to change studies in order to study the exploratory behaviour of animals and humans. In a reaction to change study, subjects are presented with an environment and must process, organize and store the position and distance between the different objects within it. They are then confronted with a new situation where they compare the new arrangement with the stored representation in order to detect the changes that were made. In these studies, performance in spatial tasks is assessed by looking at the movement of individuals within the experimental layout and their identification of the changes made to the initial arrangement. Central to these studies is the notion that novelty can only exist through reference to familiarity and habituation (defined as the decrease or cessation of a response upon repeated presentation of a stimulus), which serve as a reference for detecting changes to previously encountered information (Berlyne, 1966; 1960). Past research with animals has demonstrated that rats react to novelty and that exploratory activity can help in the updating of mental representations of space (Gaulejac & Gallo, 1996; Thinus-Blanc et al., 1987; O'Keefe & Nadel, 1978). More recently, Thinus-Blanc and Gaunet (1999) have shown that rats are able to encode not only the topological but also the geometric properties of an environment.

Learning the layout and the spatial relationships among objects within an environment through active exploration can sometimes result in mental representations that are less precise but more flexible when compared to orientation specific representations that result from learning maps or other figural displays. Several studies have been conducted regarding the manner an environment is learned and the type of representations constructed. In an experiment with blindfolded subjects, Levine et al. (1982) found significant alignment effects when subjects were asked to point to locations along a route after having learned them from a map. Differences disappeared when the route and map were aligned. Thorndyke et al. (1982) however, showed that when subjects directly explored a building their mental representations were not necessarily tied to any specific orientation when compared to subjects that learned the same layout through a map.

Presson and Hazelrigg (1984) distinguish between primary and secondary representations. Primary representations are constructed on the basis of an individual's own experience while immersed within an environment. Secondary representations on the other hand are external, detached, and formed on the basis of symbolic representations.[59] Although secondary representations have the advantage of being very precise allowing the individual to simultaneously grasp the relationship between all objects within a layout, these relationships are picturelike, usually collected from one vantage point and coded according to a specific orientation. Active exploration provides the individual with several vantage points and information from successive encounters in the environment. Primary representations also benefit from convergent inputs provided by proprioceptive information. They provide the individual with direct and accurate information on scale and context not requiring any form of mental operation.

7.3.1 Exploratory strategies: Solving the problem of classification

Spatial knowledge involves learning the self-to-object and object-to-object relationships in the environment. As we shall see however, the literature on exploratory strategies is rather limited. This is partly due to some methodological difficulties associated with the somewhat subjective classification of exploratory strategies. Movement in space must be captured, coded and classified into different strategies and this will almost always bring some form of bias. Research in orientation and mobility has identified a series of exploratory strategies that can be used during navigation to facilitate the development of this knowledge. Gaunet and Thinus-Blanc (1996) define strategies as "functional rules, which are implemented by the subject during the various phases of information processing," (p. 968). There are three primary strategies used to explore space by individuals who are blind or visually impaired (Hill & Ponder, 1976). The first two of these strategies are egocentric, or used to learn the self-to-objects relationships in the environment. The third strategy is allocentric as it facilitates the knowledge of object-to-object relationships. Many orientation and mobility manuals however, tend limit their discussion to egocentric type of exploratory strategies (Blasch et al., 1997).

1. Perimeter: The individual walks the outside border of a space and is able to learn about the size, shape as well as the objects around the edge of the area.
2. Gridline: The individual investigates the internal features of an area by systematically walking straight-line paths from one side to the other.
3. Reference point: This strategy involves walking from a known location to a target object and returning to the object before walking to another target object. It should be noted that although considered allocentric the reference point strategy is only able to provide the individual with knowledge of the specific relationship between reference

[59] Secondary representations are said to adhere to two concepts: 1-The equiavailability principle or the notion that all information in a mental representation is equally available. 2-Specific orientation hypothesis or the notion that mental representations have a specific orientation.

point and a specific target object. Knowledge regarding the relationship between the other different objects in the environment must be mentally inferred by the individual. This becomes possible when all the reference and target object relationships are assembled.

Tellevik (1992) suggested that the manner in which individuals structure their navigation, (approach a wayfinding task) can influence what they learn and remember about the space. He argued (a) that different experiences may lead to different types of knowledge and (b) that systematic exploratory patterns may be more helpful in remembering spatial relations when compared to random movement. In his experiment, ten blindfolded adults[60] were asked to explore and locate four objects inside a room (6.5 X 5.2 meters). The room was an open space with only a few objects located along the wall. Subjects explored the space in two trials (the furniture along the wall was moved between trials) and their search pattern was videotaped. Subjects were then asked to make triadic comparisons of straight-line distances between the different objects. They were also asked to place the starting point and all target objects on a small-scale raised lined plastic paper. Results revealed that subjects usually began (1st trial) by adopting a perimeter or gridline strategy but as they became familiar with the spatial layout (2nd trial) switched to a reference point strategy that also allowed them to make more contacts with the target objects. Results from the raised line paper task revealed that the mean number of objects correctly relocated was greater in the second trial when subjects tended to use a reference point strategy. The authors conclude that different search patterns seem to influence the availability and processing of different kinds of spatial knowledge.

In line with the idea that subjects construct their own representations through active navigation and that experience is better understood in its natural environment, Hill et al. (1993) put forward a simple method for studying mental representations of space and at the same time doing away with some of the problems inherent in the strict classifications of blind and visually impaired subjects based on their visual acuity. Hill was a professor of special education, deeply interested in orientation and mobility and intrigued by the large variation in performance between individuals in spatial tasks. In their study, sixty-five individuals (congenital = 40; adventitious = 25)[61] were given seven minutes to freely explore an open bounded space (4.6 X 4.6 meter gym) with the goal of locating four

[60] Here it is important to note that all of Tellevik's subjects were mobility instructors who can not only be considered as good navigators but were also probably familiar with the different exploratory strategies.

[61] All subjects were blind or had light perception. Congenitally blind subjects lost their vision at birth or before the two years. Adventitiously blind all lost their sight after eight years.

objects and remembering their position. The exploratory behaviour of each subject was videotaped and these were coded into different search patterns or *strategies*. Subjects were also interviewed regarding the strategies they thought they had used when exploring the space. Hill et al. (1993) argued that there are four strategies that can be implemented in order to locate and develop a good knowledge of the absolute and relative position of different objects. Note that these four strategies are allocentric where spatial coding is not related to the subject's body.

1. Home-base to object: This strategy is similar to the *reference point* strategy identified by Hill and Ponder (1976) where the subject uses an object (or location) as an anchor or home base from where straight line movements or direct routes can be made to several other objects.
2. Object to object: Walking back-and-forth in a straight line or over a direct route between two objects.
3. Perimeter to object: Walking back-and-forth between the perimeter of the area and the object.
4. Imaginary: Imagining a geometrical form, pattern or object (triangle, rectangle, Braille cell) that approximates the spatial arrangement of the target objects.

In the experiment, participants were asked to make a series of heading judgements between the different locations and the accuracy and latency of their response was recorded. Hill et al. (1993) argued that there is much to learn by investigating the accuracy of heading judgements in relation to the frequency and type of exploratory strategies used during exploration. In order to investigate this relationship, the authors classified the participants in terms of their performance in the heading task, irrespective of their visual condition (congenital or adventitious) by separating the best 15 and worst fifteen performers (top & bottom 25%) and contrasting the strategies used by the individuals in these two groups. Results revealed that the best performers significantly used and verbalized a wider variety of strategies and that the majority of these strategies tended to be object related or allocentric. After locating all the objects "the participants walked back-and-forth in a straight line among objects, the perimeter and target objects, and/or the home base and the target objects" (Hill et al., 1993, p. 299). The worst performers did not vary much in the type of strategies used, most of them using only egocentric strategies such as the perimeter and gridline. Many of which tended to randomly wander around the area with no apparent strategy.

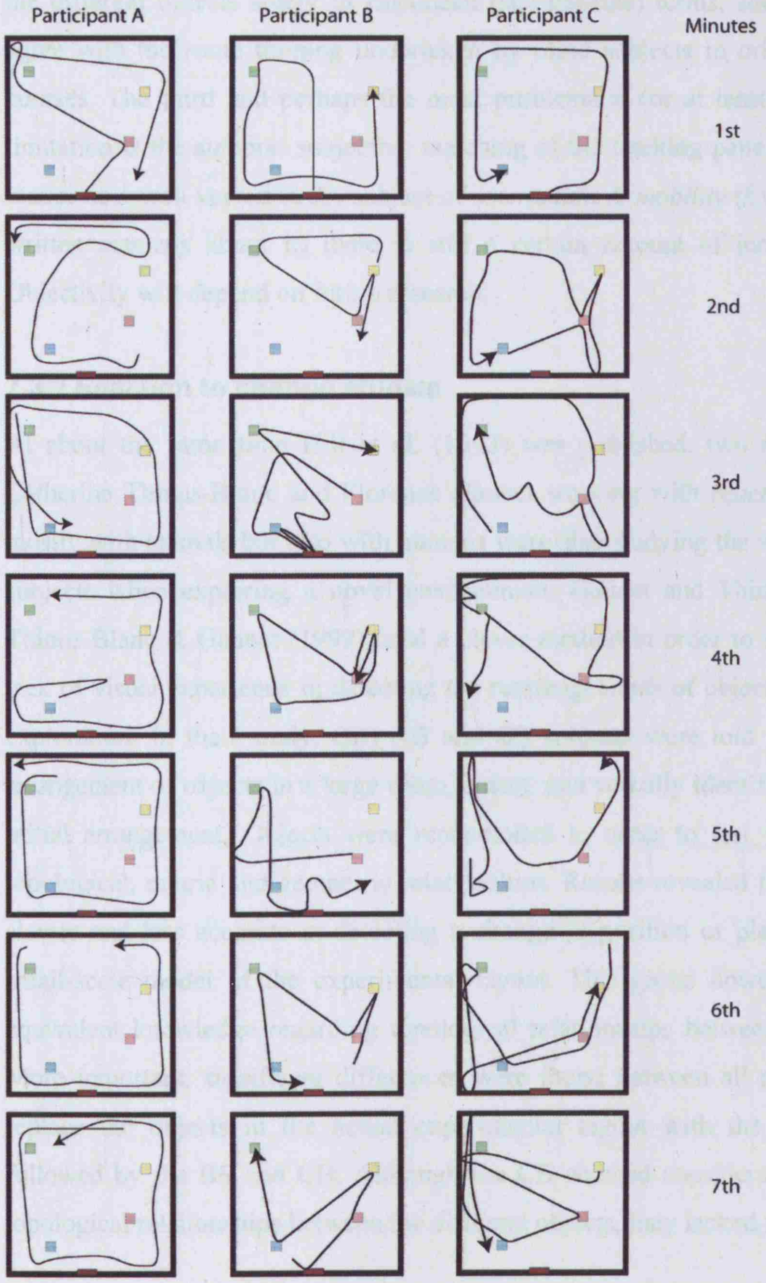
7.3.1.1 Subject tracking

Past research has shown that individuals who are congenitally blind tend to perform at a lower level when compared to the adventitiously blind in tasks that require knowledge of the absolute and relative position of objects (Rieser, et al., 1992; Rieser et al., 1986). Although the vast majority of worst performers (14/15) in Hill et al. (1993) experiment were indeed congenitally blind, a considerable number of best performers (6/15) had also lost their sight at an early age. By classifying the subjects in terms of their performance and relating the performance to the strategies adopted during exploration, these authors not only shifted the focus from the actual visual condition but also made way for an analysis of mobility factors that can contribute in the development of accurate mental representations of space. Hill et al. (1993) study was of particular importance and a major influence in the development of the second experiment presented in this thesis. For this reason, it is critical that we take a deeper look at the methods used in the *tracking* analysis of exploratory strategies.

Like Tellevik (1992), a series of rules were created in order to isolate and identify the different exploratory strategies. The videos of each individual track were watched and a match was made between the established rules and the recorded patterns. Figure 7.14 below is a minute-by-minute example of the exploratory patterns of three participants and can be used to demonstrate how the researchers classified the different sequence of movements and the type of contact with the objects. Throughout the seven-minute period, participant "A" moved in a counter-clockwise direction exploring the perimeter of the room. There were no attempts to make any object-to-object connections and only 12 object contacts were made. This subject belonged to the worst performing group having an average 118° pointing error. The authors classified the subject as egocentric having employed only the perimeter strategy. Participant "B" ranked among the good performers (avg. pointing error = 15°) and within the first minute located three of the objects by employing a gridline strategy. During the 2^{nd} minute the subject used a home-base strategy and in the 4^{th} minute began a series of object-to-object movements. In total this participant made 36 object contacts and used 6 object based allocentric strategies. Participant "C" another top performer (avg. pointing error = 9°) was able to locate all objects within the first minute by implementing a perimeter type strategy. In the 2^{nd} minute the subject engaged in a series of object-to-object strategies. Around the fifth minute the subject also implemented several perimeter to object strategies. The participant made 35 object contacts and used a total 6 object based allocentric strategies.

There are at least three limitations in this study. The first limitation is related to the scale or the size of the experimental layout. Although the subjects only had a limited time to locate and remember the position of the four objects, it seems hard to believe that even if the subjects wandered randomly about the space they would not come into contact with the different objects.

Figure 7.14 - Exploratory strategies: Good and bad performers



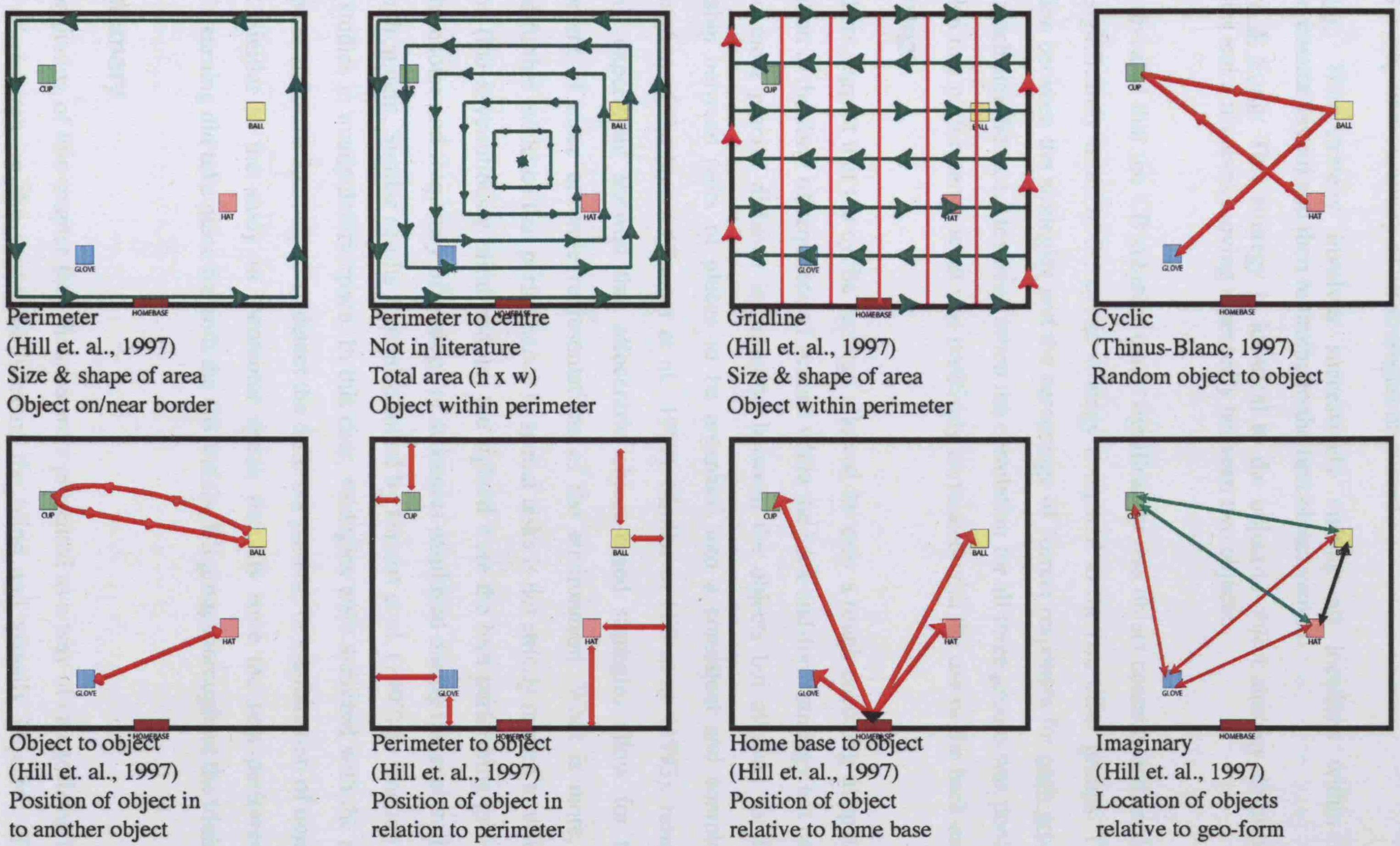
Source: Hill et al. (1993)

The second limitation is the actual complexity of the space. Hill's experimental layout is completely open, a situation that is highly unrealistic and difficult to generalise. In addition, it is possible that the openness of the space had an influence on the type of strategy adopted. The gridline strategy that requires the individual to make "U" shaped back-and-forth strides from one side to the other of the space is easier to engage in an open space when all straight-line patterns are available. More important is the idea that the open character of the space forces the individual to think of the relationship between the different objects solely in Euclidean (straight-line) terms, something that does not agree with the route training undertaken by blind subjects in orientation and mobility courses. The third and perhaps the most problematic (or at least the hardest to solve) limitation is the authors' subjective matching of the tracking patterns into strategies. No matter how well versed in the subject of *orientation & mobility* (Everett Hill has actually written manuals about it) there is still a certain amount of incorrigible subjectivity. Objectivity will depend on future research.

7.3.2 Reaction to change studies

At about the same time Hill et al. (1993) was published, two researchers in France, Catherine Thinus-Blanc and Florence Gaunet working with *reaction to change studies* mostly with animals but also with humans were also studying the strategies used by their subjects when exploring a novel environment. Gaunet and Thinus-Blanc (1996), and Thinus-Blanc & Gaunet (1999) used a clever method in order to study the effect of the lack of visual experience in detecting the rearrangements of objects in a room after free exploration. In their study, CB, AB and BS subjects were told to explore the spatial arrangement of objects in a large room, detect, and verbally identify changes made to the initial arrangement. Objects were repositioned in order to test for the knowledge of topological, metric and geometric relationships. Results revealed that the CB group was slower and less accurate at detecting a change in position or placing the objects on a small-scale model of the experimental layout. This group however, demonstrated an equivalent knowledge regarding topological relationships between the various objects. More important, significant differences were found between all groups when asked to replace the objects in the actual experimental layout with the AB performing best followed by the BS and CB. Although the CB showed considerable knowledge of the topological relationships between the different objects, they lacked metric knowledge.

Figure 7.15 - Strategies for exploration



Gaunet and Thinus-Blanc (1996) discuss two additional strategies in their analysis of the search patterns used by the subjects in their exploration of the initial layout. Figure 7.15 above is a graphical summary of all strategies discussed.

1. Cyclic: This strategy involves successively visiting all locations within an experimental layout and then returning to the first object visited.
2. Back & Forth: This strategy is identical to the object-to-object strategy described earlier and it involves moving repeatedly between two objects.

Results revealed that the CB subjects made significantly less object contacts and tended to rely significantly more in the cyclic strategy compared to the two other groups. The correlation between the strategies and the percentage of correct responses for each group did not reach significance. However, when the correlation for all three groups was pooled it revealed that performance level was positively correlated with the use of the back-and-forth strategy.

The authors suggest that the cyclic strategy allowed for only a rough encoding of spatial information in the form of sequence of actions while the back-and-forth strategy not only provided more precise distance information between the objects but allowed for the relationship between pairs of places to be organised into a consistent and complete representation of the layout (Gaunet et al., 1997). Similar to Hill et al. (1993), results from this experiment showed that allocentric object based strategies allow for the development of more accurate representations of the environment. What is more, it provided further evidence that performance in spatial tasks is not strictly related to visual condition (the adventitiously blind and not the sighted were the best performing group) but to the choice and frequency of strategy or strategies employed during the exploration of an environment. Similar results were also found by Gaunet et al. (1997) in reaction to change studies in manipulatory space. In this case, strategies were analyzed with the aid of computer software that helped to detect the different patterns or combination of object contact. Similar to the study in locomotor space, the AB were the best performers although learning did take place for both the CB and the BS groups throughout the trials.

7.4 Summary

In the beginning of this chapter four theories were presented as a way of categorizing the history of research on the spatial abilities of the blind and visually impaired. The deficiency theory holds that vision was essential to the formation of mental representations. The inefficiency theory argues that the other senses are inferior to vision and that although the blind and visually impaired are able to understand and manipulate spatial representations these are less effective. The difference theory believes that the spatial abilities of the blind and visually impaired are functionally equivalent to that of the sighted. Yet, despite a large amount of research, results still remain somewhat inconclusive. There are however, certain patterns and these should not be ignored and are reviewed below.

We should start by saying that the deficiency theory is incorrect. This is a simple matter and backed by a considerable amount of evidence reviewed above on the ability of the congenitally and adventitiously blind to form and manipulate mental representations of space. Even if these representations are not as accurate and complete, the ability of blind individuals to complete tasks that require the estimation of distances, directions or the construction of models is enough to show that they working or at least refereeing back to a mental construct of reality. The problem arises when discussing the inefficiency, difference theories, as results are highly variable and a tremendous amount of difference exists not only between groups but also within subjects of the same group. It is not uncommon to find congenitally or adventitiously blind individuals performing at the same level (sometimes better) than their sighted counterparts. In most cases however, the performance of the adventitiously blind is superior to that of the congenitally blind and this is often attributed to previous familiarity with visual imagery.

Results from mental matching or triangle completion experiments have shown that for the most part, the performance of the congenitally and adventurously blind is inferior to the sighted. These differences however tend to disappear as the shape of objects get more complex or the routes travelled become irregular and not optically familiar. The results of Klatzky et al. (1999; 1997) and Loomis et al. (1993) regarding the ability of the blind to calculate accurate homing vectors are particularly relevant as they provide convincing evidence on the navigation (or haptic) abilities of this population by means of proprioceptive information without recourse to visual stimuli.

Proprioceptive information can act as an important aid in the formation of representations. The congenitally blind however tend to underperform in tasks that require the estimation of distances and directions in medium or large-scale spaces. This is often attributed to the fact that the formation of mental representations in larger spaces requires movement and the quick integration of a large amount of piecemeal information. In these experiments it is often assumed that the absence of sight, especially at an early age, has particular consequences for the development of Euclidean knowledge. This is usually demonstrated when blind and visually impaired individuals make large direction errors in pointing tasks or overestimate straight-line distances.

The notion that the blind (particularly the congenitally blind) are only able to develop route knowledge is false. What is true is that given the lack of appropriate and convergent information these individuals may have a greater propensity to develop this type of knowledge. This was well demonstrated by Rieser et al. (1980) who showed that when subjects are not given any details as to the metric of estimation, most subjects responded in terms of functional distances regardless of their visual experience but that the sighted and adventitiously blind were more flexible when asked to estimate in a specific metric. Others have argued that that the total and partial absence of vision does not prevent but hinders the development of Euclidean knowledge especially when objects are located on a different plane or at a considerable distance from the individual.

Imagery and the manipulation of spatial images has also been a topic of interest but of considerable debate. In general it is believed that vision is not necessary for the creation and manipulation of "images" but that sight has a facilitating effect when these are used to solve spatial tasks. This is evident from the difference in accuracy but more important by the faster reaction times recoded by the sighted. The blind and particularly the congenitally blind have also shown considerable difficulties in inferential tasks. These differences are often attributed to the higher level of cognitive processing that is necessary for the organization and updating of the representation. Taking a Gibsonian approach, Rieser et al. (1986) have also suggested that this difference in performance is also related to the experience the blindfolded sighted and adventitiously blind have with optic flow information. Differences however may be also related to the individual's level of independent mobility and/or field of vision.

The last section of the chapter discussed several studies on exploratory behaviour and search patterns that can be used to locate and remember the position of different objects as well as the different characteristics (size, shape) of the environment. These were presented in relation to movement capturing techniques and reaction to change studies. The different exploratory strategies were then isolated, explained and considered in terms of their efficiency and type of information they are able to provide. This involved a differentiation between egocentric and allocentric strategies. Allocentric strategies, particularly object-to-object and cyclic strategies were considered superior given their ability to provide information on the relative position of objects. However, these are not exclusive and their functionality will depend on the actual task. It is the combination of different strategies that can lead to the accurate construction of mental representation and eventually a better performance. Perimeter and gridline strategies for example, are essential if the task involves acquiring knowledge of the shape and size of the space. These strategies although egocentric, are often employed at the beginning of the search and can provide a significant reference frame for other allocentric type (perimeter to centre, perimeter to object) of strategies.

Chapter 8
Methods and issues of validity

"Good research is difficult to do, but bad research is not worth doing at all" – David Warren (1984, p. 301)

8.1 Introduction

Researchers in the field of psychology, geography and planning (Golledge, 1999; Golledge et al., 1996; Passini 1985; Rieser, et al., 1980; Golledge et al., 1976) have employed a wide variety of methods to assess the extent of the cognitive map knowledge of sighted individuals. Many of these techniques have been adapted for the collection and analysis of data on the content and accuracy of mental representations of space by individuals who are blind and visually impaired. Siegel and Cousins (1985) observe that one should be cautious when interpreting results from tests that involve the externalization of mental representations. They argue that similar tests can generate different results given that the subject's responses are essentially re-representations of the environment. Errors occur because these re-representations are two levels removed from the actual environment and require two different types of mental operations (Huertas & Ochaíta, 1992). Performance not only depends on the collected environmental knowledge but also on the understanding and application of the procedures that are necessary to elicit this knowledge.

Liben (1981) distinguishes between three levels of spatial representation. *Spatial storage* refers to information about space that is contained in the head. This is a tacit neurophysiological structure that can be converted at anytime into explicit *spatial thought* defined as "thinking that is concerned or makes use of space" (Liben, 1981, p. 13). *Spatial products* are the external products that can be used to represent space. That is, exteriorized mental representations that can be expressed in a variety of formats (sketch map, model, verbal description, heading judgements, path completion) depending on the situation or task (Lloyd, 1989). Given a spatial task, both spatial thought and storage have to be converted into spatial products. Methods should try to minimize the disparity between the stored information and the externalized product.

The literature on spatial cognition by the blind and visually impaired is filled with contradictions and interpretations (Thinus-Blanc & Gaunet, 1997; Warren, 1994: 1984). While efforts have been made (Blades et al., 2002; Ungar, 2000; Passini, 1990; Kitchin et al., 1997; Kitchin & Jacobson, 1997; Ungar et al., 1997; Jacobson et al., 1995; Golledge et al., 1988), there is still a considerable amount of research conducted with small sample sizes and confined to laboratory type settings (Bigelow, 1991; Rieser, 1986; Landau, 1984; Fletcher, 1980). Mutually supportive techniques are necessary to account for the heterogeneity of skills between participants. Kitchin & Jacobson (1997) examined the validity of drawing conclusions from these tests. They argued that multiple mutually supportive tests are necessary for the interpretation, application and generalization of results. One-dimensional testing can lead to incorrect conclusions given that performance may be a consequence of a testing artefact (a person lacking the skills to build an accurate model) rather than ability (Millar, 1994; Kirasic et al., 1984). In addition, Zacharias (2000) notes that methods that rely solely on the power of recall of respondents have been shown to be partial, spatially distorted and temporally imprecise. This has lead several authors (Gaunet et al., 1996; Hill et al., 1993; Tellevik, 1992) to pay closer attention to the real-time actions and behaviour as this often conflicts with the response from cued externalizations.

The previous chapter reviewed several studies on the ability to understand, represent and navigate space by the blind and visually impaired. This chapter takes a comprehensive look at some of the techniques that have been used for the collection and particularly the analysis of cognitive data and works as an introduction to the methods used in the two experiments conducted for this thesis. Three categories of spatial tasks (heading estimation, distance estimation and graphical reproduction) are considered. The concept of individual differences is revisited this time with the focus on the inadequacy and misinterpretation of some commonly used statistical techniques. The chapter concludes by considering the importance of participant description and the usefulness of ethnographic and qualitative data as a complement to the interpretation of results.

8.2 Data collection and analysis

Many of the methods described in this section are presented in detail in the book by Kitchin and Blades (2002): The Cognition of Geographic Space. This review however, is seen as indispensable for understanding the procedures themselves as well as the reason for their selection in the two experiments discussed in the following chapters. Methods can be divided into tests that measure aspects of the subject's knowledge regarding the relationship between two locations (also known as route-based techniques) and those that measure configurational knowledge (Kitchin & Jacobson, 1997). Route-based techniques include both direction and distance estimation. Tests that measure configurational knowledge are primarily graphic or involve some type of reconstruction or modelling of the experienced environment.[62]

8.2.1 Heading tasks

A common method used for eliciting information on the position of environmental features is the estimation of directions gathered though pointing judgements. Pointing within or outside the immediate field of vision "involves an active interplay between both immediate perception and a large-scale spatial image or representation" (Hardwick et al., 1976, p. 1). This type of testing is relatively easy to administer and has been used with varying degrees of success with both sighted, visually impaired and blind individuals (Ungar et al., 1996; Bigelow, 1991; Dodds et al., 1983) of different ages and cultural background (Ochaíta & Huertas, 1993). Subjects usually walk a route, explore a room or table top design and are asked to make a series of pointing estimations to different locations using a compass, dial/pointer (Hollins & Kelly, 1988) or their body. Montello et al. (1999) found that performance in pointing tasks differed when individuals were asked to make pointing judgements by actually turning their body instead of pointing with a dial. For this reason, it is important to allow participants time to familiarize themselves with the apparatus prior to the testing phase. Researchers should also check for consistency in pointing judgements by asking the same individual to repeatedly point to the same target location(s) from different origin points.

Performance in heading tasks is evaluated by comparing the estimated angle (pointed angle) to the real angle. There are three different types of errors that can be calculated. Absolute error, also known as mean unsigned error, is the unsigned difference between the estimated and real value and provides a general indication of pointing accuracy. This result however, should be interpreted with care given that the unsigned value cannot

[62] In some cases, data collected through route-based techniques can be used to measure an individual's configurational knowledge of the space and vice-versa.

account for any directional bias. Constant error is the signed difference between the estimated and the real angle and provides information on directional biases and distortions in the representations. Variable error is a measure of the spread or variability between estimations. Like standard the deviation, variable error can act as an indicator of variability between subjects.

There has been some discussion as to which error score should be used in this type of testing. Absolute errors are probably the best measure of performance, as it requires a low constant and variable error. As argued by Hegarty et al. (2002) one would not consider an individual to have high spatial ability if the individual had a large bias large (constant error) in pointing to targets but varied very little around this biased pointing direction. "Nor would [an individual] be considered to have high ability if [the] estimates [were] always centred on the correct direction but were highly variable" (Hegarty et al., p. 432).

The first step in the analysis of pointing judgements is the conversion of the estimated angles to conform to a circular logic. Angle estimates are constrained to a 360° range and cannot deviate by more than 180 degrees from the real values (Kitchin & Blades, 2002). When the difference between estimated and real angle is higher than |180| and the value of the real angle is lower than the estimated, the conversion consists of subtracting 360 from the estimated value and shifting the operator. When the difference between estimated angle and the real is higher than |180| and the real angle is higher than the estimated the conversion consists of adding 360 to the estimated value. Table 8.1 is an example for two situations when the difference between real and estimated angles exceeds 180.

Table 8.1 - Real and estimated angle conversion

Real value	Estimated value	Converted value
69	285	360 – 285 = (-) 75
285	69	360 + 69 = 429

Linear or non-linear regression techniques can be used to assess the level of variance (or degree of fit), expressed through the r^2 value between the real and estimated angle values. If research is concerned with assessing the performance of different groups, a series of inferential statistical tests (t-test, ANOVA, general linear models) can be conducted with the raw angle estimates or the r^2 values for each participant obtained through the regression.

8.2.2 Distance tasks

Montello (1991) differentiates between cognitive and perceptual distance. Perceptual distance refers to an individual's knowledge of the distance between places that can be directly perceived (visible from each other) during the estimation task. Cognitive distance are the mental representations of environmental distances that are too far apart to be perceived from a single vantage point and require both movement and sequential integration. The accuracy of distance estimations can vary depending on the actual method used to obtain the estimate. Montello (1991) has identified four main categories of tests used to measure cognitive distances: ratio scaling, interval and ordinal scaling, mapping and reproduction.

1. Ratio scaling: Can be used for the estimation of distances in small and large-scale spaces. Distances are usually estimated through *magnitude production, magnitude estimation, ratio production* and *ratio estimation.* The first two consist of assigning a number or adjusting a test distance so its length or number matches a standard provided by the experimenter. In ratio production or estimation the subject adjusts the length of a test distance or directly estimates the ratio of lengths of two distances (or one of the lines) in relation to a standard. Perhaps the biggest problem associated with these methods is their sensitivity to context effects produced by the stimulus, especially if subject has several standards on which to base their response. The method has also been criticized for the ratio calculations and scale translations subjects must conduct before responding.

2. Interval & ordinal scaling: Ordinal measurements provide information about the rank order of distances without information on metric values. Interval measurements are based on the exact metric. In a *paired comparison*, different sets of possible pairs are presented and the subject is asked to determine which member of the pair is longer or shorter. The *triad technique* has been extensively used both in psychology and geography with both sighted and visually impaired subjects (Ungar et al., 1996; Rieser, 1986, 1980). Here subjects are presented with sets of three locations and asked to judge which two locations are closest together and which two locations are furthest apart. The *ranking technique* consists of asking the subject to arrange a series of distances in increasing or decreasing order. Finally, in the *rating scale technique*, subjects are asked to assign the estimated distances to a set of predetermined classes. Ordinal data can be analysed with non-metric multidimensional scaling (MDS). MDS takes a matrix of proximity data (dissimilarities) and collapses it in a space of one or

more dimensions. The MDS algorithm looks for the spatial configuration that will best reproduce the relationship between all the items with the least amount of stress. Triadic comparison and MDS will be discussed in more detail in the next section, as this was the chosen mode for the collection of distance information.

3. Mapping: Estimating distances through mapping involves the drawing of maps, the construction of scaled models or the positioning of locations on a grid or a matrix. The researcher usually provides a distance standard or a cue (a building in its exact position) as a scale. This type of distance estimation is somewhat different from the preceding methods given that mapping forces the individual to simultaneously represent the entire spatial arrangement. An advantage of mapping is that it elicits both distance and direction information.

4. Reproduction: Reproduction is defined as a non-symbolic estimation of distances made at the same scale as the actual environment. The two most commonly used methods involve re-walking a specific distance, or replacing elements to form a configuration that was previously experienced. This method has been used with the sighted (Loomis et al., 1993), visually impaired and blind subjects (Klatzky et al., 1990; Passini et al., 1990). The main advantage of this method is that distances are estimated in the same environment where the test was conducted. Keeping the environment constant can avoid errors associated with the adjustment of the representation in terms of scale translations and ratio calculations.

8.2.2.1 Triadic comparisons and balanced incomplete block designs

There are two types of tests that can be conducted using the triad method. In the classical approach, participants walk a route and learn the location of different elements in the environment. They are then presented with sets of triads and asked to judge which of the three locations is the furthest from the other two (or which two locations are the closest together). One of the main advantages of the triad technique is the simple nature of the response that is required from the subject. Triads are used in order to alleviate some of the cognitive burden placed on respondents when faced with demanding tasks or the inability to estimate to an exact metric. Unfortunately, triadic comparisons of large sets are plagued by redundancy. That is, tests that require the individual to estimate the distances between a large set of locations (usually more than 6) often require the subject to respond to long questionnaires which can be very time consuming and cognitively taxing.

A balanced incomplete block (BIB) design can be used to reduce experimental time and the accompanied cognitive load (Burton & Nerlove, 1976). Instead of a full factorial, a BIB design uses a fractional factorial to generate a subset of all possible triads so that every pair of items appears in an equal number of triads. In a BIB, the total number of triads is reduced by presenting each pair of items only a limited number of times. The number of times any two items are paired together is denoted by the Greek symbol lambda (λ). Thus in a λ4 BIB design each pair of locations is represented four times. Given a task comprised of ten items (or locations), a λ4 BIB generates 60 triads. The solution of a λ4 BIB of a set of ten locations consists of six cycles of ten triads and generates a total of sixty triads. The first row of table 8.2 presents the six cycles. The remaining triads are generated by adding 1 to each number in the set taking into consideration that the maximum number of locations is 10.

Table 8.2 - Solution for λ4 BIBD for n=10 (60 triads)

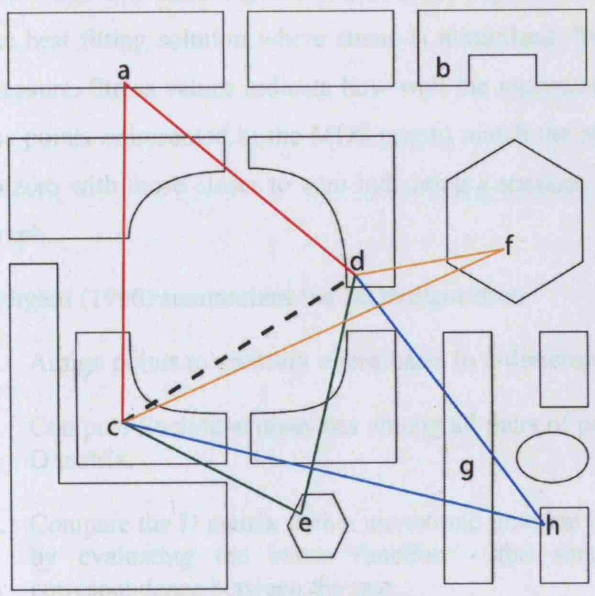
	1,4,5	1,5,6	1,3,5	1,3,6	1,4,7	1,2,3
+1	2,5,6	2,6,7	2,4,6	2,4,7	2,5,8	2,3,4
+2	3,6,7	3,7,8	3,5,7	3,5,8	3,6,9	3,4,5
+3	4,7,8	4,8,9	4,6,8	4,6,9	4,7,10	4,5,6
+4	5,8,9	5,9,10	5,7,9	5,7,10	5,8,1	5,6,7
+5	6,9,10	6,10,1	6,8,10	6,8,1	6,9,2	6,7,8
+6	7,10,1	7,1,2	7,9,1	7,9,2	7,10,3	7,8,9
+7	8,1,2	8,2,3	8,10,2	8,10,3	8,1,4	8,9,10
+8	9,2,3	9,3,4	9,1,3	9,1,4	9,2,5	9,10,1
+9	10,3,4	10,4,5	10,2,4	10,2,5	10,3,6	10,1,2

Adapted from Burton and Nerlove (1976)

A reduction in the number of triads inevitably leads to a reduction in accuracy. Burton and Nerlove (1976) tested for the reliability BIB by comparing results with those obtained from complete triads. They found that designs with lambda values above 1 had a satisfactory degree of reliability as repeated pairs tended to stabilize the variation in the response.

A variation of the classical approach allows for the comparison of distance estimates relative to a Euclidean or functional baseline. This method has been used with a considerable amount of success in past research with sighted, visually impaired and blind individuals (Ungar et al., 1996; Lockman et al., 1981). Participants are presented with three locations and asked to estimate which two locations are closest together and which two are the furthest apart. The triadic questionnaire is scored in the following manner: The pair judged closest is given a score of "0", the pair judged furthest a score of "2"and the remaining pair a score of "1". In a λ4 design each pair of locations is judged in the context of four different triads. The scores of these four judgements are summed to give an overall value ranging between 0 and 8 (for each pair of locations). Figure 8.1 is an example of this scoring technique. The value of the pair (c, d) is estimated through four different sets of triads: (c, d, a), (c, d, e), (c, d, h) and (c, d, f). Note that the value depends on the spatial relationship that is specific to each set. In this case, the added value for the pair (c, d) is "4".

Figure 8.1 - Scoring a λ4 BIB triad



Set 1: c,d,a	Set 2: c,d,e	Set 3: c,d,h	Set 4: c,d,f
c,d = 1	**c,d = 2**	**c,d = 0**	**c,d = 1**
c,a = 2	c,e = 0	c,h = 2	c,f =2
d,a = 0	d,e = 1	d,h = 1	d,f = 0

The researcher then calculates, also through triadic comparison, the objective Euclidean (straight line) and functional (route) distances based on the exact metrics provided by GIS software or a map. Two error scores, relative to the Euclidean and functional baselines, are calculated by subtracting the estimated scores from the real scores for each pair of location. Similar to heading data, the estimated values can be analyzed through a variety of statistical methods or regressed against the real values. Results from the triad can be arranged into an ordinal matrix of dissimilarities to be mapped and analyzed using multidimensional scaling (MDS).

8.2.2.2 Multidimensional scaling

Developed in the sixties, multidimensional scaling is a technique that allows for a two-dimensional representation of a pattern of dissimilarities[63] or distances among a set of locations (Jacobson & Kitchin, 1995). Given the ordinal matrix obtained through the triadic comparison, MDS arranges the locations on a graph (map) such that those judged closest to each other are placed next to each other on the graph and vice versa. In more technical terms, MDS uses an iterative procedure to produce an n-dimensional (usually two dimensions) configuration that best preserves the relative distance data (Lockman et al., 1981). The MDS algorithm continues to generate spatial configurations until it finds the best fitting solution where stress is minimized. Stress is basically a goodness of fit measure. Stress values indicate how well the represented locations (the distances among the points represented in the MDS graph) match the matrix data. Values range from one to zero with those closer to zero indicating a stronger match between the matrix and the graph.

Borgatti (1996) summarizes the MDS algorithm:

1. Assign points to arbitrary coordinates in n-dimensional space.
2. Compute Euclidean distances among all pairs of points, to form what we will call the D matrix.
3. Compare the D matrix with a monotonic function of the input data [known as] DHAT by evaluating the stress function - the smaller the value, the greater the correspondence between the two.
4. Adjust coordinates of each point in the direction that best maximally reduces stress.
5. Repeat steps 2 through 4 until stress does not get any lower.

[63] MDS matrices can be categorized as similarity or dissimilarity matrices. In a similarity matrix larger numbers indicate more similarity between the items. The opposite is true for dissimilarity matrices where large numbers indicate less similarity. In other words, dissimilarity implies a positive relationship among items. The matrix generated by the triadic comparison is considered a dissimilarity matrix as higher numbers represent locations that are further apart in the graph.

While it is not necessary that MDS configurations have a stress of zero[64] in order to be useful (zero stress is usually impossible to achieve in two dimensions) researchers must be careful in their interpretation as large stress values distort the configuration (Bogarti, 1996). Lockman et al. (1981) advise that researchers should use at least eight or nine different stimuli when conducting MDS in two-dimensional space in order to avoid random solutions with low stress values.

Gärling (1999) notes that MDS can provide detailed information on the distortion of mental representations such as size transformation, directional compression and elongation. It should be noted however, that MDS representations are essentially Euclidean. Unless specified, the MDS algorithm only takes into account the straight-line distances between locations and cannot account for space represented in terms of functional or the route-distance. More important is the fact that the MDS algorithm only represents the relative proximities between the different locations. It does not, and this should be emphasized, represent the absolute position of the location in space. That is, "one could use MDS to compare the relative estimated distances between two pairs of locations but could say nothing about the absolute accuracy of a given estimate as compared with the actual physical distance it estimates " (Montello, 1991, p.110). The MDS algorithm causes the spatial arrangement of elements in the environment to shift and stretch and cannot provide any absolute distance information. The solution that minimizes stress (the best fitting solution) does not depend on any correspondence with the external environment. Both the axes of graph and the orientation of the locations are meaningless and arbitrary.

The interpretation of MDS configurations depend upon the quality of the data, knowledge of the subject and the space depicted as well as a certain amount of "scientific imagination" (Gould, 1976). One way to interpret the MDS configuration is to use a topological type of analysis of clusters and dimensions. Clusters can be defined as a group of locations that are closer to each other than to other locations. Here again the position of location within a cluster should be interpreted with caution, as it is also arbitrary and not absolute. Dimensions are "item attributes that seem to order the items in the graph along a continuum" (Borgatti, 1996, p. 33). This is somewhat a harder concept

[64] Mathematically speaking non-zero stress only occurs because of lack of dimensionality. That said, interpreting matrix data in three dimensions is considerably difficult and four or more dimensions virtually impossible. Researchers have developed certain standards to qualify stress. In the case of triadic comparisons, stress can also increase due to judgement errors when estimating distances. In general values under .1 are considered excellent while anything over .15 is considered unacceptable.

to distinguish when analyzing MDS graphs that deal with the spatial representation of locations. Nonetheless, it can be conceived that locations could be organized partly due to some attributes they share in common such as size, form (architectural style) and the activity they house. Interpreting MDS graphs in terms of dimensions assumes that both researcher and subject share the same views or mentally classify items in the same manner – something that may be true in some cases but is certainly not the rule.

Several studies have used multidimensional scaling to study the mental representations of sighted (Gärling et al., 1991) and blind (Rosa & Ochaíta, 1993; Lockman, 1981) individuals. Taking in consideration some of the outlined limitations, MDS still offers several advantages for research in visual impairment and blindness. First, the constructions of the matrices necessary for the scaling procedure rely solely on distance judgements. This type of data collection does not put the blind and visually impaired subjects at a disadvantage, as the means of collection are often verbal. Second, when estimating distances, subjects are not required to simultaneously represent all the spatial relationships between the experienced items. Paired comparisons and triads are a sequential procedure that requires the individual to focus on only two or three items at a time. This allows MDS to be sensitive to the fact that in the absence of vision the formation of configurational knowledge is more complex. In third place, the subject's response is free from scale transformations present in graphical (see next section) or other distance estimation tests. Finally, MDS supports both metric and non-metric estimates and can be effective in the collection of data from populations unaccustomed to thinking in metric standards.

8.2.3 Graphical and modelling techniques

Graphical techniques can be used to measure an individual's configurational knowledge of the environment. Ever since Lynch's (1960) pioneering study, researchers have used a wide variety of sketch mapping or drawing techniques for the communication of mental representations. Kitchin and Jacobson (1997) identify four variations: *Basic* sketch mapping does not impose any drawing restrictions. Participants are given free reign in the sketching of their mental representations. The *normal* technique imposes some restrictions defined by the researcher such as specific elements that participants have to include in their sketch. In *cued* sketch mapping, a portion of the drawing is given and the participant is asked to sketch out the rest. Finally, in *longitudinal* sketch mapping the researcher is interested in the actual creation and development of the drawing (the manner in which the subject sequentially constructs the sketch). It is obvious that sketch mapping is not the most appropriate method in research with the blind and visually impaired. Yet, some researchers have adapted some of the drawing apparatus using raised line technology to account for the absence of vision. Dodds et al. (1982) used the *Sewell Raised Line Kit* to test children's knowledge of a well-known environment. Results for the blind however, were extremely poor. In contrast, Jacobson (1998) found that blind subjects were able to produce accurate drawings of their University campus used a raised line drawing board.

Sketch mapping has been widely criticized for placing more emphasis on the drawing ability of the participant than on the actual content and accuracy of the representation (Siegel, 1981).[65] Some authors (Blaut et al., 1970) argue that this method is inappropriate when used with children. Sketch mapping also requires the scaling of large-scale information to a small piece of paper further adding to the cognitive load. This critique is especially true in the case of blind and visually impaired individuals that are not accustomed to drawing or do not have a fully developed knowledge of maps and other cartographic conventions. Wood and Beck (1976) however, note that errors caused by graphical abilities or mapping (in the cartographic sense) knowledge can be greatly reduced if subjects are instructed in a "sketch mapping" language prior to testing.

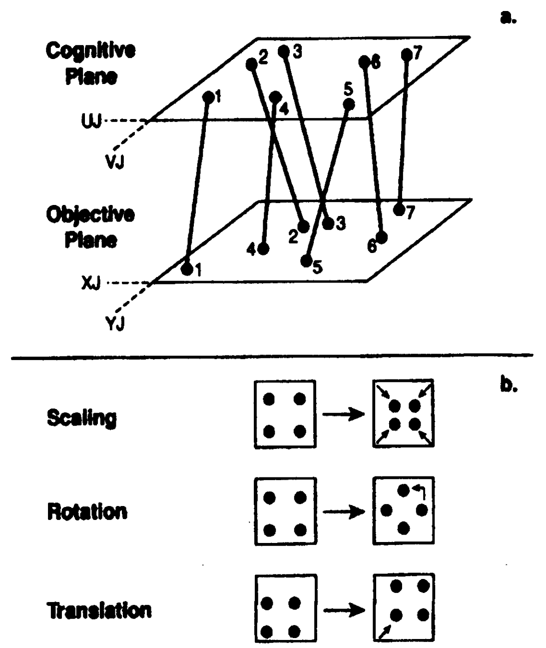
Asking subjects to construct models may be a more effective way to study the configurational knowledge of the blind and visually impaired (Huertas & Ochaíta, 1993; Passini & Proulx, 1988; Hollyfield & Foulke, 1983; Casey, 1978). Participants are required reconstruct an environment by representing the position of different elements with magnets or scaled versions of physical elements. Like in sketch mapping the researcher can provide certain cues, like the position of certain landmarks or buildings, for scale and orientation. Models are an attractive alternative given that they reduce the motor skills necessary for task completion. Model pieces that represent scaled versions of buildings and other physical elements are tactile friendly and not strictly based on any cartographic convention. In addition the construction of models has many characteristics in common with play – an activity engaged by almost every person blind or sighted when young.

[65] Here it is worth mentioning that verbal techniques suffer from the same type of criticism. While the problem is more obvious with children than adults verbal protocols can confound linguistic ability and spatial knowledge. Issues of vocabulary and basic communication can overshadow actual spatial knowledge. In addition, in the presence of vision, verbal protocols require a two-step transformation of data from a simultaneous perception to sequential description (Siegel, 1981).

8.2.3.1 Bidimensional regression

Results from graphical tests can be analyzed using bidimensional regression (Tobler, 1994). Bidimensional regression (figure 8.2) is a method that allows for the comparison of the degree of association between two planar configurations of points (Friedman & Kohler, 2003). Like in a regression the value of r^2 indicates the degree of association between the two configurations. Results from a bidimensional regression can also provide information on the distortion of the representation in terms of scale (φ), angle (θ) and horizontal & vertical translation ($\alpha 1$ & $\alpha 2$).

Figure 8.2 - Bidimensional regression



Source: Kitchin and Blades (2002)

Scale, angle and translation values indicate how much change is needed to produce the best fit between the cognitive and objective configurations (Kitchin & Blades, 2002). Scale values less than 1 indicate that the variant configuration needs to be contracted to produce the best fit. Values higher than one indicate that the configuration needs to be expanded. Positive angle values indicate that a counter clockwise rotation is necessary to produce the best fit while negative values a clockwise rotation. In terms of translations, positive $\alpha 1$ and $\alpha 2$ indicate that a west-to-east shift and south-to-north translation have taken place, and negative values an east-to-west and north-to-south translation.

Waterman and Gordon (1984) have proposed a distortion index (DI) to measure the overall distortion of the representation after all systematic transformations have been performed. Lloyd (1989) notes that this can be thought as a standardized measure of relative error. The distortion index ranges from 0 to 100 and is a dimensionless value. Both bidimensional regression and Waterman and Gordon's (1984) DI have been intensively reviewed by Friedman and Kohler (2003) who propose an elegant alternative for their calculation without disrupting the relationship between the dependent and independent variables in a regression.

The critique departs from the idea that there is an analogy between one-dimensional and bidimensional regression (Friedman & Kohler, 2003, p. 471) in the sense that one is able to regress the referent configuration (X) or (XY) on the variant configuration (A) or (AB) and vice versa. Equation 8.1 presents a one-dimensional regression for "X" and "A" as independent and equation 8.2 is a bidimensional regression for "XY" and "AB" as independent.

if X independent, A dependent $\quad$ *if A independent, X dependent*

$$(A'B') = \alpha + \beta \cdot (XY) \qquad (X'Y') = \alpha + \beta \cdot (AB) \tag{8.1}$$

if XY independent, AB dependent $\quad$ *if AB independent, XY dependent*

$$(A'B') = \alpha + \beta \cdot (XY) \qquad (X'Y') = \alpha + \beta \cdot (AB)$$

or $\quad$ *or*

$$\begin{pmatrix} A' \\ B' \end{pmatrix} = \begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix} + \begin{pmatrix} \beta_1 & -\beta_2 \\ \beta_2 & \beta_1 \end{pmatrix} \cdot \begin{pmatrix} X \\ Y \end{pmatrix} \qquad \begin{pmatrix} X' \\ Y' \end{pmatrix} = \begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix} + \begin{pmatrix} \beta_1 & -\beta_2 \\ \beta_2 & \beta_1 \end{pmatrix} \cdot \begin{pmatrix} A \\ B \end{pmatrix} \tag{8.2}$$

Source: Friedman and Kohler (2003)

Equation 8.3 extends this analogy for the calculation of the correlation coefficient (*r)* and subsequently the degree of association (r^2) between configurations in a bidimensional regression. While the value for *r* remains the same irrespective of which configuration was chosen as the independent variable, the value of the other parameters (scale, angle and horizontal and vertical translation) change when the variables exchange roles. This can have important implications in the analysis of specific type of cognitive distortions. Figure 8.3 is an example given by Friedman and Kohler (2003) to illustrate idea that the regression equations and the parameters they yield are not exact inverses.

if XY independent, AB dependent

$$r=\sqrt{\frac{\sum\left[(A'-M_A)^2+(B'-M_B)^2\right]}{\sum\left[(A-M_A)^2+(B-M_B)^2\right]}}=\sqrt{1-\frac{\sum\left[(A-A')^2+(B'-B')^2\right]}{\sum\left[(A-M_A)^2+(B-M_B)^2\right]}}$$

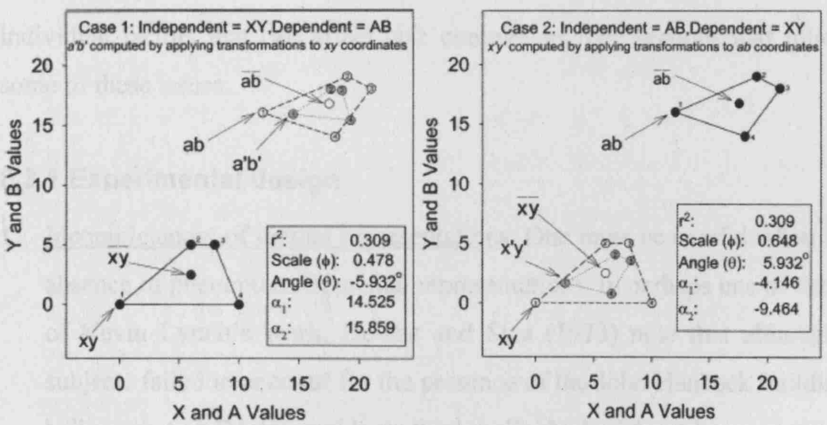
(8.3)

if AB independent, XY dependent

$$r=\sqrt{\frac{\sum\left[(X'-M_x)^2+(Y'-M_y)^2\right]}{\sum\left[(X-M_x)^2+(Y-M_y)^2\right]}}=\sqrt{1-\frac{\sum\left[(X-X')^2+(Y'-Y')^2\right]}{\sum\left[(X-M_x)^2+(Y-M_y)^2\right]}}$$

Source: Friedman and Kohler (2003)

Figure 8.3 - Bidimensional regression & other parameters



Source: Friedman and Kohler (2003)

Friedman and Kohler's critique is particularly relevant in the case of the calculation of the distortion index. Waterman and Gordon (1984) proposed the calculation of a distortion index (DI = D/Dmax) where the cognitive coordinates are assigned the role of independent variable and the referent coordinates the role of dependent variable for the computation of the distortion distance (D). Strictly assigning the referent coordinates the role dependent variable disrupts the regression analogy and does not allow for a situation when the cognitive configuration takes the role of dependent variable (which correctly observed by Friedman and Kohler is the more conventional case). These authors have proposed an alternative way for the calculation of the DI that allows for the two possible ways to regress the coordinates. In this case, D is always defined in terms of the coordinates selected as the dependent variable (equation 8.4).

$$\begin{aligned}&\textit{When } AB \textit{ is the depedent variable}\\ &D_{AB} = \sqrt{\sum[(A - A')^2 + (B + B')^2]}\\ &\textit{When } XY \textit{ is the dependent variable}\\ &D_{XY} = \sqrt{\sum[(X - X')^2 + (Y + Y')^2]}\end{aligned} \tag{8.4}$$

Source: Friedman and Kohler (2003)

8.3 Methodological problems

There are a series of methodological problems associated with cognitive mapping research. These can be divided into problems related to the experimental design as well as individual factors that can affect task completion. The sections that follow will review some of these issues.

8.3.1 Experimental design

1. Incompleteness of mental representations: One must be careful when interpreting the absence of phenomena in mental representations. In perhaps one of the best criticisms of Kevin Lynch's work, Downs and Stea (1973) note that although many of the subjects failed to account for the presence of the John Hancock building, it is hard to believe that as Boston residents these individuals did not know about this building's existence. It is important to differentiate between denotative and connotative meaning. The fact that this building did not play a significant role in the lives of these individuals (lack of connotative meaning) does not mean that these individuals were not aware of its presence (denotative meaning).

2. Spatial memory and inference tasks: Tests that require the transformation of mental images are harder to complete than tests that involve the recall or recognition (spatial memory) of elements. One should be careful when interpreting and comparing results between different experiments. Hardwick et al. (1976) found that that the accuracy and coherence of mental representations changed dramatically when the task

involved inferences in the type of mental rotation (imagining the room rotating) or perspective taking (imagine themselves moving).

3. Size of the space and performance: The layout, size and spatial complexity of the space will lead to different results. Some authors (Byrne & Salter, 1983; Dodds et al., 1982) have reported more errors in large spaces while others (Ochaíta & Huertas, 1993) argue that performance is mainly a factor involving the level of complexity. One should be very careful when comparing results between experiments. Gouteux et al. (2001) argue, "that small-scale space and navigational space differ with respect to the action programs they entail" (Gouteux et al., 2001, p. 865). Cohen and Cohen (1985) note that this active acquaintance with the environment is very important for the development of accurate representation of large-scale environments.

4. Size of groups: The percentage of the population that is congenitally blind is considerably low (not so much the case for adventitiously blind or visually impaired) and at times statistical tests are performed on small sample sizes. Haber et al. (1993) had only 7 subjects in two visually impaired groups and a control of six sighted. Byrne and Salter (1983) had eight blind subjects and eight sighted. Hollins and Kelley (1988) had only six blind subjects and Bigelow (1991) had only two blind, two visually impaired and eight sighted subjects. In an extreme case, Landau et al. (1981) based her results on the performance of one blind subject. Researchers should be encouraged to use larger sample sizes or at least report obvious but essential statistical data such as standard deviations and distributions.

5. Number of elements to process: Is performance related to spatial ability or to memory and attention? Researchers should differentiate between recall and recognition tasks and be aware of the group's capacity to mentally store elements. Furthermore, short-term memory suffers from a decay effect that can influence spatial memory tasks. It is important to distinguish the critical times for testing and make sure that all subjects are tested with the same delays.

6. Nature of response: The type of externalization (verbal, pointing, orienting, sketching, or the construction of models) will require specific mental computations and motor skills and are bound to generate different results (Siegel, 1981). Multiple

converging techniques should be used to better understand and interpret results from spatial tests.

7. Level of familiarity and experience: Experience can have a considerable effect on the content and accuracy of mental representations. How do we account for the level of experience? When do we consider an environment to be familiar? How do we measure experience with the testing procedure? These are just some of the questions that the researcher must take into account before designing the experiment. Siegel (1981) notes that repeated perceptual experience has a positive effect on the accuracy of mental representations of large-scale environments. Experience allows for the calibration of both scale and distance between different elements in the environment. Experience may also lead to more accurate representation of an area as a whole. Kirasic et al. (1984) found that although subjects did not differ in the amount of absolute error when estimating the direction of different places; those that had lived or worked in the area for longer were more systematic in their errors. The same authors also found that length of residence also affects the abstractness and flexibility of mental representations. Moar and Carlton (1982) found that subjects committed significantly fewer mistakes when estimating the direction and distance of different locations after repeated experience with the environment.

8. Method of data collection: Experiments should clearly indicate if the method of collection of spatial information was active or passive. Gale et al. (1990) found that children who actively walked the route were more effective in recalling it when compared to children who had only seen it in a film. The same type of distinction can be made between free and guided exploration. Information collected through slides (Cohen & Schuepfer, 1980), animations, movies or any virtual type of experiment are considered passive forms of exploration as they do not provide the individuals with the motor experience gathered when actively walking a route. In guided exploration the individual gains motor experience but forfeits attention to the researcher who controls the movement around space. Researchers should be aware and control for the amount of attention and motor activity that will be required of the participants.

8.3.2 Individual factors

1. Type of impairment: Warren (1984) warns about some of the problems when comparing blind, partially sighted and sighted subjects in different spatial tasks. It is

hard to classify a population that is extremely heterogeneous. This problem is further complicated given the evidence supporting the variability of individuals with the same eye condition. Individuals can vary in terms of their eye condition, visual acuity and/or field. Some researchers have argued that certain eye conditions have a larger effect on performance. Loomis et al. (1993) found that the performance of individuals with retrolental fibroplasias (retinopathy of prematurity) was significantly inferior when compared to the other VI groups. Dodds et al. (1991) found no such relation.

2. Age (age of onset impairment): What criteria should be used to distinguish the early from the late blind? Researchers from different fields vary in their interpretation of the *critical age*. For the developmental psychologist, it is usually when the infant starts to coordinate movement with vision while for the neuropsychologist this is related to the development of the brain, which reaches its full maturity only after puberty. Rieser et al. (1992) classified as early blind those affected during the first three years, Herman et al. (1983b) until the first year while Millar (1979) before 20 months. Lowenfeld (1981) remarks that it is generally agreed that children who lose their sight before the age of five do not retain any useful visual imagery. In addition, it is important to distinguish static from progressive conditions. This is of particular importance in long-term studies.

3. Level of education and intelligence: Some authors (Thinus-Blanc et al., 1999) have cleverly matched participants in terms of their IQ. Spatial tasks can involve complex mental calculations and performance may be related to the level of education or intelligence.

4. Level of orientation and mobility: Many spatial tasks involve learning the location of elements along a route. Good orientation and mobility skills play an important role in the coding and construction of the mental representation. Mobility instructors teach different strategies when walking in familiar and unfamiliar environments and these can prove beneficial during the testing phase.

5. Affective development: As discussed in chapter 3, confidence and quality of life can also affect performance and researchers should control for the emotional state of the participants. Studies have identified that sudden (accident) or late loss of the visual field is usually associated with depression and difficulties in rehabilitation.

8.4 Individual differences and inferential statistics

This section addresses some of the limitations of inferential statistics particularly null hypothesis significance testing (NHST) in the analysis and interpretation of results of data on the representation of space in the total or partial absence of vision. The purpose of this section is to explore some aspects of this more than justified critique and discuss a variety of alternative and complimentary methods.

The disciplines of geography and psychology have a long tradition of comparing between different groups of participants. More often than not, research has focused on the way in which individuals within a group are similar to one another but different from individuals in another group (Lewis & Collis, 1997). When comparing the performance of the blind and visually impaired in spatial tasks, subjects are usually divided into different groups and a sighted control is assigned. Comparing the performance across groups can provide important information on the role of vision in the development of mental representations and can assist in the formulation of theories on sensory substitution and proprioception. At times however, this inter-group method of comparison can be misleading especially when the adopted methodology does not allow for individuals to fully express their abilities. This is usually the case in tests that use blindfolded sighted controls. In many situations the control group is forced to operate at a disadvantage and rely on manipulatory and tactile strategies[66] that would not usually be used if vision were available. The same is true for blind and visually impaired subjects in experiments when the type, format and amount of information provided for the completion of a specific task favours the visual sense (Millar, 1997: 2000).

Not enough attention has been given to the ways in which individuals within a specific group differ from one another (Lewis & Collis, 1997). The phenomenological world of the visually impaired is qualitatively different from that of the sighted (Rosa, 1993). Individuals with visual impairment and blindness form part of a population that is extremely heterogeneous that many times cannot be classified into specific groups or categories. The tradition of making comparisons between groups assumes that individuals that make up a particular group share the same characteristics. Individuals are grouped together because they have been diagnosed with the same eye or medical condition or have the same visual acuity. This type of classification can sometimes be restrictive.

[66] Primary strategies are the natural, predisposed and frequently relied upon strategies used when problem solving. Secondary strategies are the best-adapted alternative when faced with a situation where the natural response cannot be elicited.

Consider the case of individuals who are diagnosed with the closest match condition. In such cases, the expert does not know the exact nature of the impairment and bases his diagnosis on the present manifestation of symptoms and behaviours. Some of the participants in this research have been diagnosed with a specific condition, most of the time retinitis pigmentosa[67] (RP), but do not exhibit many of the characteristics that the condition incurs. This type of unforced professional error cannot account for latent behaviours or symptoms and may cause a significant amount of confusion if these individuals are mixed together in a group.[68]

The total or partial absence of vision cannot fully account for differences in performance in different spatial tasks. Such strict causality is theoretically sterile (Warren, 1994), as it does not recognize the growing evidence on the spatial abilities of the blind and visually impaired. The development of spatial abilities is also mediated through interaction and experience with the environment and culture. In this manner, while individuals in a particular group may have a similar medical, functional or clinical diagnosis (or any combination of these), it does not mean that they are entirely homogeneous. Comparing between groups can be beneficial if the researcher is capable of controlling for a certain amount of cohesion within each specific group. This method is better suited in situations when there are large and clear differences between groups. When differences are small and hard to identify a differential or individual differences approach may be more suitable.

The individual differences approach takes into account the influence different factors can have on the specific individual (Lewis, 2003). It shifts the focus from the actual effect to the possible nature and causes of its presence. Research in visual impairment and blindness is filled with contradictions and interpretations and it is not uncommon to find similar studies with conflicting results. Many of these discrepancies however, can often be attributed to the fact that researchers were working with samples that were not equivalent (Warren, 1984). In this manner, a crucial step in the analysis consists of a

[67] Retinitis pigmentosa (RP) is a group of hereditary diseases that result in the degeneration of the retina. As a progressive disease, it begins with damage and destruction to the rods in the mid periphery, gradually advancing to the macula. Tunnel vision, poor night vision and myopia are observed in most cases.

[68] Schinazi (2005) further discusses the problems of classification based on visual acuity. He considers two individuals, the first with RP the other with myopia that have the same visual acuity. The individual with RP however, also has poor night vision. While still impaired due to a low visual acuity and a restricted visual field, performance in a particular spatial task will probably change in situations with different lighting levels. How can this individual be classified in the same group with someone with myopia whose performance is not strictly dependent on lighting?

detailed description of the characteristics of the group and of each subject as an individual.

8.4.1 The shortcomings of null hypothesis significance testing (NHST)

Researchers often overlook the need for detailed descriptions, many times the space and attention forfeited in exchange for statistical significance testing. The wide availability of computers coupled with user-friendly statistical packages has fuelled a bogus revolution whose main order is to test for significance. This over reliance on statistical testing rather logical reasoning is particularly problematic when used to explain human behaviour. Many of tests commonly used (Student's t-test, ANOVA) rely on group averages and are based on the assumption of a normal distribution. An analysis solely based on group means is unrealistic and restrictive. Significance testing does not tell us whether differences actually matter nor provide any explanations regarding an effect.

Results from statistical testing can be somewhat deceptive, at times giving the illusion of objectivity. As Cohen (1990) has impeccably noted, what researchers would like to know is how likely there are differences in the population given the data. Unfortunately, all that NHST can provide is information on how likely is the data given the assumption that there are no differences in the population.

A variety of methods such as effect size measures, confidence intervals that combined with graphical tools can be useful complements to NHST. One of the main shortcomings of NHST is that it can only identify the direction of a difference (A > or < B) and does not provide any information regarding its size. The effect size is basically the standardized mean difference between different groups, a measure of the magnitude of the impact of the independent variable on the dependent variable and can be interpreted as the "true" measure of the significance of a difference (see equation 8.5). Contrary to p values effect size indicators have the advantage of not being sensitive to sample sizes. More important, they can provide important information on the practical (clinical) significance of a difference (an effect can be statistically significant and mathematically real but too small to be important.

$$Effect\ size = \frac{(Mean\ of\ experimental\ group) - (Mean\ of\ control\ group)}{Standard\ Deviation} \qquad (8.5)$$

Here it should be noted that there are no exact guidelines as to what indicates a small or large effect. Cohen (1994; 1990) has written substantially on the topic and provides some guidelines for their interpretation based on the effect size of differences that are familiar. Table 8.3 presents a simple guide to interpreting effect sizes. Effect sizes can be converted into statements about the overlap between two groups. This can be a valuable tool when discussing the magnitude of the difference between groups. The first column in the table presents the actual effect size. The second presents the probability of guessing which group a person belongs to on the basis of their performance on a specific task.

Table 8.3 - Interpreting effect sizes

Effect size	Probability of guessing group	Cohen's (d)
0.0	0.50	
0.1	0.52	SMALL
0.2	0.54	
0.3	0.56	
0.4	0.58	
0.5	0.60	MEDIUM
0.6	0.62	
0.7	0.65	
0.8	0.66	
0.9	0.67	
1.0	0.69	
1.2	0.73	LARGE
1.4	0.76	
1.6	0.79	
1.8	0.82	
2.0	0.84	
2.5	0.90	VERY LARGE
3.0	0.93	

***Adapted from (Coe, 2000)**

It should also be noted that effect sizes are descriptive and not inferential. They are descriptive of the sample data and offer no information for the rest of the population. Effect sizes should be interpreted with care, as they are highly dependent on the situation. It is up to the investigator to become acquainted with the different characteristics of the data in order to understand what constitutes a small or large effect. Finally, confidence intervals and box plots are other useful tools for the interpretation of results and appealing complements to NHST. Like NHST, confidence intervals can provide information as to whether the difference between two means is statistically significant. Box plots (a visual display of the five number summary) are particularly useful when viewed side-by-side and used to compare data from different groups.

8.5 Summary

In this chapter we have reviewed a variety of methods that will be adopted in the analysis of mental representations for the two experiments conducted with students at the RLSB. Heading judgements, distance estimation and model construction techniques were considered in relation to various analytical tools. This included regressing real and estimated values, general linear models, triadic comparisons, multidimensional scaling and bidimensional regression. The chapter also discussed several methodological problems related to the implementation, reliability and overall validity of these methods. These included both individual and problems related to the experimental design.

Many renowned researchers (Kevin Lynch and Jean Piaget come to mind) have managed to reach important conclusions without relying on significance testing (Cohen, 1994). Unfortunately many are still under the illusion that results accompanied by significant *p* values are more robust and a fundamental requirement for publication. NHST can sometimes be a trivial exercise as rejecting the null hypothesis is usually the case of securing a large enough sample. Results that are not statistically significant should also be reported as they force the researcher to pay attention to the array of variables that are brought by each individual and are beyond the control of the experimenter. The individual differences approach combines the logic of the case study technique with the advantages of quantitative methods. There are however, several difficulties with this approach. These are related to the vast array of factors (physical, clinical, environmental) that even if identified can have different effects on each participant. Nonetheless, it is exactly this complexity that should interest researchers. Good research is not only concerned in identifying an effect (or a difference) but also in uncovering the facts that can explain the reasons behind the difference. Explaining the difference is what will aid professionals in the design of intervening programs that are specifically catered to the group or the individual.

Chapter 9

Experiment 1 – The content and accuracy of mental representation of a well-known environment

9.1 Introduction

This chapter presents the first experiment on the content and accuracy of mental representations of a well-known environment. The experiment was conducted with students from Dorton College at the Royal London Society for the Blind campus in Sevenoaks, Kent. The chapter begins with a description of the different buildings and structures that make up the study area. The experiment is then explained and the participants are presented along with the rationale for their classification. Subjects were asked to perform three spatial tasks (pointing judgements, distance estimation and model construction) and the chapter is structured accordingly. The requirements of each task are described followed by the results, analysis and discussion. The last section of the chapter presents the results from the mobility questionnaire, the low-vision quality of life questionnaire and the numeracy and literacy assessment as a complement to the results and motivation for pursuing the second experiment. Testing for the first experiment took place from March to June of 2005.

9.1.1 The RLSB campus

The campus of the Royal London Society of the Blind (RLSB) comprises an area of $107845m^2$ and is made up of eight buildings, a maintenance shed and a fountain. These are known as: B-Block, ELJ, A-Block, Student Centre, Thomas Lucas, Mansion House, Nursery, School, Fountain and Shed. The campus can be divided into two areas: the *college area* and the *mansion area.* This division is the result of the clustering of different buildings (and structures) and the academic or administrative functions they serve. Figure 9.1 is a plan view of the campus with all the buildings and structures. Figure 9.2 presents photographs of the front entrance of the different buildings, the shed and the fountain.

Figure 9.1 - Plan view of RLSB campus

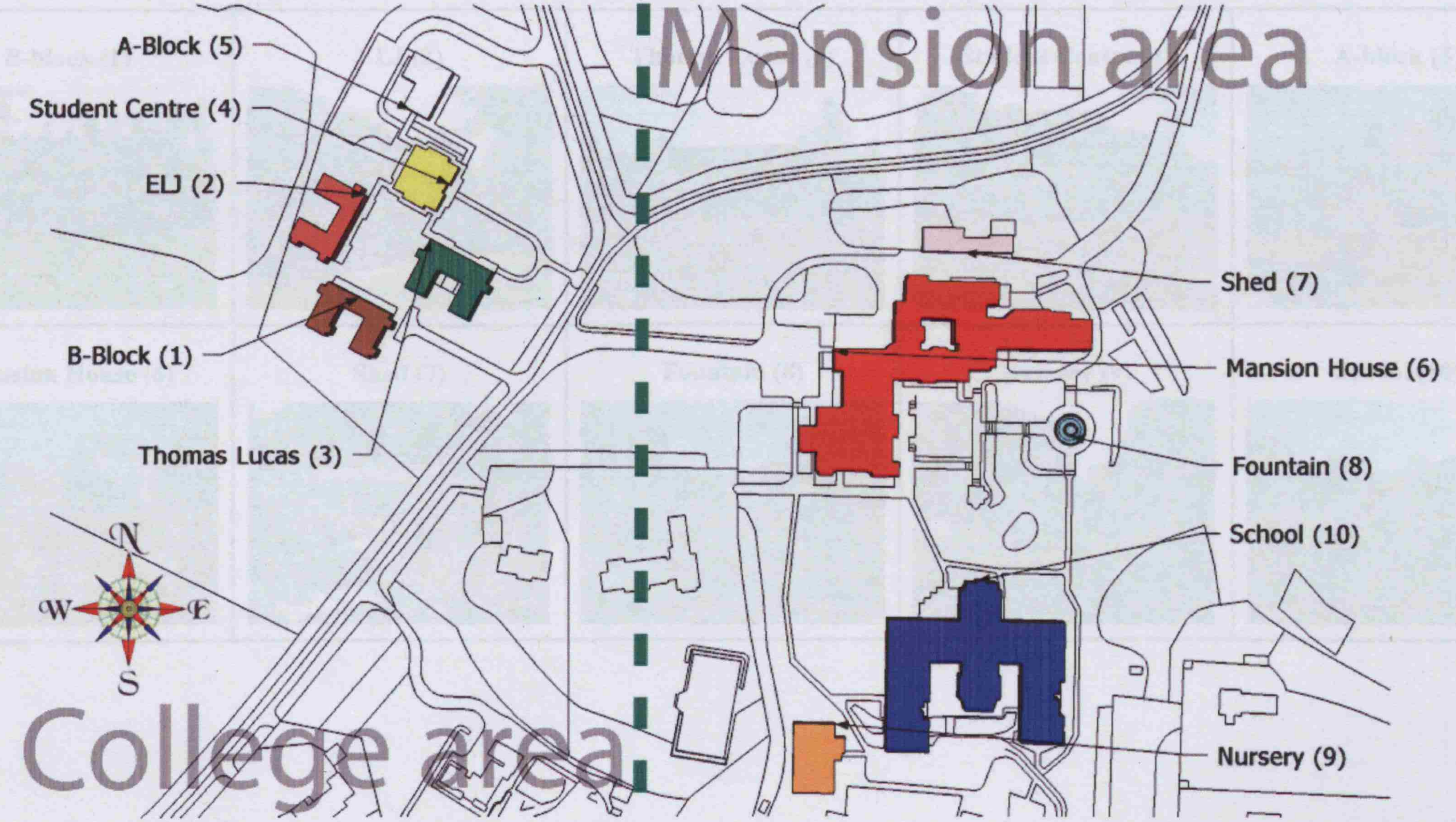
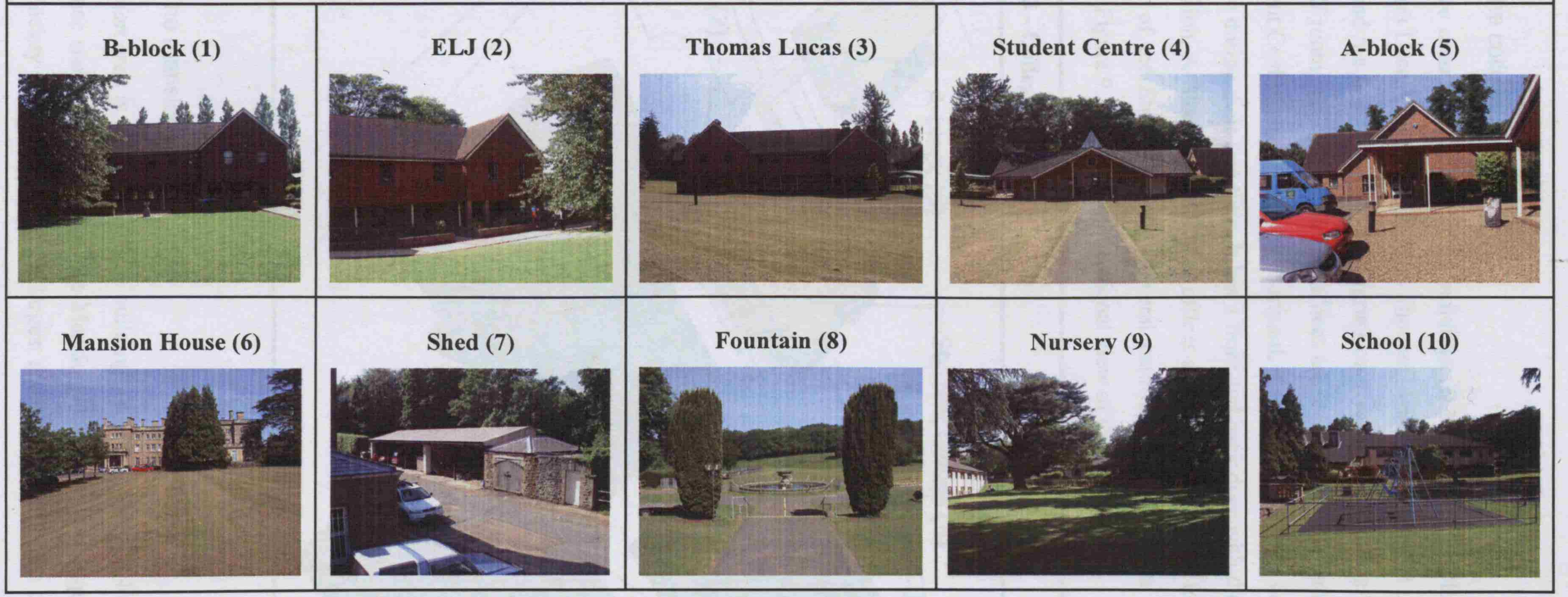


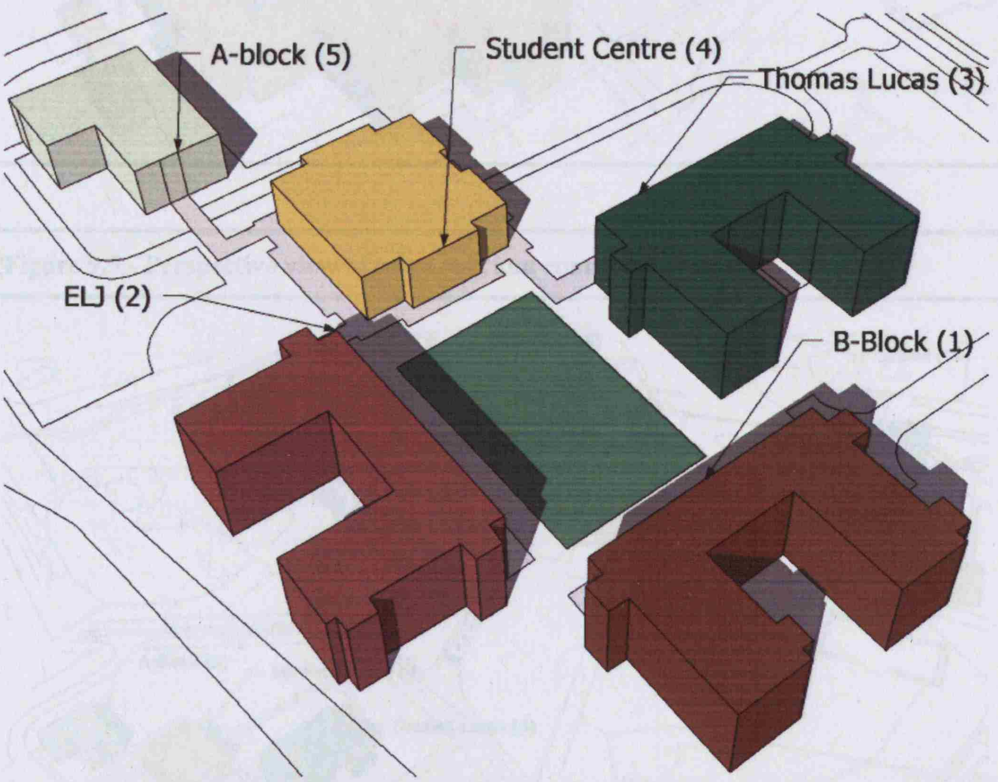
Figure 9.2 - RLSB campus buildings and structures



9.1.1.1 The college area

The *college area* is made up of five buildings (B-Block, ELJ, A-Block, Student Centre and Thomas Lucas). B-block, ELJ and Thomas Lucas are residential units for the college students and are distributed around a grass courtyard. The Principal's office, computer room, staff room and other academic offices are located on the ground floor of B-block. The Student Centre, also facing the courtyard, is where the students have their meals and congregate during their free time. It has a front and back door with the front area serving as a reception. A-Block is made up of offices and classrooms and is located a few meters northwest of the Student Centre. Several pathways link the front entrances of these buildings. Figure 9.3 is a three-dimensional view of the *college area*.

Figure 9.3 - College area



9.1.1.2 The mansion area

The *mansion area* is made up of three buildings (Mansion House, Nursery and School) a maintenance shed and a fountain. The Mansion House is the headquarters of the Royal London Society for the Blind and the largest and oldest building on campus. The ground floor of the building is mainly comprised of offices and a large reception area where events are hosted. The other floors act as residential units for both school children and staff.

Figure 9.4 - Mansion area

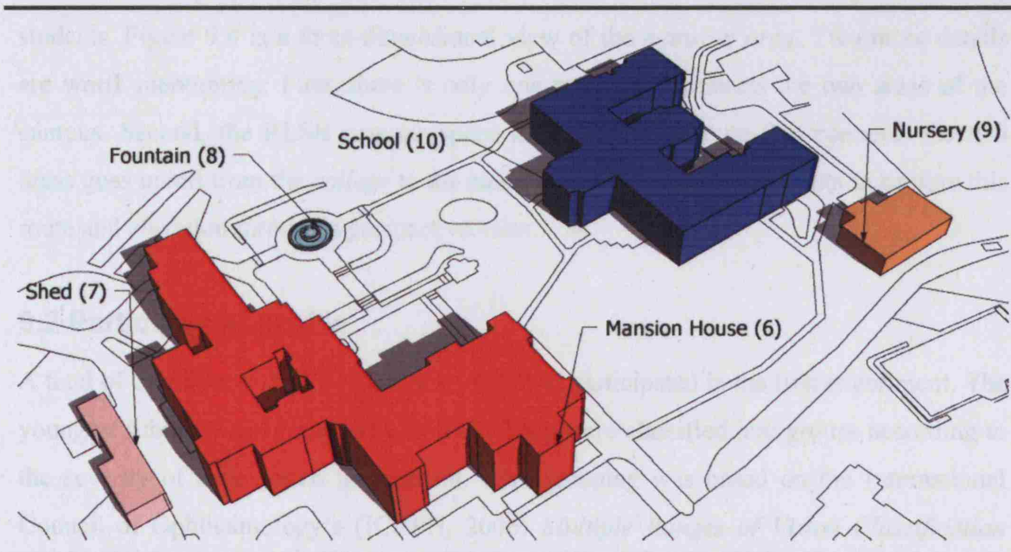
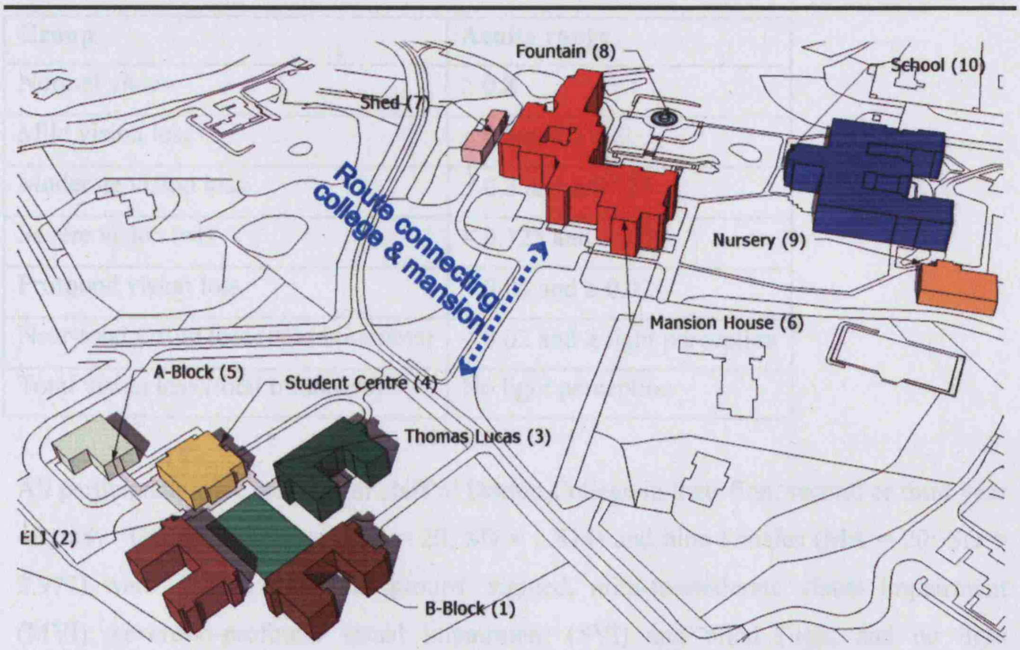


Figure 9.5 - Perspective view of two areas and connecting route



The School is where some of the college-based students attend class. The Nursery is located southwest of the School, and is specifically designed for blind and visually impaired toddlers who do not fully interact with the college students. Finally, a Fountain and a Shed were also chosen for this study. The first for being a prominent landmark around the campus, the second because it is located in an area not usually travelled by students. Figure 9.4 is a three-dimensional view of the *mansion area*. Two more details are worth mentioning: First, there is only one route that connects the two areas of the campus. Second, the RLSB campus space is not flat. The route that connects the two areas goes uphill from the *college* to the *mansion area*. Figure 9.5 attempts to capture this route and elevation through a perspective view.

9.2 Participants' profile

A total of 29 subjects (MA[69] = 20; SD[70] = 2.194) participated in the first experiment. The youngest subject was 17 and the oldest 27. They were classified into groups according to the severity of their visual impairment. This grouping was based on the International Council of Ophthalmology's (ICOPH, 2006) *Multiple Ranges of Vision Classification* (table 9.1).

Table 9.1 - ICOPH multiple ranges of vision

Group	Acuity range
Normal vision	≥ 0.8
Mild vision loss	< 0.8 and ≥ 0.3
Moderate vision loss	< 0.3 and ≥ 0.125
Severe vision loss	< 0.125 and ≥ 0.05
Profound vision loss	< 0.05 and ≥ 0.02
Near-total vision loss (near blindness)	< 0.02 and ≥ light perception
Total vision loss (total blindness)	No light perception

All participants were students or staff of Dorton College in their first, second or third year of study. The twenty males (MA = 20; SD = 1.814) and nine females (MA = 20; SD = 2.977) were divided into four groups: sighted, mild-to-moderate visual impairment (MVI), severe-to-profound visual impairment (SVI) and blind (light and no light

[69] MA = Mean age

[70] SD = Standard deviation

perception). Most subjects (21) were blind or visually impaired from birth. Table 9.2 presents how the acuity range classification was adapted for this experiment along with some of the characteristics of each group. The same method of classification was used for both experiments.

Table 9.2 - Group characteristics

Group	Sighted	MVI	SVI	Blind
Number of subjects	5	9	8	7
Visual acuity	> 0.8	< 0.8 ≥ 0.125	< 0.125 ≥ 0.02	LP & NLP
Congenital & adventitious	-	8 congenital 1 adventitious	7 congenital 1 adventitious	6 congenital 1 adventitious
Gender	3 M & 2 F	6 M & 3 F	7 M & 1 F	4 M & 3 F
Mean age (SD)	23 (2.550)	20 (1.414)	20 (2.066)	19 (0.951)
Median age	22	19	21	19
Minimum age	21	18	18	17
Maximum age	27	22	24	20

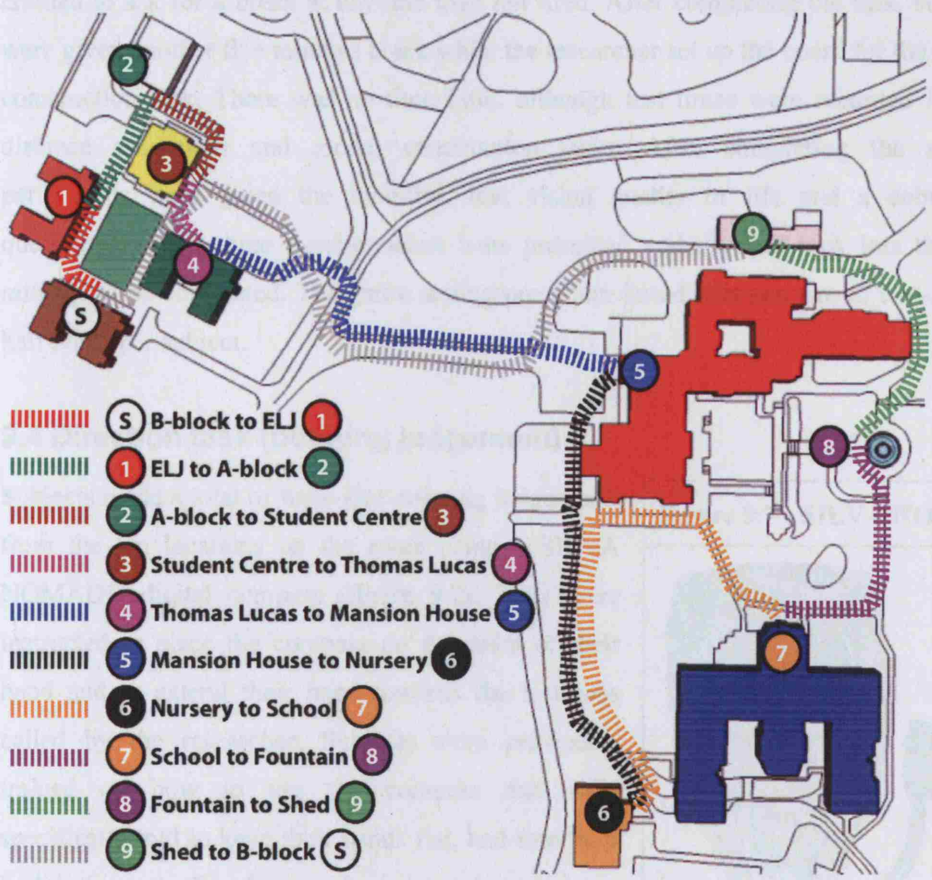
***LP = Light perception** ****NLP = No light perception**

Taking into consideration the previous discussions on the importance of participant description, details on each participant are provided in addition to the group data. Table A1 in the appendix presents detailed information on the vision (visual acuity, visual field, near vision, colour vision, prescribed visual condition and age of onset impairment) and other characteristics (additional conditions or disabilities, years of mobility training and scores for literacy, numeracy or a combined foundation skills assessment) for each of the blind and visually impaired participants.

9.3 Experiment 1: Content and accuracy of mental representations

The first experiment tested the content and accuracy of mental representations of the RLSB campus - a well-known environment for the students of Dorton College. Participants were guided along a route (1.232 km) around the RLSB campus and were asked to remember the location of ten different buildings or structures. They were told to think of the buildings but asked to remember a specific location, the front door, as this was the location where they would be placed in order to make the pointing judgements. Participants either held the researchers arm or walked beside him. Those who needed were allowed to use their long-canes. Upon arriving at a location the researcher stopped, named the location and allowed the subject to touch the front door (for the fountain subjects touched southern edge of the gate protecting it). Subjects were then told the name of the next location they would visit. No information was provided in terms of heading, distance or time. Figure 9.6 illustrates the route and the ordering of the walk.

Figure 9.6 - Route around the RLSB campus



9.3.1 Participant preparation

Before walking the route, the researcher sat down with each participant to describe and explain the experiment and the subsequent tasks they would have to complete. They were told to pay attention to the absolute and relative position between the different locations, as they would need to make pointing judgements, estimate distances and construct a model of the campus. Subjects were also introduced and trained in using the digital compass. All students were tested at approximately the same time of the day (between 10:00 a.m. & 3:00 p.m.) in order to keep the light levels consistent.

Tests were always conducted in the same order and began immediately after the guided walk. For the pointing task, the subjects were brought back to the starting point and handed the digital compass. At this point subjects were given one last chance to ask questions. The researcher answered these as long as they did not interfere with the tests. After the pointing task, participants were brought to the Mansion House, offered a cup of tea and given five minutes to relax. The researcher then went over the distance estimation task and told participants that given the long nature of the questionnaire they were entitled to ask for a break at anytime they felt tired. After completing the task, subjects were given another five minutes break while the researcher set up the board for the model construction task. There was no time limit, although test times were recorded for the distance estimation and model construction tasks. After completing the model, participants were given the mobility, low vision quality of life and a debriefing questionnaire. All three questionnaires were presented verbally and took less then 30 minutes to be completed. The entire testing procedure lasted between two to two-and-a-half hours per subject.

9.4 Direction task (pointing judgement)

Subjects made a total of forty-five pointing judgements from the ten locations on the route using a SILVA NOMAD© digital compass (figure 9.7). They were instructed to place the compass on the palm of their hand and to extend their hand towards the locations called by the researcher. Subjects were previously trained on how to use the compass and were specifically told to keep their hands flat, and turn their bodies instead of making awkward hand movements when pointing to locations that were not situated directly in front of them. After finishing all pointing judgements from a location, subjects were told the name of the place they were heading next. The task began at the starting point (B-Block) and followed the same route as in the guided walk.

Figure 9.7 - SILVA NOMAD

9.4.1 Pointing judgement: Regression

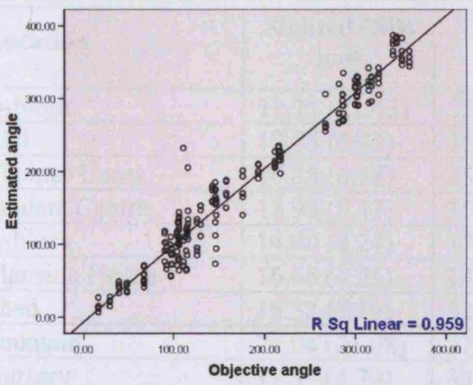
Estimated angles were converted to conform to a circular logic (see chapter 8) so that the difference between the estimated and real values was kept under 180°.[71] The estimated

[71] This is critical for the calculation of error scores and avoids the formation or large residuals in regression analysis.

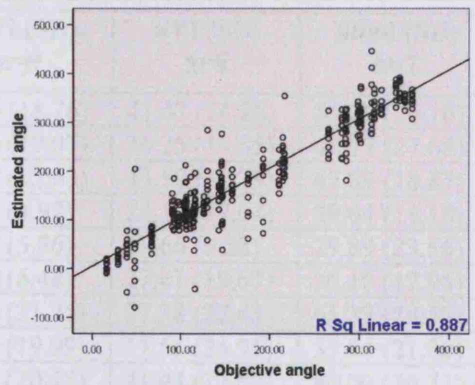
angles were regressed onto the objective angles for the four groups. Results from the regression indicate a positive linear relationship between the two data sets: Sighted Y' = -6.26 + (1.05X); MVI Y' = 4.80 + (1.00X); SVI Y' = 13.07 + (.96X) and blind Y' = 1.76 + (1.00X). Figure 9.8 presents scatter plots of the regression along with the degree of variance (r^2) between the estimated and the real angles for the four groups. Looking at the four scatter plots we notice the sighted group had the highest degree of fit followed by the MVI, SVI and the blind groups (sighted r^2 = 0.96; MVI r^2 = 0.89; SVI r^2 = 0.81; blind r^2 = 0.69).

Figure 9.8 - Regression between estimated and objective angles (RLSB)

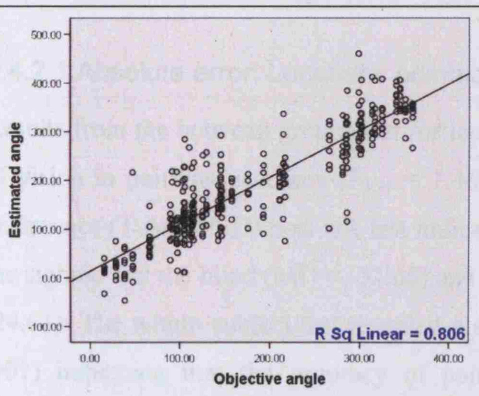
Regression sighted: Y' = -6.26 + (1.05X)



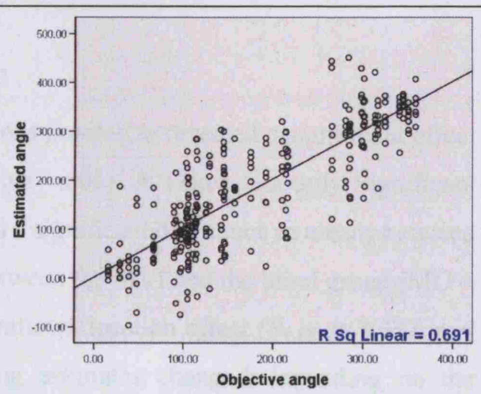
Regression MVI: Y' = 4.80 + (1.00X)



Regression SVI: Y' = 13.07 + (.96X)



Regression blind: Y' = 1.76 + (1.00X)



9.4.2 Pointing judgements: Absolute error (locations)

Repeated measures ANOVAS were conducted in order to further investigate the results from the pointing task. When investigating absolute error it is worth considering the accuracy of pointing judgements in relation to locations that were *pointed to* and locations from where the estimations were made *from*. Here it can be hypothesized that familiar and regularly frequented locations offer the subject a more stable frame of reference to base their estimations. For the RLSB, it was expected that estimations from college locations and important landmarks would be accompanied by lower error scores for all groups but that the sighted and MVI groups would benefit from the perspective afforded by locations on higher ground. Figures 9.9 and 9.10 present the mean absolute error for each of the ten locations that were *pointed to* or *estimated from*. These figures are complemented by tables 9.3 and 9.4 where the mean absolute pointing error and standard deviation for each of these locations are presented.

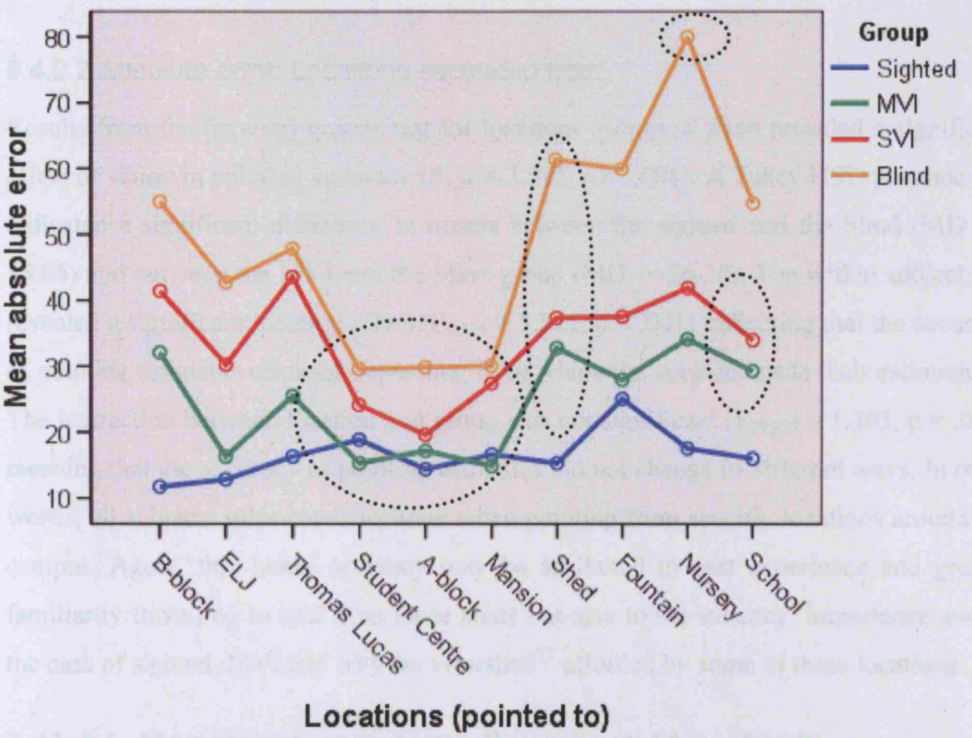
Table 9.3 - Mean absolute error for locations pointed to (RLSB)

Location	Sighted (SD) n=5	MVI (SD) n=9	SVI (SD) n=8	Blind (SD) n=7
B-block	11.75 (11.43)	32.06 (18.76)	41.47 (24.26)	55.00 (26.10)
ELJ	12.85 (6.93)	16.28 (10.07)	30.25 (19.55)	42.77 (27.68)
Thomas Lucas	16.35 (6.28)	25.47 (15.93)	43.59 (32.79)	47.89 (18.87)
Student Centre	18.90 (5.13)	15.31 (4.97)	24.19 (12.64)	29.64 (11.18)
A-block	14.40 (4.24)	17.17 (5.86)	19.66 (9.58)	29.89 (23.56)
Mansion House	16.65 (4.25)	14.89 (6.48)	27.41 (19.67)	30.10 (17.95)
Shed	15.32 (7.19)	32.76 (21.75)	37.38 (22.43)	61.37 (29.52)
Fountain	25.04 (21.08)	27.93 (19.99)	37.55 (24.95)	59.94 (21.00)
Nursery	17.55 (4.79)	34.11 (20.15)	41.94 (27.82)	80.00 (30.71)
Total (10 locations)	16.48 (5.70)	24.52 (10.91)	33.74 (11.45)	49.14 (12.95)

9.4.2.1 Absolute error: Locations pointed to

Results from the between groups test for locations *pointed to* revealed a significant effect of vision in pointing accuracy ($F_{3,25} = 7.469$, $p < .001$). A Tukey Honestly Significant Difference (Tukey HSD) post hoc test indicated a significant difference in means between the sighted and the blind (MD = -32.65) and between the MVI and the blind group (MD = -24.61). The within subject test revealed a significant location effect ($F_{9,225} = 8.337$, $p < .001$) indicating that the accuracy of pointing estimates changed depending on the location. The interaction between location and group was also significant ($F_{27,225} = 1.669$, $p = .024$) meaning that the accuracy of pointing estimates changed in different ways. In other words, subjects were more accurate when *pointing to* specific locations around the campus. This better accuracy when *pointing to* some of the locations may be attributed to past experience and greater familiarity travelling to and from these areas.

Figure 9.9 - Mean absolute angle error for locations pointed to (RLSB)



Several trends can be observed from the graph. Mean absolute error for the blind and the SVI groups is higher for all locations when compared to the sighted and the MVI groups. The lines for the MVI, SVI and blind groups follow a similar trend that it noticeably different from that of the sighted group. This is particularly true for the SVI and the blind groups. The MVI, SVI and blind groups were more accurate in *pointing to* ELJ when compared to the other (B-Block and Thomas Lucas) residential units. This was not the case for the sighted group who was more accurate when *pointing to* B-block (the starting point). Performance for the MVI, SVI and groups is better at locations they are more familiar with and where most of their activities take place. These include the Student Centre (where they eat their meals and congregate in their free time), A-Block (where they attend most of their classes) and the Mansion House (where they use many of the facilities such as the pool, gym, radio-station and assemble for major events). With the exception of the Mansion House, the mean absolute error for the blind group for locations situated in the *mansion area* of the campus is higher then all other locations in the *college area*. The MVI, SVI and blind groups seems to have the most difficulty when *pointing to* Thomas Lucas in the *college area* and the Nursery and Shed in the *mansion area*. The

Nursery and Shed were specifically included in the route given that these locations were known but not usually frequented by the college students.

9.4.2.2 Absolute error: Locations estimated from

Results from the between groups test for locations *estimated from* revealed a significant effect of vision in pointing accuracy ($F_{3,25} = 7.712$, $p < .001$). A Tukey HSD post hoc test indicated a significant difference in means between the sighted and the blind (MD = -35.06) and between the MVI and the blind group (MD = -26.26). The within subject test revealed a significant location effect ($F_{9,225} = 5.311$, $p < .001$) indicating that the accuracy of pointing estimates changed depending from where the subjects made their estimations. The interaction between location and group was not significant ($F_{27,225} = 1.303$, $p = .024$) meaning that the accuracy of pointing estimates did not change in different ways. In other words, all subjects were more accurate when pointing from specific locations around the campus. Again, this better accuracy may be attributed to past experience and greater familiarity travelling to and from these areas but also to the saliency, importance and in the case of sighted, MVI and SVI the viewshed[72] afforded by some of these locations.

Table 9.4 - Mean absolute error for locations estimated from (RLSB)

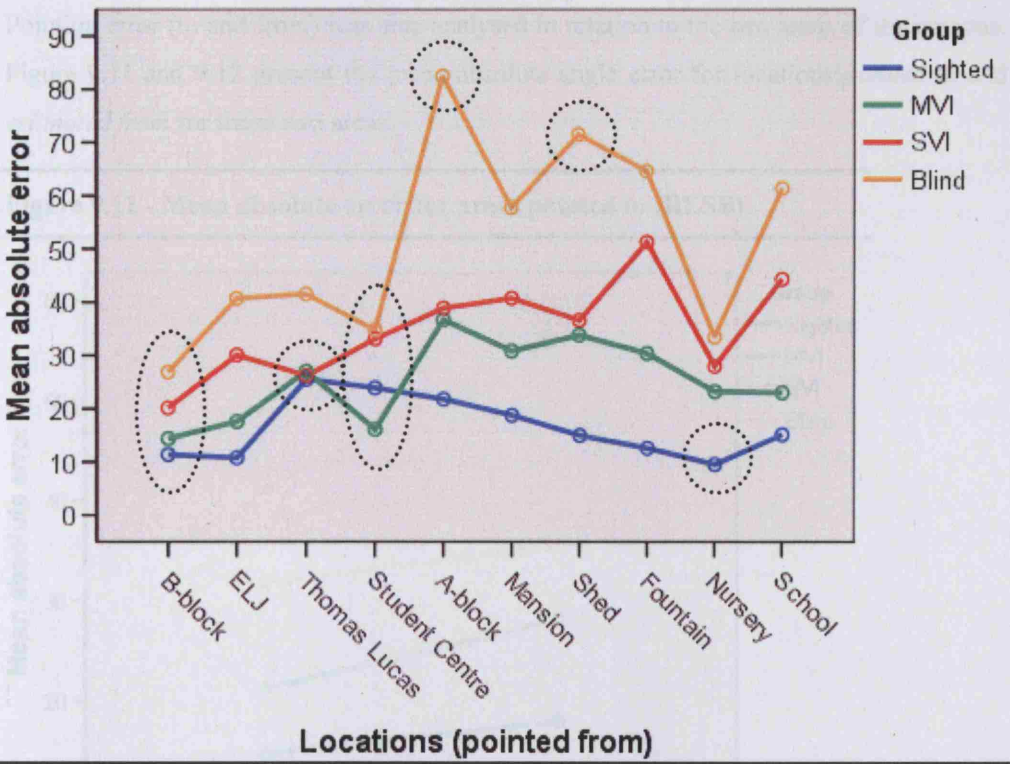
Location	**Sighted (n, SD) n=5**	**MVI (n, SD) n=9**	**SVI (n, SD) n=8**	**Blind (n, SD) n=7**
B-block	11.36 (6.18)	14.33 (9.16)	20.18 (12.65)	26.89 (17.59)
ELJ	10.76 (4.61)	17.53 (6.93)	30.10 (23.20)	40.71 (37.77)
Thomas Lucas	25.48 (5.85)	26.98 (8.09)	26.23 (11.65)	41.54 (12.10)
Student Centre	23.88 (20.33)	16.04 (6.13)	33.13 (40.24)	34.74 (20.70)
A-block	21.76 (10.28)	36.62 (25.21)	38.90 (27.14)	82.46 (38.94)
Mansion	18.72 (7.62)	30.78 (19.64)	40.75 (31.37)	57.77 (24.52)
Shed	14.95 (11.27)	33.75 (25.46)	36.60 (21.24)	71.50 (31.65)
Fountain	12.55 (9.39)	30.31 (17.47)	51.28 (33.40)	64.60 (34.41)
Nursery	9.52 (4.86)	23.18 (16.96)	28.00 (25.60)	33.46 (15.55)
School	15.10 (6.61)	22.94 (19.13)	44.31 (44.32)	61.36 (33.03)
Total (10 locations)	16.40 (5.96)	25.25 (12.10)	34.95 (18.06)	51.50 (13.51)

Several trends can be observed from the graph. All groups were particularly accurate when pointing from the starting point (B-block) and the Student Centre. The Student-Centre acts as an important reference point as students usually meet at this location before walking to classes or other locations around the college. The sighted and MVI groups performed best when pointing from ELJ. This may be to the orientation of this particular

[72] Viewshed: Everything visible from a particular vantage point.

building, which allows for a comprehensive view of the *college area* and some of the buildings in the *mansion area*.

Figure 9.10 - Mean absolute angle error for locations estimated from (RLSB)

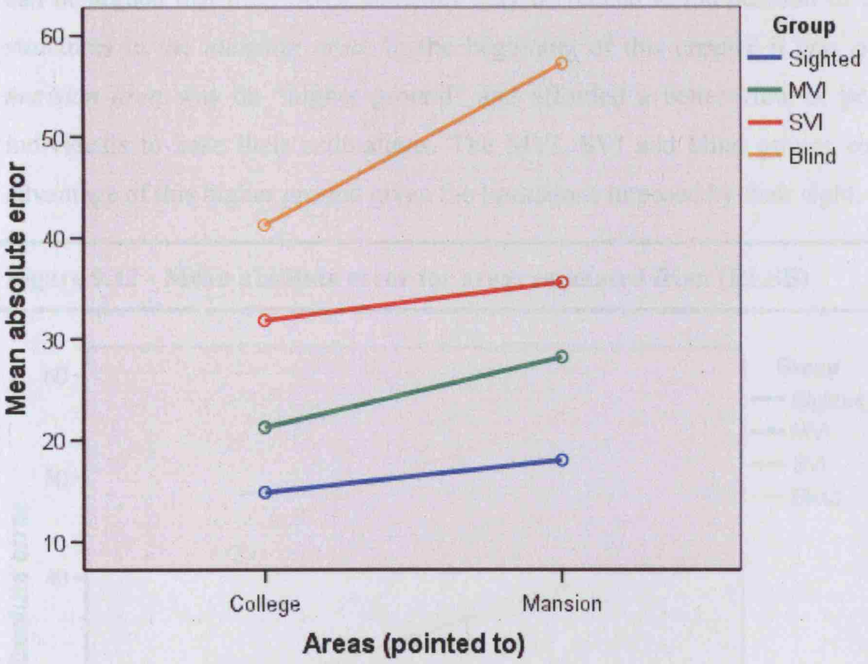


There is very little difference between the means for the sighted (25.48), MVI (26.98) and SVI (26.23) groups when *pointing from* Thomas Lucas. All three groups seem to have particular problems when *pointing from* this location in the *college area*. Again, this may be related to the actual position of the building. Unlike the other residential units, the front door for Thomas Lucas (where locations were *estimated from*) is located on the side of the building and not in the front part facing the courtyard. Subjects were specifically instructed to point to the front door of the buildings. In addition, the blind group had particular problems when *estimating from* A-block (M = 82.46) and this may be related to the route taken to reach this destination. In the *mansion area* of the campus all groups performed best when *estimating from* the Nursery. This is somewhat a strange result given that this is not a much-frequented location. The high accuracy of the sighted and MVI groups however, may be due to the fact that the Nursery is on high ground and allows for a good view of almost all locations except the Shed and Fountain. In the *mansion area* of the campus the SVI and blind group had particular problems when *pointing from* the Shed, the Fountain and the School.

9.4.3 Absolute error: Areas pointed to and estimated from

Pointing error (to and from) was also analysed in relation to the two areas of the campus. Figure 9.11 and 9.12 present the mean absolute angle error for locations *pointed to* and *estimated from* for these two areas.

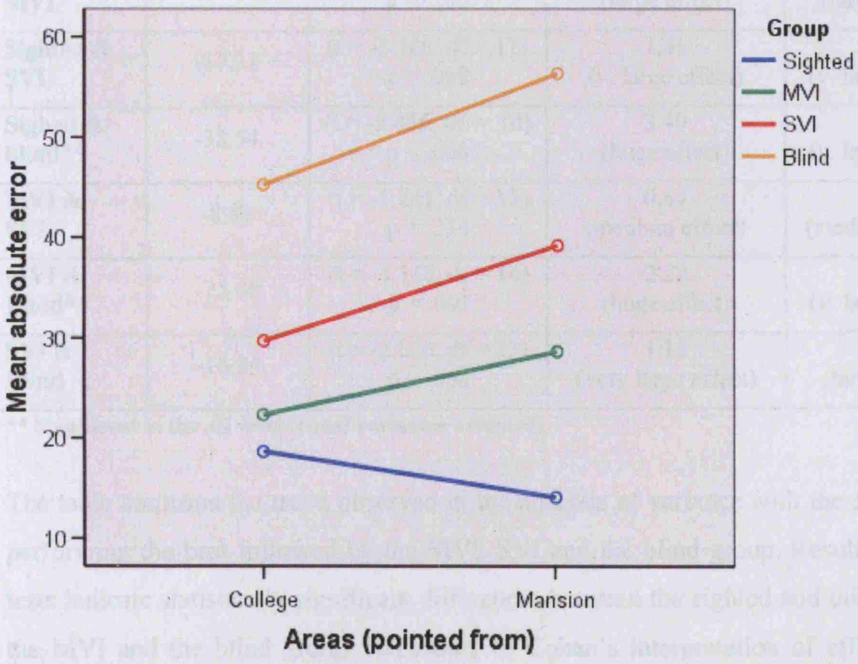
Figure 9.11 - Mean absolute error for areas pointed to (RLSB)



Given that all but one subject that participated in the study either lived or worked in the *college area* of the campus, it was expected that pointing accuracy would be greater in this area. A repeated measures ANOVA revealed significant differences ($F_{3,25} = 7.425$, $p < .001$) between groups when *pointing to* locations in the two different areas of the campus. As expected a Tukey HSD test revealed significant differences between the sighted and the blind group and between the MVI and the blind. More important, results from the within subject test revealed a significant area effect ($F_{1,25} = 15.746$, $p < .001$) indicating that groups were more accurate when *pointing to* locations in the *college area.* The interaction between area and group was not significant (lines in the graph are relatively parallel).

In relation to the areas *estimated from* results from a repeated measures ANOVA revealed significant differences ($F_{3,25} = 7.607$, $p < .001$) between groups when *pointing from* locations in the two areas of the college. Here again a Tukey HSD test showed that differences exist between the sighted and the blind group and between the MVI and the blind group. Results from the within subject test revealed a slight area effect ($F_{1,25} = 4.014$, $p < .056$) and the interaction between area and group was not significant ($F_{3,25} = 1.298$, $p = .297$). Looking at the graph we note that the MVI, SVI, and blind groups were more accurate when *pointing from* the *college area*. This was not the case for the sighted group who were more accurate when *pointing from* locations in the *mansion area*. Here it can be argued that their better accuracy may be related to the position of buildings and structures in the *mansion area*. In the beginning of this chapter it was noted that the *mansion area* was on "higher ground" and afforded a better view or perspective for individuals to base their estimations. The MVI, SVI and blind groups could not take advantage of this higher ground given the limitations imposed by their sight.

Figure 9.12 - Mean absolute error for areas estimated from (RLSB)



9.4.3.1 Effect sizes: Absolute error

In the previous chapter we discussed the importance of verifying for the magnitude of an effect when interpreting data found to be statistically significant. An effect can be statistically significant but of no real consequence if the difference between the means is too small to be important or have any practical application. This is particularly relevant in the pointing task where the objective angle of a location represents a specific point in the building. During the pointing task, subjects were told to concentrate on an exact point for each location. However, it is still possible that many of the estimations were made within the area of the building but outside the exact area they were told to focus on. A certain degree of error (between 5 to 15 degrees) is expected from all participants, as it is more probable that estimates will fall "close to" rather than "precisely on" the exact objective location. Evaluating the mean difference together with the size of an effect can provide further insight on the performance between the different groups. A series of independent sample t-tests were conducted for each pair of groups for locations *pointed to*. These are presented in table 9.5 along with the effect size and the relative percent change.

Table 9.5 - Mean difference & effect size for locations pointed to (RLSB)

Group	Mean difference	Test statistic	Relative size of Cohen's (d)	Relative size of % change
Sighted & MVI	-8.49	(t = -1.517, df = 2) p = .155	0.91 (large effect)	-34 (large decrease)
Sighted & SVI	-17.31	(t = -2.108, df = 11) p = .059	1.31 (v. large effect)	-51 (v. large decrease)
Sighed & blind**	-33.54	(t = -5.436, df = 10) p = .000	3.49 (huge effect)	-67 (v. large decrease)
MVI & SVI	-8.82	(t = -1.241, df = 15) p = .234	0.64 (medium effect)	-26 (medium decrease)
MVI & Blind**	-25.06	(t = -4.118, df = 14) p = .001	2.22 (huge effect)	-50 (v. large decrease)
SVI & Blind	-16.24	(t = -2.026, df = 13) p = .064	1.13 (very large effect)	-32 (large decrease)

**** Significant at the .01 level (equal variances assumed)**

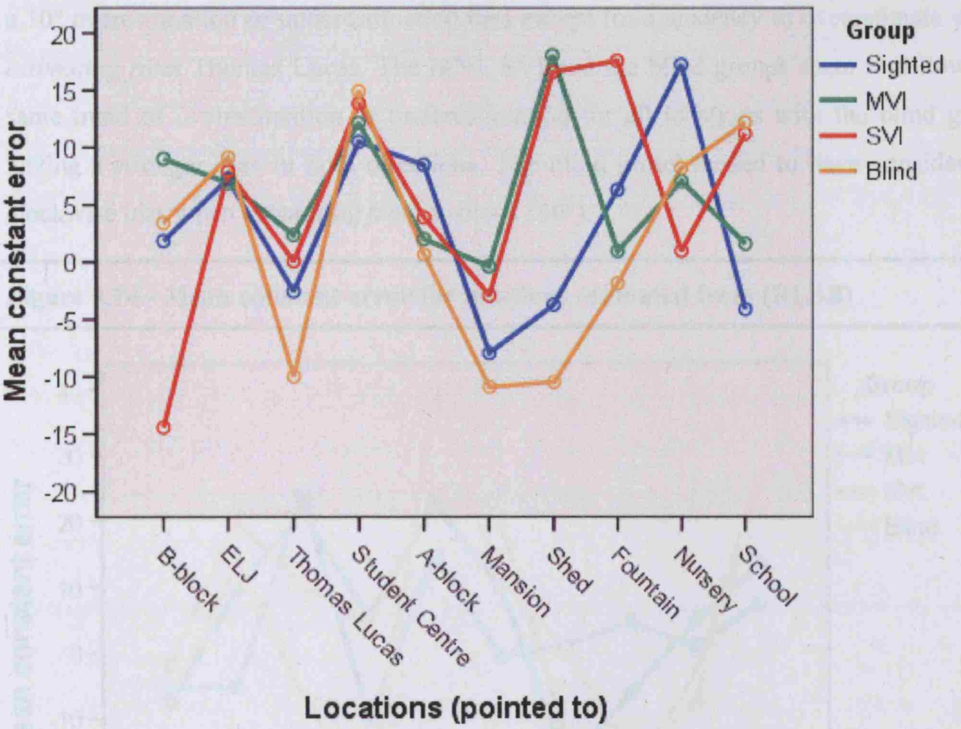
The table confirms the trend observed in the analysis of variance with the sighted group performing the best followed by the MVI, SVI and the blind group. Results from the t-tests indicate statistically significant differences between the sighted and blind group and the MVI and the blind group. According to Cohen's interpretation of effect sizes, the mean difference for these groups is considered "huge." This interpretation is somewhat exaggerated but still applicable for this particular task considering that the mean absolute angle error for the blind (49.14°) is twice as large as the MVI (24.52°) and almost three times larger than the sighted (16.48°). According to Cohen's interpretation, the effect size of the difference between the sighted and the SVI (34.95°) group and the SVI and the blind group, although not statistically significant, is still "very large." This is of considerable importance given that it suggests that although there is linear type of relationship between visual acuity and pointing accuracy, performance in the groups with vision (total or partial) is still substantially superior when compared to that of the blind.

9.4.4 Pointing judgements: Constant error

In perhaps one of the earliest studies in mental representation, Trowbridge (1913) asked participants to make a series of direction estimates from New York City to other distant places. He found that although many of the subjects committed large direction errors most of these deviations were coordinated. In chapter 6 we reviewed several studies that examined the distortions and hierarchical character of mental representations. There it was shown that the direction and relative distances between different locations can be influenced by the saliency of landmarks, the size and number of intersections in a route, the presence of barriers, the level of familiarity and length of residence of subjects. In this section we consider some of these distortions by looking at the constant error (the signed difference between the estimated and the real angles) made by participants during the pointing task. Spray (1986) notes that absolute error can act as a general indicator of accuracy but it does not take into account if the subjects consistently underestimate or overestimate the direction of a location or a set of locations. Here it will be argued that despite differences in accuracy, systematic distortions are evidence of (a) the ability of the blind and visually impaired to represent space and (b) evidence that blind and visually impaired are operating with representations of space that share many characteristics in common with those of the sighted. We are not particularly interested in the magnitude of the bias by the different groups but whether there are any similarities in the pattern of clockwise and counter clockwise distortions.

Figures 9.13 and 9.14 display the mean constant error for the ten locations *pointed to* and *estimated from*. Errors scores higher than zero indicate an overestimation (a clockwise bias) while scores lower than zero indicate an underestimation (a counter clockwise bias). Results from the repeated measures ANOVA for locations pointed to revealed no significant differences between groups ($F_{3,25} = .279$, $p = .840$). In addition, no significant differences were found for the within subjects test ($F_{9,225} = 1.575$, $p = .124$) and for the interaction between locations and group ($F_{27,225} = .800$, $p = .749$). Results from the repeated measures ANOVA for locations *estimated from* also revealed no significant differences between groups ($F_{3,25} = .166$, $p = .918$). The within subject test however, revealed a significant location effect ($F_{3,25} = 4.992$, $p < .001$) indicating that subjects were more prone to commit clockwise or counter clockwise distortions when pointing from specific locations. The interaction between location and group was not significant ($F_{27,225}$ = .881, p = .638).

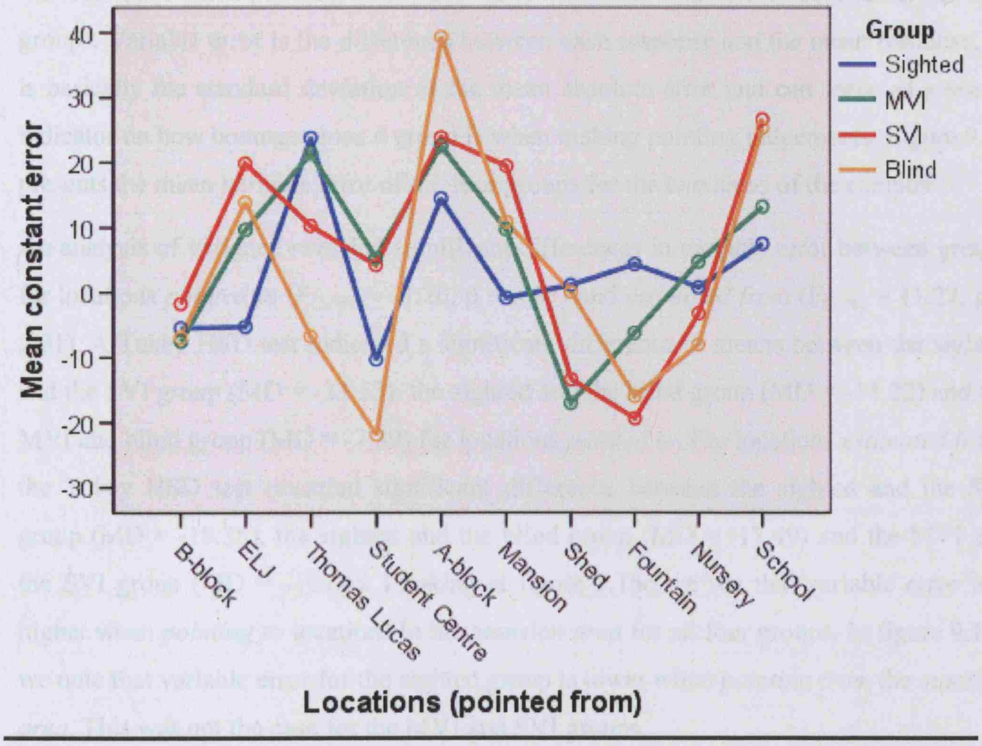
Figure 9.13 - Mean constant error for locations pointed to (RLSB)



Certain patterns can be observed by looking at figures 9.13 and 9.14. When *pointing to* locations the SVI group had a significant counter clockwise bias and tended to underestimate the direction of the starting point (B-block). This group also overestimated (clock wise bias) the locations of the Shed and the Fountain. This group was less biased when *pointing to* Thomas Lucas, A-block and the Nursery. The direction of the Shed was also overestimated by the MVI group which was the least biased of all the groups with mean constant error scores approaching zero for Thomas Lucas, A-Block, Mansion House, Fountain and School. The sighted group tended to underestimate the direction of the Mansion House and overestimate the direction of the Nursery. For the other locations, their mean constant error varied between -5° and 10° with errors approaching zero only when *pointing to* B-block and Thomas Lucas. Contrary to the three other groups the blind groups underestimated the position of Thomas Lucas. This group also underestimated the location of the Mansion House and the Shed. Error scores approached zero only when *pointing to* the A-block and Fountain. For the most part the pointing bias of the blind group followed that of the sighted group. In general constant error for all groups was particularly low.

In relation to the constant error for locations *estimated from*, the sighted group was the least biased when *estimating from* locations in the *mansion area.* Most scores fall within a 10° overestimation or underestimation bias except for a tendency to overestimate when *estimating from* Thomas Lucas. The MVI, SVI and the blind groups seem to follow the same trend of overestimation or underestimation for all locations with the blind group having a stronger bias in both directions. The blind group tended to have considerable clockwise bias when *estimating from* A-block (40°).

Figure 9.14 - Mean constant error for locations estimated from (RLSB)



9.4.4.1 Constant error and the similarity of direction distortions

Following Tversky's (1992) argument that distortions in mental representations are related to errors during the encoding, storage and decoding of spatial information, the two graphs above show that despite a difference in the accuracy of pointing estimation, the blind and visually impaired groups share many of the distortions committed by the sighted group. This trend can be observed for locations *pointed to* or *estimated from* where the pattern of clockwise or counter clockwise bias for the different groups is strikingly similar. Although it is hard to pinpoint an exact reason for these distortions, the fact that they exist is enough evidence that the visually impaired and particularly the blind, are able to mentally represent spatial information during navigation. Moreover, the similarity in distortions across groups also suggests that despite differences in visual acuity and in the case of the blind the total absence of vision, these individuals are using similar organisational concepts in the construction and manipulation of these representations. It remains to be seen if this similarity in distortions will also be present when these individuals are asked to estimate distances and build a model of the campus.

9.4.5 Pointing judgments: Variable error

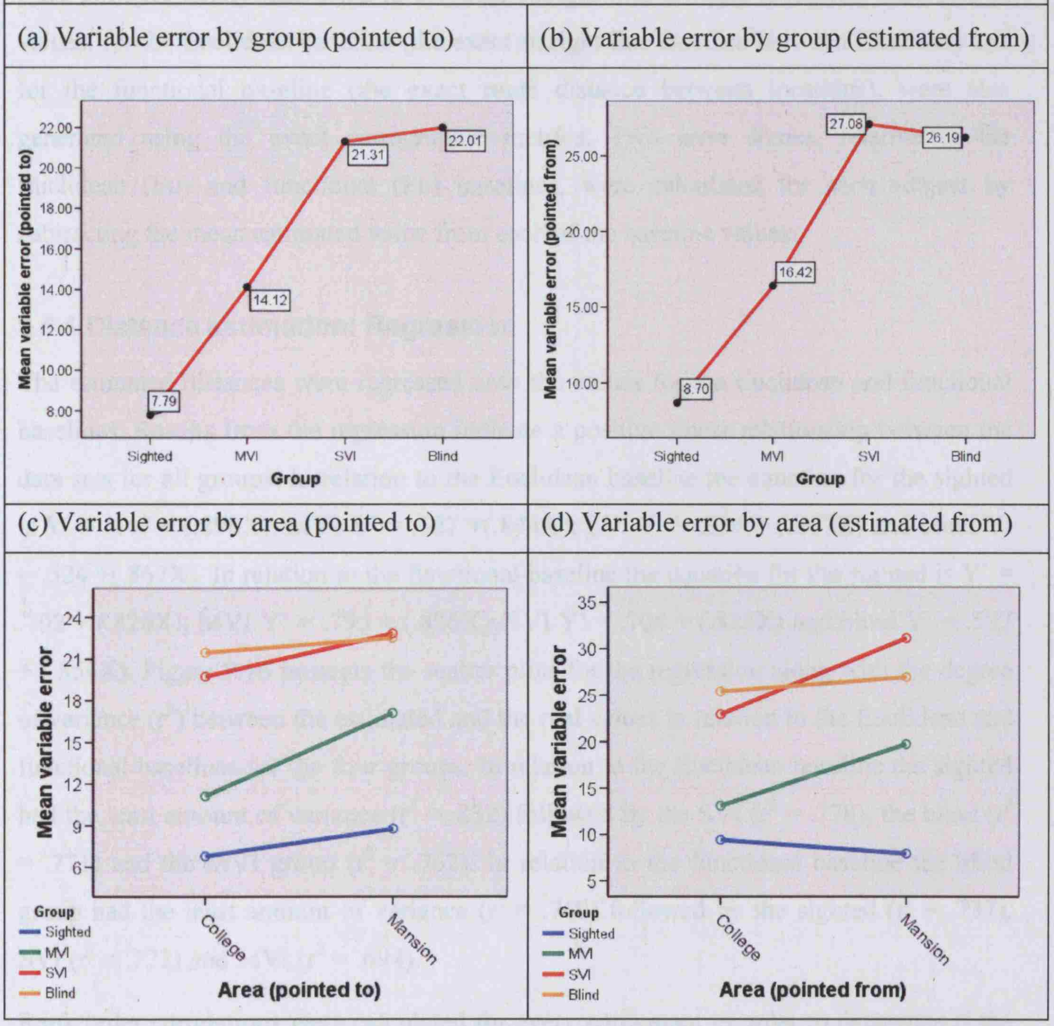
Variable error when pointing *to* or *from* the ten locations was also calculated for the four groups. Variable error is the difference between each response and the mean response. It is basically the standard deviation of the mean absolute error and can serve as a useful indicator on how homogeneous a group is when making pointing judgements. Figure 9.15 presents the mean variable error of the four groups for the two areas of the campus.

An analysis of variance revealed significant differences in variable error between groups for locations *pointed to* ($F_{(3,36)} = 11.20$, $p < .001$) and *estimated from* ($F_{(3,36)} = 11.27$, $p < .001$). A Tukey HSD test indicated a significant difference in means between the sighted and the SVI group (MD = -13.53), the sighted and the blind group (MD = -14.22) and the MVI and blind group (MD = -7.89) for locations *pointed to*. For locations *estimated from*, the Tukey HSD test revealed significant difference between the sighted and the SVI group (MD = -18.38), the sighted and the blind group (MD = -17.49) and the MVI and the SVI group (MD = -10.66). Looking at figure 9.15c we see that variable error was higher when *pointing to* locations in the *mansion area* for all four groups. In figure 9.15d we note that variable error for the sighted group is lower when *pointing from* the *mansion area*. This was not the case for the MVI and SVI groups.

9.4.5.1 Variable error and individual differences

As noted above, variable error serves as an indicator of group homogeneity. In the case of the sighted, the larger visual perspective afforded by the locations in the *mansion area* may have facilitated their pointing judgements to other locations making them a more homogenous group. At the same time, the larger variable error for the MVI and SVI in the *mansion area* may be due to the fact that these groups were classified according to their visual acuity and that some of the individuals in each of the groups were taking advantage (or could take advantage) of their vision when making pointing judgements while other could not. This may be the reason why the blind had a slightly lower variable error that the SVI for locations *estimated from*.

Figure 9.15 - Mean variable error for locations pointed *to* and *from (RLSB)*



9.5 Distance estimation

The distance estimation task took place after all pointing judgements were completed. Knowledge of the relative distance between the ten locations visited during the walk was tested with the method of triadic comparison. A questionnaire of sixty triads was generated using a lambda 4 (λ4) balanced incomplete block design (see chapter 8). For all subjects the questionnaire was verbally administered. For each triad, subjects were asked to estimate which two locations were the closest together and which two were the furthest apart. The pair judged closest was given a score of "0", the pair judged furthest a score of "2" and the remaining pair a score of "1". In a λ4 design each pair of locations is judged in the context of four different triads. The scores of these four judgements are combined to give an overall value ranging between 0 and 8 for each pair of locations. Participants were not specifically instructed to estimate straight-line or route distances. Two sets of values, for the Euclidean baseline (the exact straight line distance between locations) and for the functional baseline (the exact route distance between locations), were also generated using the exact cartographic metrics. Two error scores, relative to the Euclidean (Eu) and functional (Fu) baselines, were calculated for each subject by subtracting the mean estimated value from each of the baseline values.

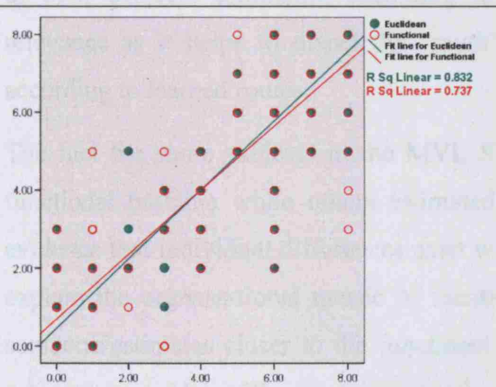
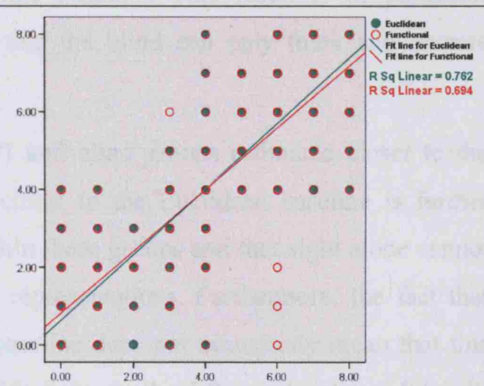
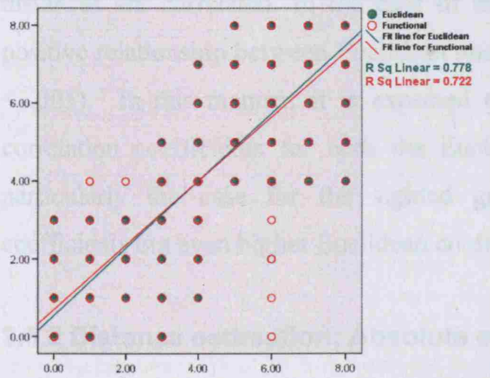
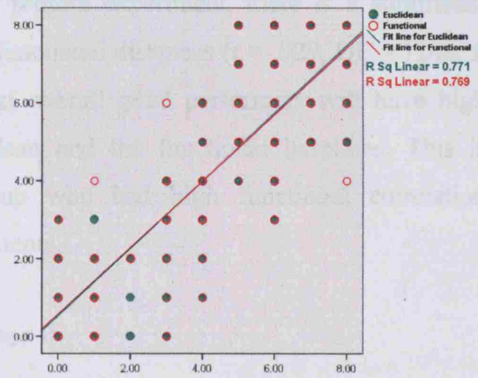
9.5.1 Distance estimation: Regression

The estimated distances were regressed onto the values for the Euclidean and functional baselines. Results from the regression indicate a positive linear relationship between the data sets for all groups. In relation to the Euclidean baseline the equation for the sighted is Y' = .447 + (.890X); MVI Y' = .627 +(.844X); SVI Y' = .534 + (.867X) and blind Y' = .524 +(.867X). In relation to the functional baseline the equation for the sighted is Y' = .702 + (.826X); MVI Y' = .795 + (.826X); SVI Y' = .704 + (.825X) and blind Y' = .577 + (.854X). Figure 9.16 presents the scatter plots for the regression along with the degree of variance (r^2) between the estimated and the real values in relation to the Euclidean and functional baselines for the four groups. In relation to the Euclidean baseline the sighted had the least amount of variance (r^2 = .832) followed by the SVI (r^2 = .778), the blind (r^2 = .771) and the MVI group (r^2 = .762). In relation to the functional baseline the blind group had the least amount of variance (r^2 = .769) followed by the sighted (r^2 = .737), SVI (r^2 = .722) and MVI (r^2 = .694).

Rank order correlations were calculated for every participant in order to determine if the estimated values conforms closer to the Euclidean or functional baselines. This is an important step in the analysis as it looks for possible individual differences that can be confounded in the group regression. Given that individuals were not specifically instructed to judge straight line or route distances, this analysis can also provide important information on the type of representation evoked when estimating distances. Table A2 in the appendix presents the correlation coefficient and significance level for each participant in relation to the Euclidean and functional baseline (higher correlations are marked by a star).

For the sighted group, all distance judgements correlated more highly with the Euclidean baseline. In the case of the MVI and SVI groups, only two subjects in each group tended to make judgements that correlated more highly with the functional baseline. The blind group was equally divided with three subjects estimating closer to the Euclidean baseline and three closer to the functional baseline. One subject in this group had the same correlation coefficient for both baselines.

Figure 9.16 – Regression of estimated distances in relation to (Eu) and (Pu) - RLSB

Sighted (a)	MVI (b)
	
Regression Euclidean: Y' = .447 + (.890X) Regression functional: Y' = .702 + (.826X)	Regression Euclidean: Y' = .627 + (.844X) Regression functional: Y' = .826 + (.795X)
SVI (c)	**Blind (d)**
	
Regression Euclidean: Y' = .534 + (.867X) Regression functional: Y' = .704 + (.825X)	Regression Euclidean: Y' = .524 + (.867X) Regression functional: Y' = .577 + (.854X)

9.5.1.1 Discussion: Distance regression

The fact that the blind group had the least amount of variance in relation to the functional baseline is consistent with past research that has found that the blind have difficulty representing Euclidean concepts (Lockman et al., 1981). The blind group however, had a higher degree of fit than the MVI group in relation to the Euclidean baseline and this may be indicative that vision is not necessary for the understanding and use of Euclidean concepts. These results are at odds with Rieser et al., (1980) where it was found that if subjects were not given any specific instruction as to how to externalize their representation of distances most subjects tended to behave as if they had received route instructions. In this experiment subjects were not given any instructions and their estimates related more closely to the Euclidean baseline. This was the case for the majority of subjects in the sighted, MVI and SVI groups. Even the blind group had 50% of their subjects estimating according to this baseline. This result is of particular relevance as it helps to dispel the "myth" that the blind can only think and operate according to learned routes.

The fact the some subjects in the MVI, SVI and blind groups estimated closer to the functional baseline while others estimated closer to the Euclidean baseline is further evidence that individual differences exist within these groups and that sight alone cannot explain the organizational metric of mental representations. Furthermore, the fact that someone estimates closer to the functional baseline does not necessarily mean that this subject has no idea of the Euclidean relationship between the different locations. It is still possible that a subject may be able to adapt their mode of externalization depending on the type of instruction given. Finally, it should be pointed that Euclidean and functional distances are correlated. In the case of the present experiment, there is a significant positive relationship between Euclidean and functional distances ($r = .929$, $DF = 1248$, $P < .001$). In this manner, it is expected that overall good performers will have high correlation coefficients for both the Euclidean and the functional baselines. This is particularly the case for the sighted group who had high functional correlation coefficients but even higher Euclidean coefficients.

9.5.2 Distance estimation: Absolute error

In order to further investigate the performance of the different groups in the distance estimation task, the ten locations around campus were separated into three areas. This division is similar to the one used in the pointing task:

1. College area: This is a relatively dense area where the minimum distance between locations is 26.46 meters (B-block to ELJ) and the maximum distance is 72.05 meters (B-block to A-block).

2. Mansion area: This is an area with a lower density where the minimum distance between locations is 61.22 (Mansion House to Shed) and the maximum distance is 193.01 meters (Shed to Nursery).

3. Between areas: This area is intended to account for the estimations between locations in the *college* and the *mansion* areas. The minimum distance between locations in the two areas is 143.09 meters (Thomas Lucas to Mansion) and the maximum distance is 288.55 meters (A-block to Nursery).

Table 9.6 presents the distances (in meters) between all the locations in the RLSB campus. Table 9.7 presents the closest neighbours for each location.

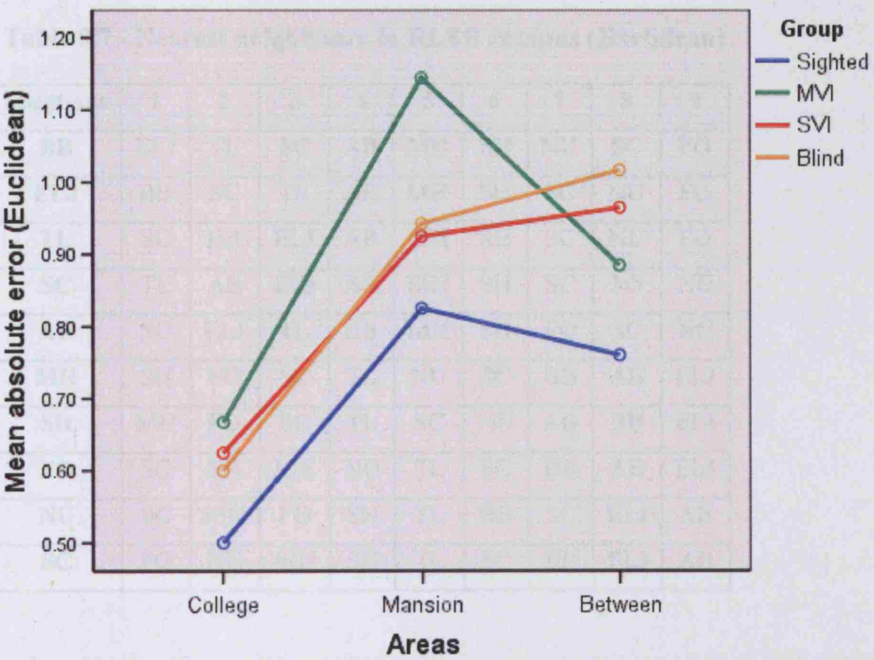
Table 9.6 - Euclidean (Eu) and functional (Fu) distances (RLSB)[73]

Locations	BB	ELJ	TL	SC	AB	MH	SH	FO	NU	SC
BB (Eu)		26.51	40.88	51.42	72.07	176.59	221.38	268.13	246.85	252.59
BB (Fu)		33.78	57.91	66.04	93.35	224.61	291.44	377.26	376.19	344.35
ELJ (Eu)	26.51		43.29	38.22	49.24	186.01	225.17	278.25	268.51	268.29
ELJ (Fu)	33.78		70.51	58.75	59.21	236.70	303.11	388.29	388.61	355.60
TL (Eu)	40.88	43.29		26.29	56.92	142.74	182.99	234.98	233.50	226.85
TL (Fu)	57.91	70.51		35.70	77.15	166.37	232.93	319.27	318.37	286.27
SC (Eu)	51.42	38.22	26.29		30.75	157.86	191.31	249.57	258.07	246.82
SC (Fu)	66.04	58.75	35.70		44.80	179.49	247.19	331.69	331.97	299.87
AB (Eu)	72.07	49.24	56.92	30.75		181.46	208.29	271.76	288.19	273.63
AB (Fu)	93.35	58.21	77.15	44.8		220.06	286.67	371.95	371.36	340.44
MH (Eu)	176.59	186.01	142.74	157.86	181.46		61.03	92.25	147.53	98.55
MH (Fu)	224.61	236.70	166.37	179.49	220.06		116.14	177.99	178.37	145.90
SH (Eu)	221.38	225.17	182.99	191.31	208.29	61.03		79.01	192.71	122.89
SH (Fu)	291.44	303.11	232.93	247.19	286.67	116.14		110.75	269.69	207.89
FO (Eu)	268.13	278.25	234.98	249.57	271.76	92.25	79.01		148.56	65.71
FO (Fu)	377.26	388.29	319.27	331.69	371.95	177.99	110.75		212.94	91.08
NU (Eu)	246.85	268.51	233.50	258.07	288.19	147.53	192.71	148.56		83.12
NU (Fu)	376.19	388.61	318.37	331.97	371.36	178.37	269.69	212.94		195.90
SC (Eu)	252.59	268.29	226.85	246.82	273.63	98.55	122.89	65.71	83.12	
SC (Fu)	344.35	355.60	286.27	299.87	340.44	145.90	207.89	91.08	195.90	

A repeated measures ANOVA was conducted in order to investigate the effect of vision on distance estimation relative to the Euclidean baseline. Figure 9.17 presents the mean absolute error relative to the Euclidean baseline for the four groups broken down by the areas.

[73] Location codes: BB = B-block; ELJ = ELJ; TL = Thomas Lucas; SC = Student Centre; AB = A-block; MH = Mansion House; SH = Shed; FO = Fountain; NU = Nursery, SC = School.

Figure 9.17 - Mean absolute distance error by area (RLSB)



Results from the between groups test did not reveal any significant differences ($F_{3,24}$ = .984, p = .458) in the accuracy of distance estimations with all groups performing at a high level. The sighted were the best performing group but contrary to expectation the MVI performed worst than the SVI and blind groups. The within subject test revealed a significant area effect ($F_{2,48}$ = 18.341, p < .001) indicating that the accuracy of distance estimations varied between areas. All groups were more accurate when estimating distances between locations situated in the *college area*. Similar to angle estimations this better accuracy is probably related to the fact that subjects were more familiar with locations in this area. The interaction between area and groups was not significant ($F_{6,48}$ = .943, p = .474).

Results from the ANOVA point to two different trends: Both the sighted and the MVI were more accurate when estimating distances between locations that they were familiar with (college area) and those between areas (when the actual distance between locations was larger). The performance of the MVI group follows the same trend as the sighted group except that it is accompanied by a 34% increase in error when estimating the distance of locations in the *college area*, 37% for location in the *mansion area* and 17% for locations situated between the two areas. This was not the case for the SVI and blind groups who were more accurate when estimating distances in the *college* and *mansion* areas of the campus.

Table 9.7 - Nearest neighbours in RLSB campus (Euclidean)

Locations	1	2	3	4	5	6	7	8	9
BB	ELJ	TL	SC	AB	MH	SH	NU	SC	FO
ELJ	BB	SC	TL	AB	MH	SH	SC	NU	FO
TL	SC	BB	ELJ	AB	MH	SH	SC	NU	FO
SC	TL	AB	ELJ	BB	MH	SH	SC	FO	NU
AB	SC	ELJ	TL	BB	MH	SH	FO	SC	NU
MH	SH	FO	SC	TL	NU	SC	BB	AB	ELJ
SH	MH	FO	SC	TL	SC	NU	AB	BB	ELJ
FO	SC	SH	MA	NU	TL	SC	BB	AB	ELJ
NU	SC	MH	FO	SH	TL	BB	SC	ELJ	AB
SC	FO	NU	MH	SH	TL	SC	BB	ELJ	AB

9.5.2.1 Effect size: Absolute error

A series of independent sample t-tests were conducted for each pair of groups and these are presented in table 9.8 along with the effect size and the relative size of percent change.

Table 9.8 - Mean difference & effect size for distance estimation in the RLSB

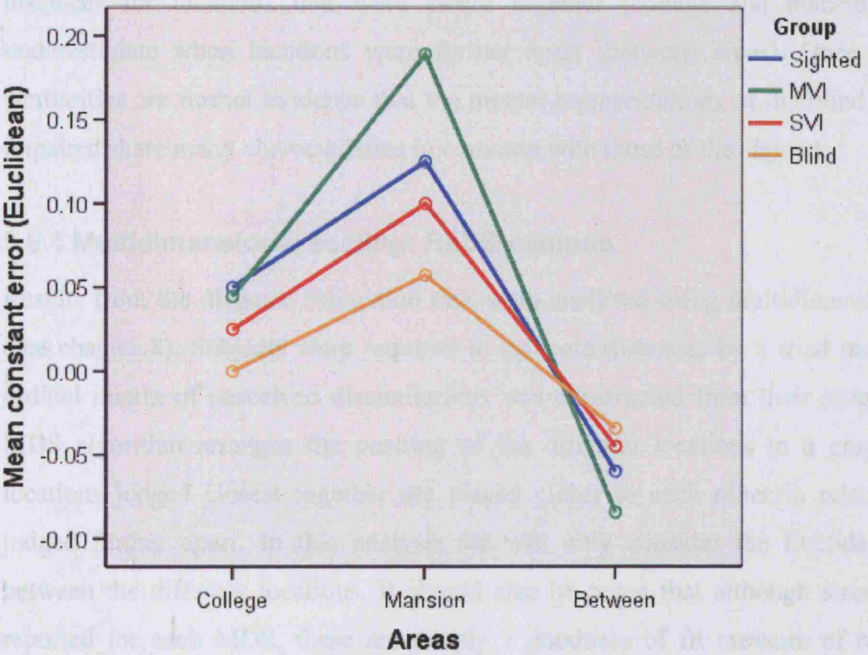
Group	Mean difference	Test statistic	Relative size of Cohen's (d)	Relative size of % change
Sighted & MVI	-.177	(t = -1.09, df = 11) p = .297	.71 (medium effect)	-20 (medium decrease)
Sighted & SVI	-.164	(t = -1.49, df = 10) p = .168	1 (large effect)	-19 (medium decrease)
Sighed & Blind	-.191	(t = -1.41, df = 9) p = .191	.98 (large effect)	-21 (medium decrease)
MVI & SVI	.013	(t = .119, df = 15) p = .907	0.06 (negligible effect)	2 (negligible change)
MVI & Blind	-.014	(t = -.111, df = 14) p = .913)	0.06 (negligible effect)	-2 (negligible change)
SVI & Blind	-.027	(t = -.296, df = 13) p = .772)	0.16 (small effect)	-3 (negligible change)

Looking at the table we learn of an important detail masqueraded by the statistical analysis. While the results from the ANOVA led the conclusion that the MVI was the worst performing group (in relation to the Euclidean baseline), a quick glance at the table confirms that the real difference is between the sighted and the three other groups. In addition, the effect size for the difference between the sighted and SVI group and the sighted and the blind group is higher than that for the sighted and the MVI group although the relative percent change tends to be similar across the three groups. The fact that effect size and the relative percent change for the MVI, SVI and the blind groups are negligible further confirms that these groups performed at a similar level but one that was inferior to the sighted.

9.5.3 Distance estimation: Constant error

Mean constant error was also calculated for the four groups in relation to the three areas in the RLSB campus. Figure 9.18 presents the mean constant error for locations in the three areas of the campus.

Figure 9.18 - Mean constant error by area (RLSB)



A repeated measures ANOVA was conducted and results revealed (within subjects) a significant area effect ($F_{2,48} = 4.282$, $p = .019$). The interaction between areas and group was not significant. In other words, all groups followed a pattern of over and under estimation that varied according to the area. These results are consistent with Klatzky et al. (1995) who compared the ability of blind and sighted subjects to estimate distances in small scale space and found that although there were no significant differences between groups in terms of absolute error, both the blind and the sighted tended to overestimate short distances and underestimate longer distances. This was also the case for Lederman et al. (1985) who found that in the absence of vision, blind and blindfolded sighted subjects tended to increasingly overestimate the length of Euclidean distances as the actual length of the explored path increased. These authors argue that the overestimation may be related to a form of parallel distortion from temporal and haptic inputs. In the absence of vision, time (temporal distance) can be an important variable during estimation but one that can be easily distorted.

9.5.3.1 Constant error and the similarity of distance distortions

Results from the constant error analysis in the distance estimation task further confirm the trend observed in the previous section regarding the similarity of distortions across groups. A quick glance at figure 9.18 above is enough to show that despite differences in accuracy (which were also very small for this task), all groups tended to overestimate distances for locations that were closer together (college and mansion area) and underestimate when locations were further apart (between areas). Once again, these similarities are further evidence that the mental representations of the blind and visually impaired share many characteristics in common with those of the sighted.

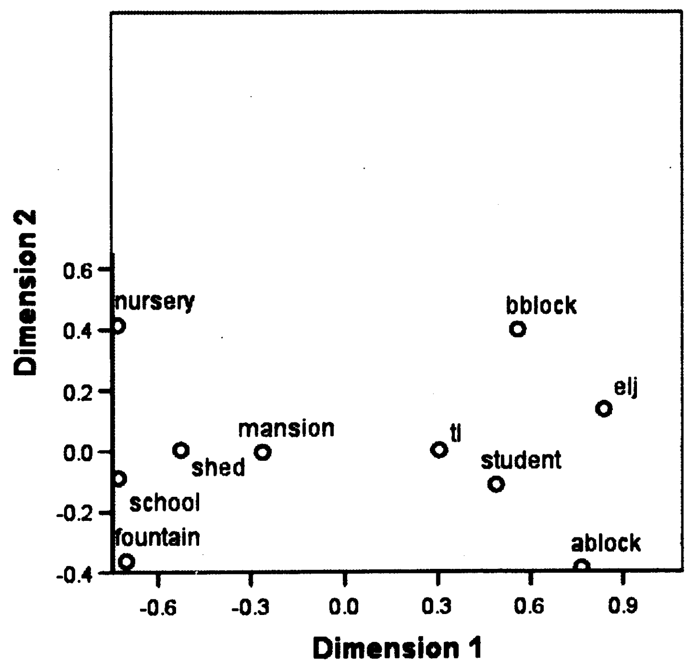
9.5.4 Multidimensional scaling: RLSB campus

Results from the distance estimation task were analyzed using multidimensional scaling (see chapter 8). Subjects were required to estimate distances by a triad method and an ordinal matrix of perceived dissimilarities was constructed from their judgements. The MDS algorithm arranges the position of the different locations in a graph such that locations judged closest together are placed closer to each other in relation to those judged further apart. In this analysis we will only consider the Euclidean distances between the different locations. It should also be noted that although stress values are reported for each MDS, these are simply a goodness of fit measure of how well the representation matches the matrix data. They do not provide any information regarding the degree of fit of the different locations in relation to their absolute position in space.

The different representations were produced with the PROXSCAL algorithm in SPSS and distortions for each of the groups or individual representations were analysed by discussing the tendency subjects had to underestimate or overestimate different pairs or sets of locations. This is essentially a cluster type of analysis where the relative position of the different locations is compared to those from a representation derived from the Euclidean baseline.

Results from the distance estimation task showed that irrespective of their visual conditions subjects had a tendency to underestimate the distance between locations that were far from each other and overestimate distances when locations were closer together. This tendency was observed by comparing the constant error for each group when *pointing to* locations in the two areas of the RLSB. The MDS analysis follows the same rationale except that it looks in detail at the over and underestimation for locations within each area. Cross-area distortions are also considered but to a lesser extent. Figure 9.19 is a representation of the different locations in the RLSB campus derived from the Euclidean baseline and will serve as a guide in the discussion of clusters and distortions. Figure 9.20 presents the MDS output for the four groups as well as the different types of distortions (red for underestimation, blue for overestimation and yellow for overlaps). Figures 9.21 present examples of distortions for specific individuals in each group.

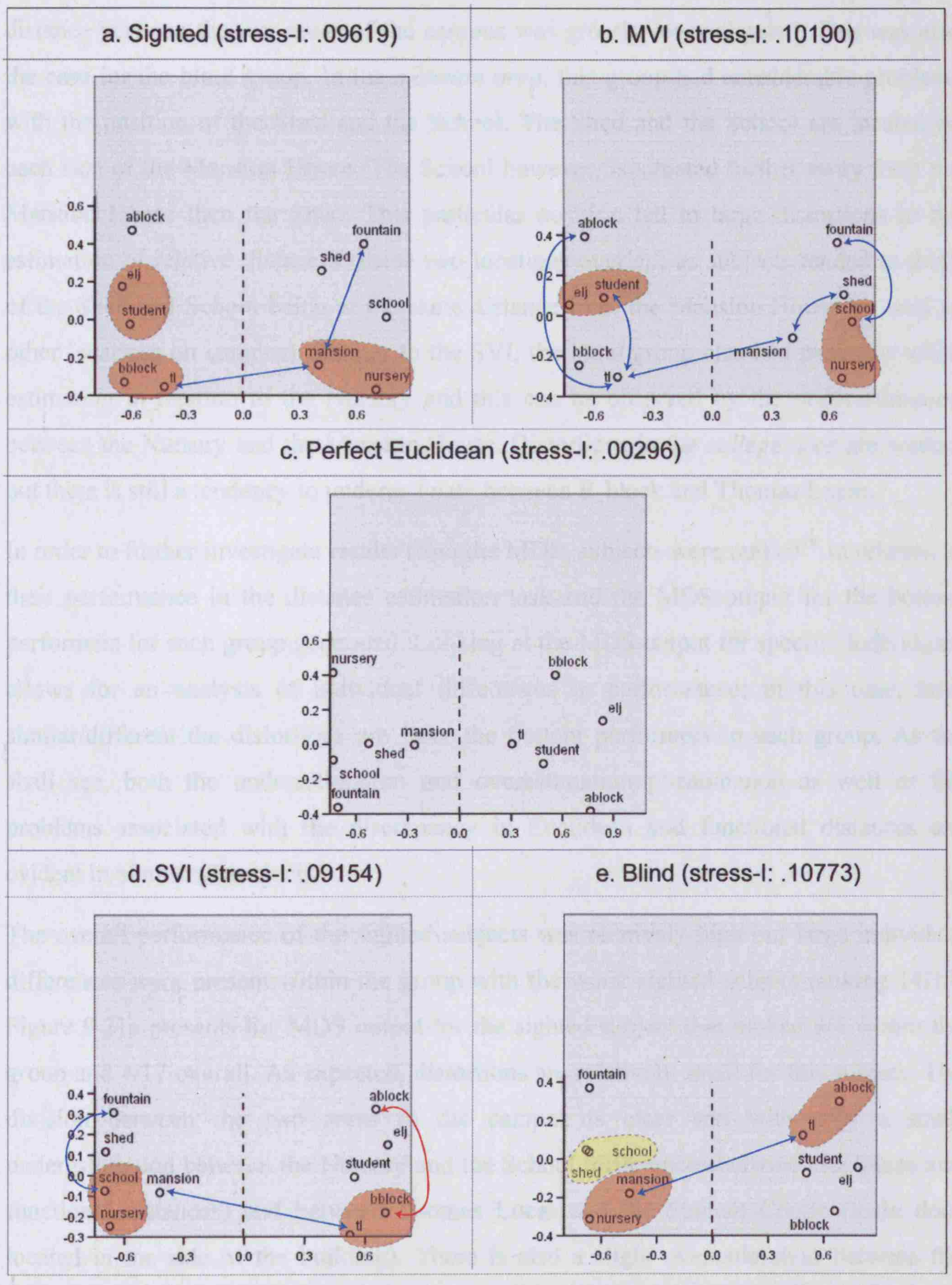
Figure 9.19 - MDS for Euclidean baseline (Stress-I: .00296)



Looking at the MDS for the sighted group (figure 9.20a) one notices that there is a clear division between the two areas (black dotted line) in the campus although there is a slight overestimation (blue arrow) of the distance between these two areas. In relation to locations in the *college area*, the group tended to underestimate the distance between ELJ and the Student Centre and between B-block and Thomas Lucas. In the *mansion area*, individuals underestimated the location between the Nursery and the Mansion House and overestimated the distance between the Mansion House and the Fountain. This overestimation is probably related to the difference between the Euclidean and the functional distance between these two locations as experienced when individuals walked the route. Although the Fountain is located directly behind the Mansion House individuals were forced to walk around this building (the largest building on campus) to get to it.

The MVI group (figure 9.20b) had the lowest performance in the distance estimation task and this can be observed from the type of distortions committed. Similar to the sighted group, individuals in this group had a clear idea about the division between the locations in the two areas of the campus although there was tendency to overestimate the gap between areas. In the *college area*, the position of Thomas Lucas caused particular problems. This is evident from the overestimation between Thomas Lucas and the Student Centre and Thomas Lucas and A-block. Subjects also tended to underestimate the distance between the Student Centre and ELJ. Both these distortions may be related to the fact that subjects were asked to estimate distances in relation to the front/main door of the building, which was located on the side of the building. In the *mansion area* subjects in this group tended to overestimate the distance between Mansion and the Shed and the Mansion and the School. Again this may be related to the difference between the Euclidean and the functional distances between these locations. A slight overestimation also exists in relation to the School and the Fountain. In addition, subjects in this group tended to underestimate the distance between the School and the Nursery. In this case, the real Euclidean distance between these locations was considerably shorter than the functional distance (see table 9.6). Together with the results form the sighted group, we begin to notice a trend in distortions whereby it can be said that errors are a factor of the discrepancy between the Euclidean and functional distances.

Figure 9.20 - MDS output for 4 groups (RLSB campus)



● & ⇒ = Underestimate ● & ⇒ = Overestimate ● = Overlap

The SVI and the blind groups (figures 9.20d & 9.20e) tended to commit similar types of distortions. In the SVI group subjects tended to underestimate the distance between the School and the Nursery and overestimate the distance between the Fountain and the

School. In the *college area* subjects in this group tended to underestimate the distance between A-block and B-block and between B-block and Thomas Lucas. Finally, the distance between the two areas of the campus was grossly overestimated. This was also the case for the blind group. In the *mansion area,* this group had considerable problems with the position of the Shed and the School. The Shed and the School are located on each side of the Mansion House. The School however, is situated further away from the Mansion House then the Shed. This particular position led to large distortions in the estimation of relative distances (these two locations overlap) as subjects tended to think of the Shed and School being at the same distance from the Mansion House (as well as other locations on campus). Similar to the SVI, the blind group also had problems when estimating in relation to the Nursery and this can be observed by the underestimation between the Nursery and the Mansion House. Distortions in the *college area* are weaker but there is still a tendency to underestimate between B-block and Thomas Lucas.

In order to further investigate results from the MDS, subjects were ranked[74] in relation to their performance in the distance estimation task and the MDS output for the bottom performers for each group generated. Looking at the MDS output for specific individuals allows for an analysis of individual differences in performance; in this case, how similar/different the distortions are from the bottom performers in each group. As we shall see, both the underestimation and overestimation phenomenon as well as the problems associated with the discrepancy in Euclidean and functional distances are evident in almost all subjects.

The overall performance of the sighted subjects was relatively high but large individual differences were present within the group with the worst sighted subject ranking 14/17. Figure 9.21a presents the MDS output for the sighted subject that ranked 3/4 within the group and 4/17 overall. As expected, distortions are relatively small for this subject. The division between the two areas of the campus is clear and with only a small underestimation between the Nursery and the School (differences between Euclidean and functional distances) and between Thomas Lucas and the Student Centre (main door located in the side of the building). There is also a slight overestimation between the School and the Fountain.

Figure 9.21b presents the MDS output for the worst performer in the sighted group. Looking at the figure we note that the subject tended to underestimate distances within the clusters but overestimate distances between clusters. On the college side of the campus, the subject underestimated the distance between Thomas Lucas and B-block and between the Student Centre and ELJ. The subject overestimated the location between the Thomas Lucas and A-block, Thomas Lucas and Student Centre and Student Centre and A-block. In the *mansion area*, the subject underestimated the distance of the Nursery in relation to the Mansion and the School and overestimated the distance between the School and the Fountain and Mansion and the Shed. Finally, although it is clear that the subject could separate between the two areas in the campus, the distance between these two areas was grossly overestimated.

The MVI group was the worst performing group and bottom performers rank 15/17 and 17/17. In both cases the subjects were able to separate between the two areas of the campus but tended to grossly overestimate the distance between these areas. Figure 9.21c shows the MDS output for the subject that ranked 15/17. Here we note two clusters of underestimation and it can be argued that the subject was able to estimate distances when asked to compare between areas but had considerable problems estimating distances between locations within the same area. Errors are more pronounced when we look at the two overlaps present in the *college area*. Here it is possible that the subject separated between the starting point (B-block) and the other four buildings by clustering the buildings on the north (Thomas Lucas & Student Centre) and those on south (A-block and ELJ).

Figure 9.21d presents the MDS output for the overall worst performer. Looking at the graph, one notices that this subject also tended to overestimate distances between the two areas of the campus. More interesting is the isolation of Fountain in the *mansion area* and of A-block in the *college area*. The subject also tended to overestimate the distance between Thomas Lucas and the Student Centre. In addition the subject tended to underestimate the distance between B-block and ELJ on the *college area* and the Mansion and the School, the Mansion and Nursery and the School and Nursery in the *mansion area*. Although the stress is low the representation is too distorted in relation to the Euclidean baseline for any form of pattern to be detected. Considering this was the worst performer, it is safe to say that this subject either had considerable problems with the distance estimation task or had a very distorted mental representation of the RLSB campus. The fact that this subject did not perform well in the other tasks (20/28 pointing

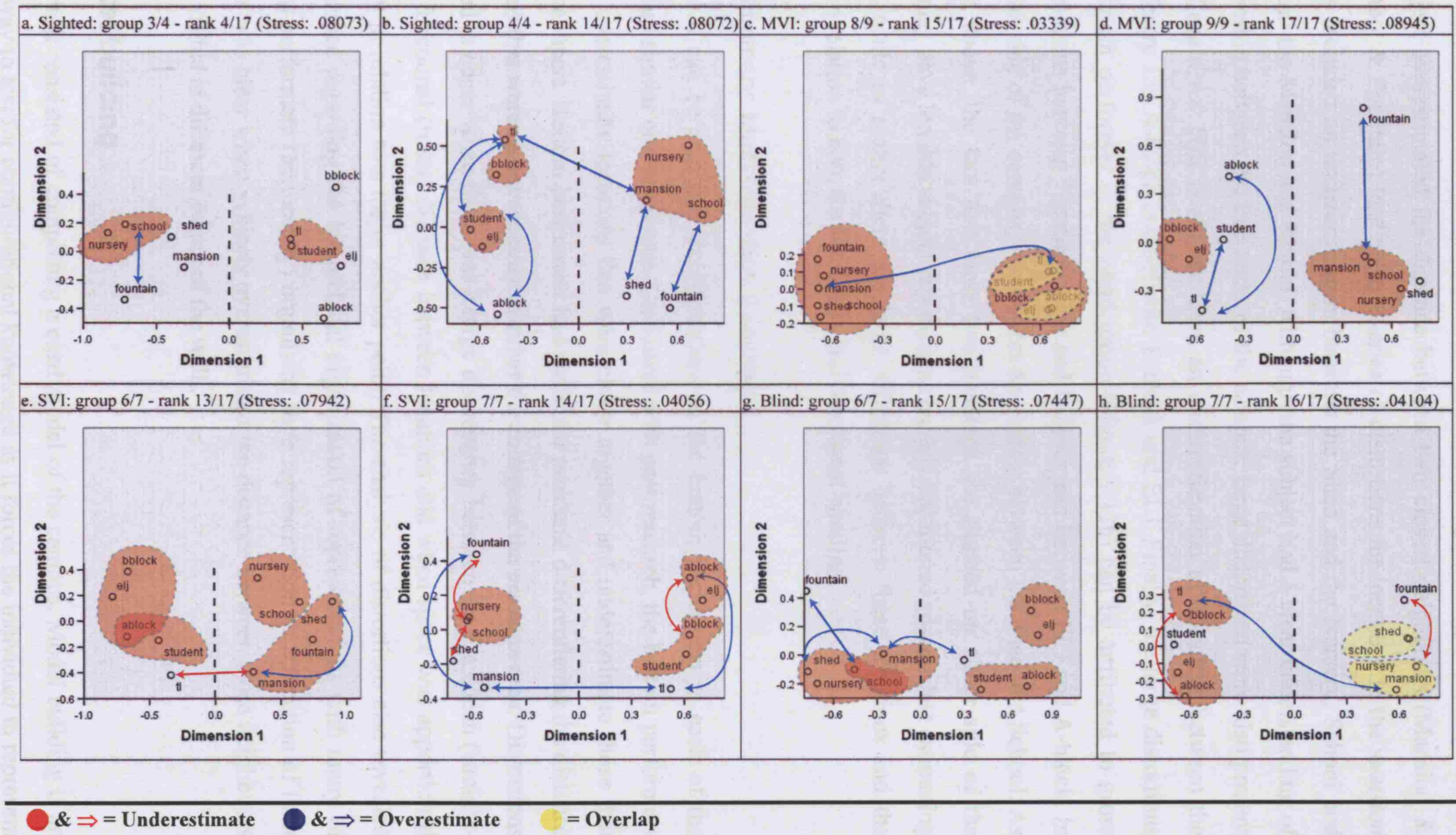
[74] Ties were allowed for the ranking - Although 29 subjects participated in the experiment subjects were ranked out of seventeen with lowest rank attributed to the highest performer. The overall rank for the subject will be presented along with the rank in relation to the group.

test and 29/29 model task) suggests that this subject had particular problems representing the RLSB campus.

In figure 9.21e we notice that the SVI subject tended to underestimate the distance between the different locations and this was probably the result of a distorted representation regarding the position of A-block in the *college area* and the Fountain in the *mansion area.* In the *college area,* B-block and ELJ are bunched together and positioned at a closer distance to A-block. This is also the case for the Student Centre. Similar to figure 9.21c the subject seems to have used A-block as the centre-point in the representation and computed the distances as a function of the order the locations were visited during the walk. In the *mansion area* we notice three different clusters where the distance between different pairs of locations was underestimated. This is the case for the Nursery and the School, the Fountain and Mansion and the Fountain and the Shed. Again, these underestimations may be related to the discrepancy between functional and Euclidean distances. In all three cases, the Euclidean distance being considerably shorter (see table 9.6). Finally we notice that the subject also overestimated the distance between the Mansion and the Shed. A quick glance at tables 9.6 and 9.7 tell us that not only there is a large discrepancy between the Euclidean and functional distances between these two locations but that the Shed is the closest neighbour to the Mansion. Following the rationale from the previous analysis, it was expected that in such a situation the subject would underestimate the distance between these two locations. However, the gross overestimation is probably related to the fact that although these are closest neighbours the Shed was the last location visited in the circuit. It seems that distortions result not only from the discrepancies between functional and Euclidean distances but are also influenced by the order locations are visited.

A similar trend is also found in figure 9.21f where the bottom performer from the SVI group grossly overestimated the distance between the Fountain and the Mansion. In this case the Fountain was the second closest neighbour to the Mansion House. A series of other distortions occur as the result of an overlap between the Nursery and the School. Here again this error may be attributed to a discrepancy between the Euclidean and functional distance between these locations. In the *college area* we notice that similar to figure 9.21c, the subject used the starting point as the centre-point in the representation and separated the area into two clusters relative to their cardinal orientation. This resulted in a gross overestimation between A-block and Thomas Lucas and underestimations between A-block and ELJ and B-block and the Student Centre.

Figure 9.21 - MDS output for bottom performers (RLSB)



The distortions observed in the MDS output for the two bottom performers in the blind group follow a similar trend to the one observed above. In figure 9.21g, we notice that the blind subject overestimated the distance between two closest neighbours (Mansion & Shed; School & Fountain) leading to a series of distortions for locations in the *mansion area*. This included an underestimation between the Shed and the Nursery, School and Nursery and the Mansion and School. Although the subject had a clear understanding of the relationship between the two areas of the campus, large distortions were also present in the *college area*. This is evident from an underestimation of distances between the Student Centre and A-block and between B-block and ELJ. Finally, the large distortions for the bottom performer in the blind group (Figure 9.13h) can be attributed to gross underestimations between Thomas Lucas and B-block and between ELJ and A-block. In the *mansion* side of the campus, one notices an overlap between the Shed and School. As mentioned above, the fact that these two locations are situated on either side of the Mansion may have led this subject represent an equally partitioned space when estimating distances, while in reality there are large difference between these locations and the Mansion in relation to both the Euclidean and functional baseline.

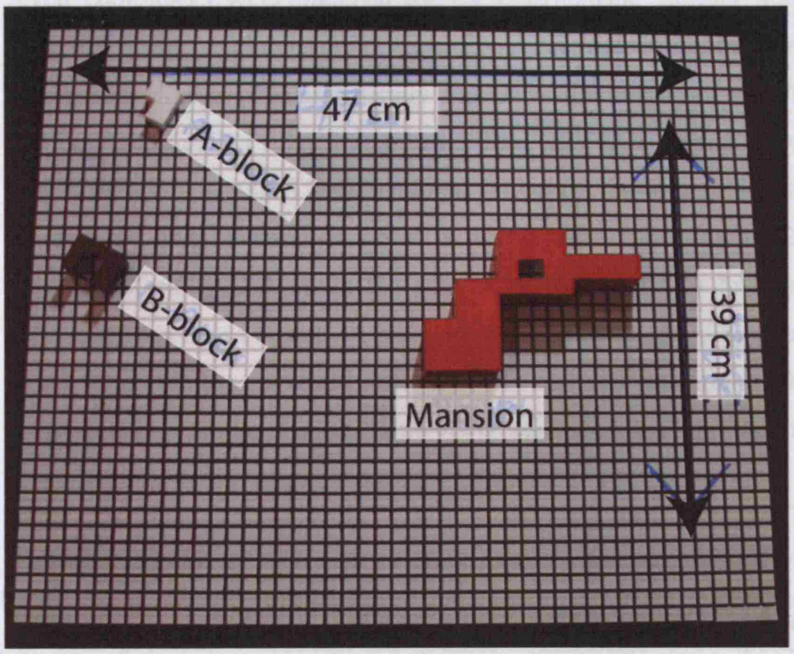
9.5.4.1 Summary: Multidimensional scaling

In general it can be said that the distortions of the bottom performers in each of the groups share similar characteristics. Consistent with past research, the bottom performers tended to overestimate locations that were closer together and underestimate those that were further apart. Bottom performers had particular problems differentiating the distance of locations that were closer together in either the *college* of the *mansion* area. Distortions also tended to occur when there was a large discrepancy between the Euclidean (straight-line) and functional (route) distance between locations and when space was apportioned incorrectly in relation to a major anchor point. The analysis of distortions also revealed some evidence regarding the hierarchical organization of representations with many of the bottom performers (temporally) organizing their representation as a function of their walk. This was clear when subjects overestimated the distance between close neighbours that were visited at different points of the walk.

9.6 Model building

The next task consisted of completing a cued model of the campus. Model building is an effective way to test for configurational knowledge as it forces the individual to represent the allocentric relationships between different elements in the environment. It should be noted however, that the constructed model is not necessarily equivalent to configurational knowledge as a model can be constructed based on the route knowledge between the different locations.

Figure 9.22 - Cued model template of the RLSB campus



Ten three-dimensional cardboard pieces representing a scaled version of the locations in the RLSB campus were created. Three of these (B-block, A-block and Mansion House) were fixed in their real cartographic locations on a gridded (1cm X 1cm) magnetic white board (47 cm X 39 cm). Students were asked to position the remaining seven pieces in relation to the fixed ones. They were told to ask for the pieces (in no particular order), which were handed to them by the investigator who also indicated the front door of the buildings. There was no time limit although the students were told that they would be timed. They were also told that they could position all locations first and later move them. The board was not fixed and the subjects could change its orientation during the task. Figure 9.22 presents the white board with the three fixed locations in their real cartographic position.

9.6.1 Bidimensional regression

The position of the estimated locations was calculated using a coordinate type system (x, y) provided by the actual margins of the white board, the bottom left grid-square representing (x1, y1). After the subject placed all pieces, the investigator marked the front door of each estimated location with a marker and calculated the coordinates. A total of seven coordinates were obtained for each participant. Results from the model were analysed using bidimensional regression. As noted in the previous chapter a bidimensional regression statistically calculates the degree of association (r^2) between two configurations of related coordinate data. Like in a normal regression, the r^2 value ranges from 0 to 1, with 1 representing a perfect fit. It also measures the fidelity in terms of scale (φ), angle (θ) and horizontal & vertical translation (α1 & α2) between where a place is in reality and where the subjects thinks it is. Results from a bidimensional regression can also be used to calculate a distortion index (DI), which is basically an index (%) of the overall distortion of the representation after all systematic transformations are performed. Table 9.9 presents the results for the model task (r^2 & DI) along with the minimum and maximum DI score for each group.

Table 9.9 - Bidimensional regression (r^2) and distortion index (DI) for RLSB campus

Group (n)	r^2 (SD)	Distortion index (SD)	Min (DI)	Max (DI)
Sighted (5)	.98 (SD = .01)	15.40 (3.64)	10.74	20.05
MVI (9)	.68 (SD = .36)	48.55 (30.72)	14.51	94.85
SVI (8)	.78 (SD = .16)	42.78 (18.61)	16.45	70.82
Blind (7)	.56 (SD = .27)	62.22 (24.41)	22.75	83.65

Given the large variation within the blind and visually impaired groups (highlighted in red) it was no surprise that Levene's test of homogeneity of variance was violated (.015). In order to make use of the data, the original distortion index values were converted to logarithms. A logarithmic conversion can normalize the data and this is particularly the case when the variance increases with the mean (as is the case for the Sighted, SVI and blind groups). Converting data to logarithms essentially squeezes all data points closer together and can correct for the assumption in an ANOVA where the variance is the same across all the data. After the logarithmic conversion, Levene's test for the homogeneity of variance was not violated (.246).

Results from a one-way ANOVA revealed a significant difference between groups in the in the accuracy of the model ($F_{3,25}$ = 6.396, p = .002). A Tukey HSD test revealed differences between the sighted and the MVI (p = .013), the sighted and SVI (p = .022) and the sighted and the blind (p = .001). Effect sizes were also calculated using the logarithmic transformed distortion index and these are presented in Table 9.10. These results confirm those from the ANOVA regarding the large difference between groups in the ability to accurately construct a model of a well-known environment. The sighted group had the least amount of distortion followed by the SVI, MVI and the blind group. This is an interesting result considering that it was expected that distortions would increase in relation to visual acuity (as was the case with the pointing task). In other words, that the MVI would outperform the SVI group.

Table 9.10 - Effect size for distortion index (DI) in model for the RLSB campus

Group	Mean difference	Test statistic	Relative size of Cohen's (d)	Relative size of % change
Sighted & MVI*	-.43	(t = -3.212, df = 12) p = .007	1.93 (huge effect)	-27 (medium decrease)
Sighted & SVI*	-.41	(t = -3.771, df = 11) p = .003	2.34 (huge effect)	-26 (medium decrease)
Sighed & blind**	-.58	(t = -5.386, df = 10) p < .001	3.45 (huge effect)	-33 (large decrease)
MVI & SVI	.02	(t = .152, df = 15) p = .881	.08 (negligible effect)	1 (negligible change)
MVI & Blind	.13	(t = -1.143, df = 14) p = .272	.62 (medium effect)	-8 (small decrease)
SVI & Blind	-.17	(t = -1.455, df = 13) p = .169	.81 (large effect)	-10 (small decrease)

* significant .05 ** significant .01

9.6.1.1 Vision, motor ability and model construction time

The higher performance of the SVI group may be related to this group's training in dealing simultaneously with visual and tactual information. Although sight seems to be an important factor in the cognition of space it cannot be denied that model construction involves some form of motor ability. Given their lower visual acuity, it can be argued that individuals in the SVI group rely more often in tactual cues to guide their actions and that this may have worked to their advantage when asked to construct the model. However, it should be noted that the difference in the DI between these two groups is neither statistically significant nor carries a large effect size. More interesting are the large individual differences that exist within the MVI, SVI and blind groups as noted by the large variation in the minimum and maximum distortion index scores. Finally, there was no significant difference between groups in the time taken to construct the model although time did vary as a function of visual acuity with the sighted constructing the model in the shortest time (230s) followed by the MVI (347s), SVI (440s) and the blind group (521s). The relationship between time taken to construct the model and overall performance was also not significant.

9.6.1.2 Bidimensional regression: Distortions and individual differences

The degree of fit in a data set for two or more groups (or individual subjects) may be similar but this does not necessarily mean that these two groups have committed the same type(s) of distortion. Results from the bidimensional regression also allow us to look at specific types of distortions in terms of translation ($\alpha 1$ & $\alpha 2$), scale and angle (θ) displacements. Table 9.11 presents a summary of the distortions including the effect size for each of the groups.

Table 9.11 - Mean difference and effect size for distortions in models (RLSB)

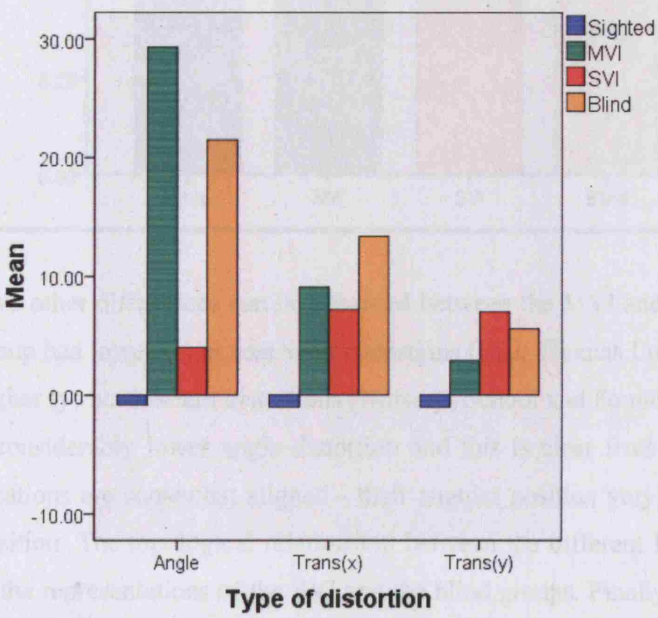
Group	Alpha 1 (x) (d)	Alpha 2 (y) (d)	Angle (d)	Scale (d)
Sighted vs. MVI	-10.07* 1.23 (v. large)	-3.96 0.59 (medium)	-30.07 0.7(medium)	.22 0.88 (large)
Sighted vs. SVI	-8.13 0.82 (large effect)	-8.06 1.04 (large effect)	-4.77 0.16 (small)	.15* 1.32 (v. large)
Sighed vs. Blind	-14.32* 1.21 (v. large)	-6.60* 1.33 (v. large)	-22.30 0.72 (medium)	.44** 2.46 (huge)
MVI vs. SVI	1.94 0.17 (small)	-4.10 0.45 (medium)	25.29 0.54 (medium)	-.07 0.28 (small)
MVI vs. Blind	-4.25 0.36 (small)	-2.64 0.35 (small)	7.77 0.16 (small)	.22 0.79 (large)
SVI vs. Blind	-6.18 0.48 (medium)	1.46 017 (small)	-17.53 0.45 (medium)	.29* 1.54 (huge)

***Significant .05 level **Significant at the .01 (equal variances not assumed)**

Figures 9.23 and 9.24 present the distortions for the four groups. Looking at the graph in figure 9.23 one notices that the sighted group had the least amount of distortion with values approximating zero for translations and angle. Distortions for the blind and MVI group follow almost the same pattern with large east/west (translation x) and angle distortions, the blind committing higher translation errors but lower angle distortions. Distortions for the SVI group are similar in terms of x and y translation. Similar to the sighted, this group's angle distortion was considerably smaller. Distortions for all groups are smaller in the *college area* when compared to the *mansion area* of the campus. In figure 9.24 we notice that the MVI (0.8), SVI (0.9) and blind (0.6) groups all have a scale distortions of less than one indicating that the cognitive space needs to be slightly contracted to fit the real space (Kitchin & Blades, 2002). This is not the case for the sighted group (1.1) where the cognitive space needs to be slightly expanded to fit the real space.

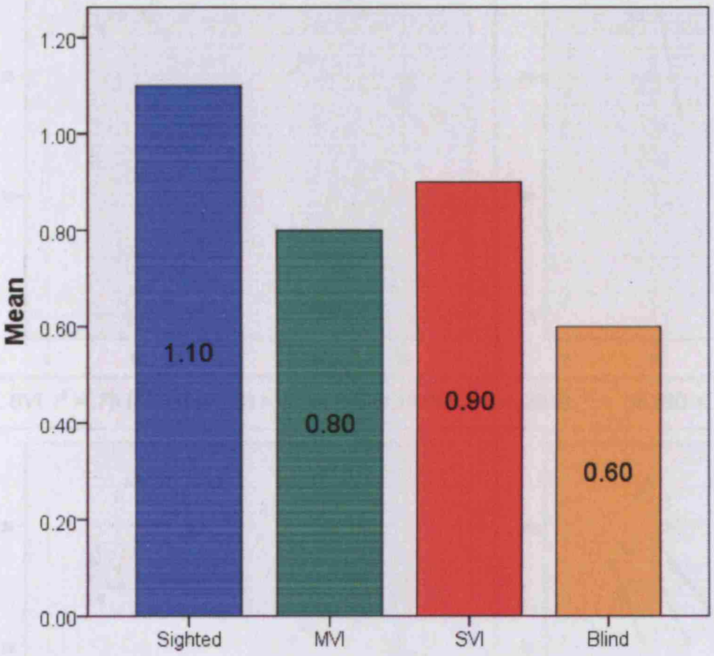
Figure 9.25 presents a scatter plot representing the results of the model task for the four groups and allows us to visualise and make sense of some of these distortions. In the figure, the blue circles represent the fixed locations while the green circles represent the real and the red circles represent the estimated locations. Black lines that connect the real and the estimated locations indicate the magnitude of the shift. Here it is important not only to consider the displacement of every location in itself but also of the overall distortion of the entire configuration.

Figure 9.23 - Angle and translation distortions (RLSB)



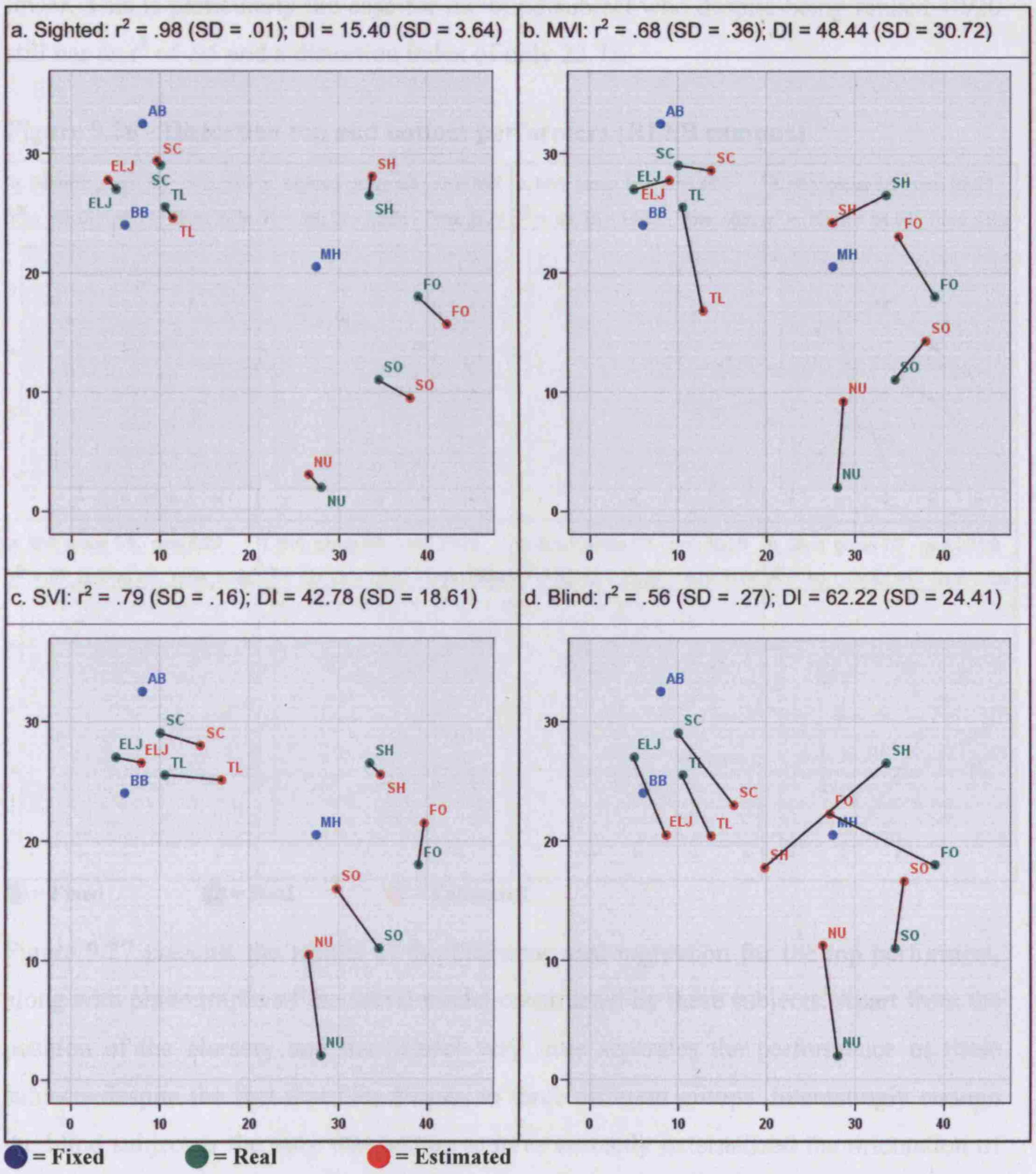
Distortions for the sighted group are relatively small for all the estimated locations (figure 9.25a). For the MVI group (figure 9.25b) there seems to be an *anchor magnetism* effect with all locations being pulled towards the Mansion House. The large angle distortion observed in figure 9.23 can also be explained by the fact that although the estimated locations are not very far from their real locations, they are positioned in different orientations. However, looking at the entire configuration we note that despite these distortions, the topological relationship between the different locations is somewhat respected. The *magnetic effect* of the Mansion House can also be clearly seen in the representations for the SVI and blind groups (figures 9.25c and 9.25d).

Figure 9.24 - Scale distortions (RLSB)



Two other differences can be observed between the MVI and SVI groups. First, the SVI group had lower (x) or east-west distortions (ELJ, Thomas Lucas and Student Centre) but higher (y) north-south distortions (Nursery, School and Fountain). Second, this group had a considerably lower angle distortion and this is clear from the fact that the estimated locations are somewhat aligned - their angular position varying very little from the real position. The topological relationship between the different locations is also maintained in the representations of the SVI and the blind groups. Finally, a familiarity effect is also present with the blind group having the most difficulty with the position of the Nursery and the Shed.

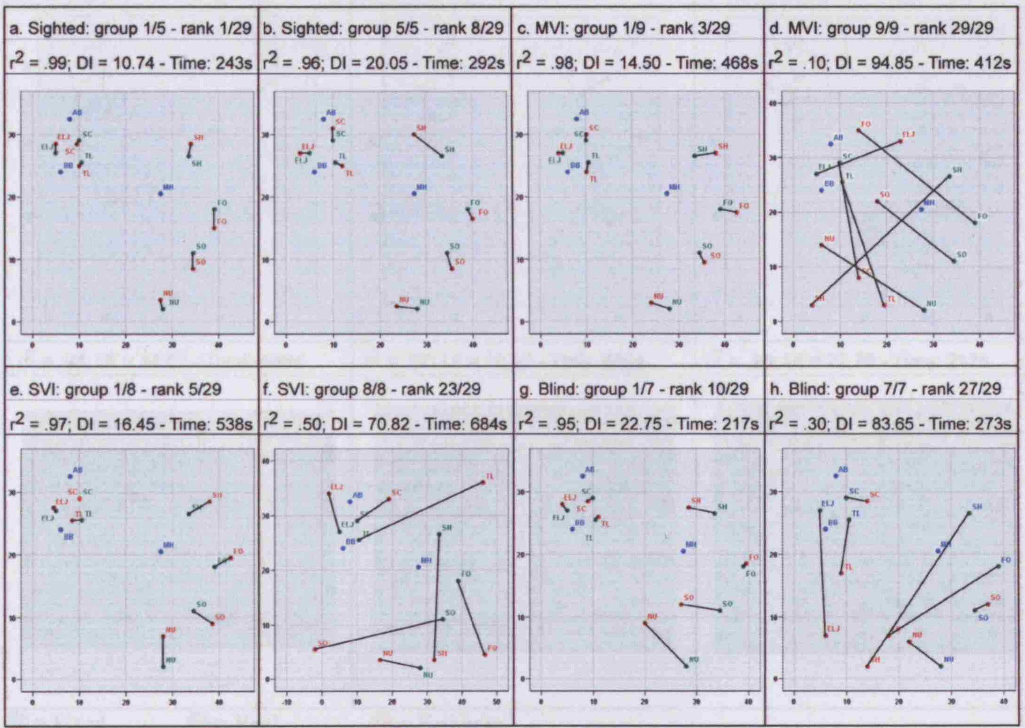
Figure 9.25 - Group distortions and magnitude of shift (RLSB)



9.6.1.3 Bidimensional regression: Top and bottom performers

In order to further investigate individual differences, subjects were ranked on the basis of their distortion index in relation to their group and overall performance. The distortions for the top and bottom performers for each of the groups were isolated and these are presented in figure 9.26 on the following page. As it can be observed, the performance of the top performers in the MVI, SVI and blind group (figures 9.26c, 9.26e and 9.26g) is considerably higher suggesting that visual acuity may not be a defining factor in the construction of mental representations as suggested by the deficiency and inefficiency theories. These subjects fall within the top ten performers and their DI is considerably lower. This is particularly the case for the blind subject who despite being ranked 10/20 still has an r^2 of .95 and a distortion index of only 22.75.

Figure 9.26 - Distortion top and bottom performers (RLSB campus)

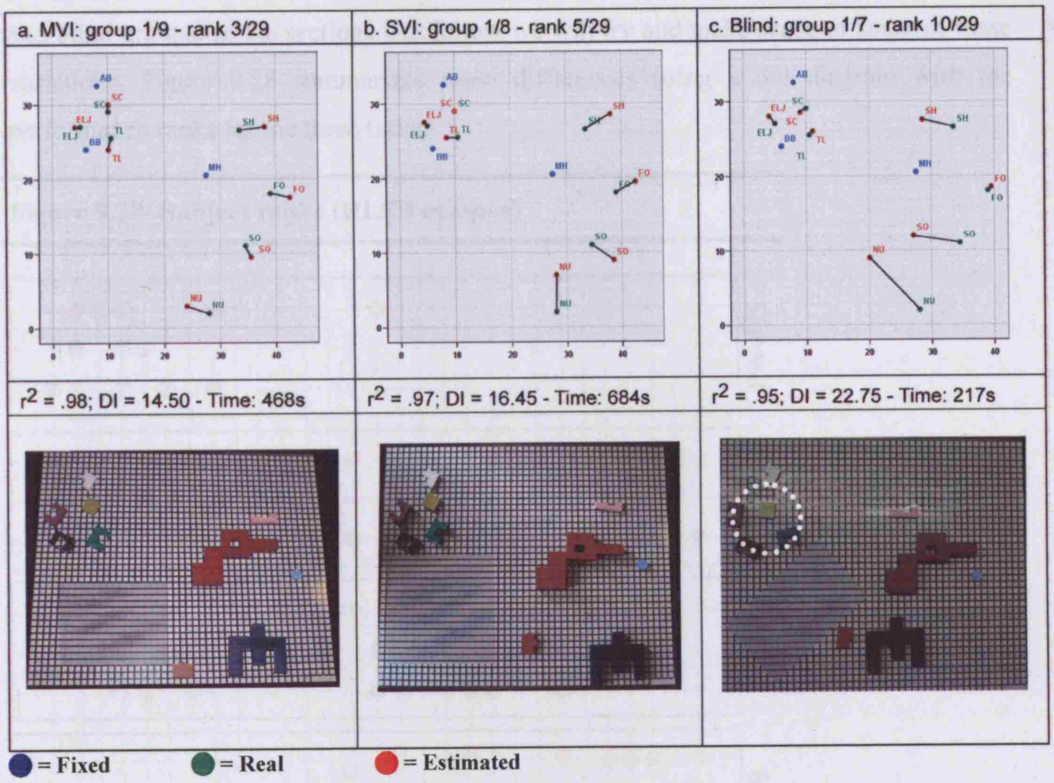


● = Fixed ● = Real ● = Estimated

Figure 9.27 presents the results of the bidimensional regression for the top performers, along with photographs of the actual model constructed by these subjects. Apart from the position of the Nursery and the School very little separates the performance of these subjects despite the fact that they belong to three different groups. Interestingly enough the blind subject is the only who seems to have correctly externalized the orientation of front door of Thomas Lucas (white circle in fig 9.27c – see also figure 9.1). Regarding the bottom performers a glance at the higher level of distortions suggests that these subjects had considerable problems externalizing their representation of the RLSB campus. However, as it has been argued before the fact that a person may not be able to externalize a representation in the form of a model does not mean that this person does not have a representation of the space in question. This notion is further backed by the fact that the bottom performers in the model construction task performed at a reasonable level in at least one of the other two tasks. The bottom MVI subject ranked 20/29 in the pointing task and 17/29 in the distance estimation task. This is also true for the bottom

SVI and blind subjects who ranked 21/29 and 23/29 in the pointing task and 8/29 and 7/29 in the distance estimation task.

Figure 9.27 - Distortions top performers

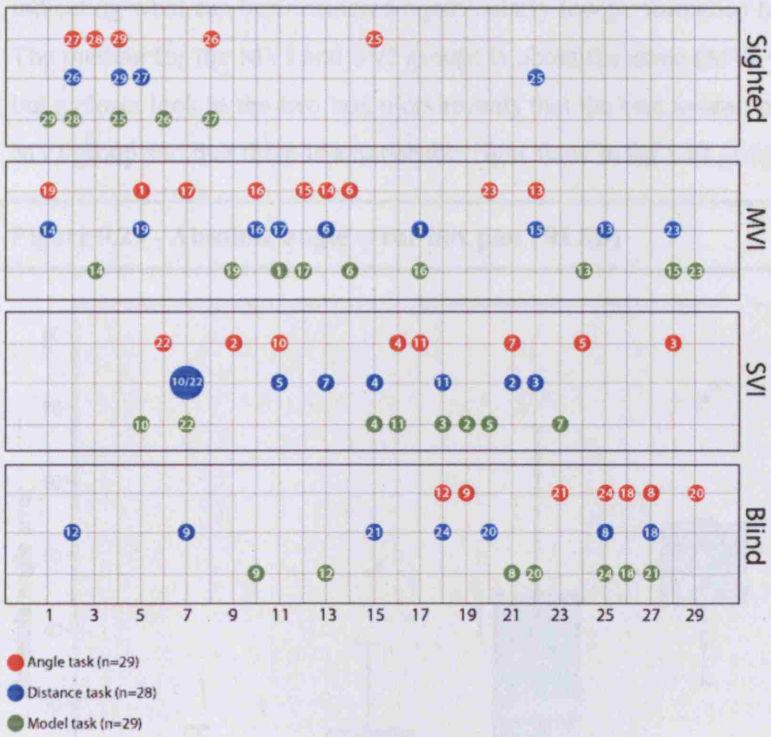


Finally, it should be noted that no significant differences were found in performance between all three tasks. Individuals who performed better in the model construction task also tended to perform best in the distance estimation and pointing judgement tasks. This was confirmed by a statistically significant positive relationship between performance in the distance estimation task and the model construction task ($r = .71$, $DF = 26$, $p < .001$). Positive and statistically significant relationships were also found between performance in the angle estimation and the model construction task ($r = .69$, $DF = 27$, $P < .001$) and performance in the angle estimation task and distance estimation task ($r = .57$, $DF = 26$, $p = .002$).

9.7 Interpreting the results

It is now clear that differences in the accuracy of mental representations exist between groups. The role of vision in the perception and cognition of space cannot in anyway be disregarded especially in relation to the quick and amalgamating power that this sense has for consolidating the relationships among different objects in the environment. But perhaps more intriguing than these variations between groups are the large individual differences that exist within each of the four groups. It seems that good and bad performers are present in all the groups but bigger differences exist within the MVI, SVI and blind groups. In the sections that follow we will try and make sense of some of these variations. Figure 9.28 summarizes these differences using a dot diagram with the performance ranks for the three tasks.

Figure 9.28- Subject ranks (RLSB campus)

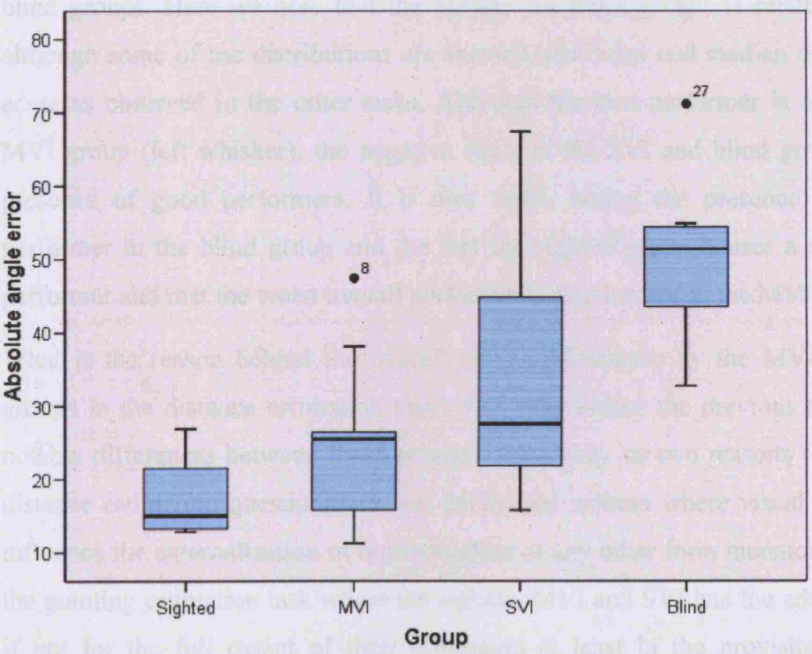


Lower ranks indicate a better performance in the sense that the subject ranked as number "1" was the best performer for that particular task. It should also be noted that ties were allowed during the ranking transformation meaning that subjects in different groups could have similar ranks for a particular task. Clusters indicate group cohesion while long spreads indicate the presence of good and bad performers. This is the case for the MVI and blind groups in the distance estimation task. For the angle estimation task we note that a spread exists for the MVI and SVI groups while the sighted tend to cluster along the lower ranks and the blind along the higher ranks. This is also the case for the model construction task where clear individual differences exist for the two visually impaired groups. The numbers inside each circle indicate the actual subject number and allows for an individual comparison of performance in all three tasks. For example subject 14 in the MVI group ranked first in the distance estimation and third in the model construction task but performed relatively worst in the angle estimation task with a rank of 13.

9.7.1 Pointing judgments: Angle error and individual differences

Figure 9.29 presents a box plot detailing the performance of the four groups in the pointing task (locations pointed to). As can be observed, the sighted are the best performing group although the distribution is skewed to the right, the right whisker indicating what can be considered a particularly low performance for someone with sight. The median for the MVI and SVI groups is about the same (MVI = 25.47; SVI = 27.52) but a closer look at the two box plots reveals that the best overall performer is part of the MVI group and that there is a noticeable right skew in the SVI group.

Figure 9.29 - Absolute angle error box plot (RLSB)



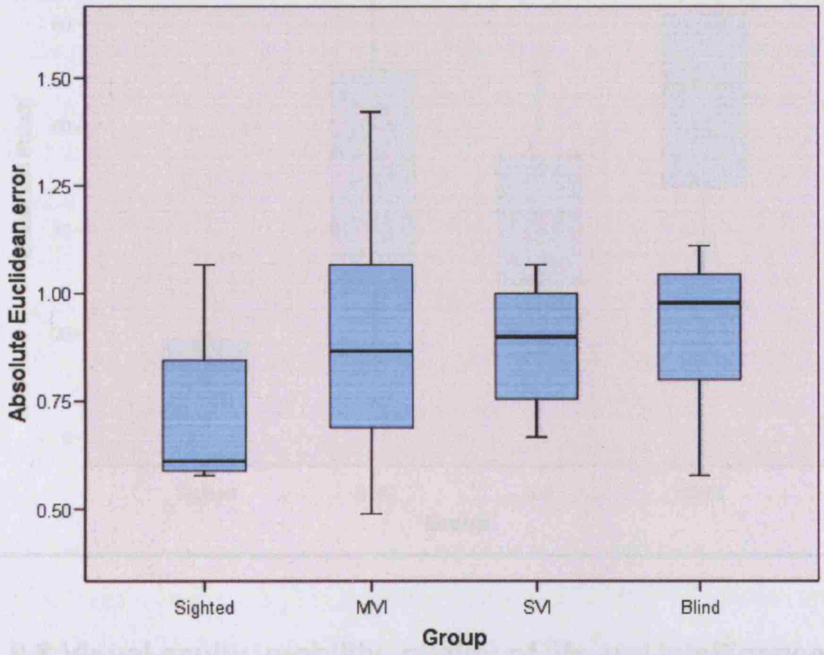
The SVI group does house a few good performers but errors tend to be above the median for the majority of subjects. An outlier is also present in the MVI group and after close inspection (subject 13 in appendix A1) it was found that this subject also had an additional disability (Lawrence Moon Biedl Syndrome), only 1 year of mobility training and scored particularly low (13/45) in the intelligence (FSA) assessment. This subject was screened to participate in the study as none of these variables seemed to affect his daily living. The subject even attended a mainstream college. Looking at the box plot for the blind group, one notices that the median is higher (51.38) but that contrary to the other groups, the skew is to the left. This is an interesting result indicating the presence of some good performers and a particularly good performer as illustrated by the left whisker. In this group we also notice the presence of an outlier (subject 20 in appendix A1) but unlike the MVI outlier this subject did not have any learning difficulties, had 5 years of mobility training and relatively high scores in the literacy and numeracy assessment (61/72 & 38/50). This subject is an outlier only for the pointing task with performance in the other two tasks well within the average for the group.

9.7.2 Distances estimation: Euclidean error and individual differences

Results from the ANOVA did not reveal any significant differences between groups and this can be seen in figure 9.30 as the box plots show a similar trend for the MVI, SVI and blind groups. Here we note that the median for these groups is relatively similar and although some of the distributions are skewed, the mean and median disparity is not as acute as observed in the other tasks. Although the best performer is once again in the MVI group (left whisker), the negative skew in the SVI and blind groups point to the presence of good performers. It is also worth noting the presence of a very good performer in the blind group and the fact the sighted group houses a considerably bad performer and that the worst overall performer is also located in the MVI group.

What is the reason behind the overall good performance by the MVI, SVI and blind groups in the distance estimation task? And why unlike the previous task are there no notable differences between these groups? There may be two reasons for this: First, the distance estimation questionnaire was performed indoors where visual acuity could not influence the externalization of representation or any other form mnemonic recall. Unlike the pointing estimation task where the sighted, MVI and SVI had the advantage of vision if not for the full extent of their estimation at least in the provision of a frame of reference, responding to the distance estimation questionnaire required only the mental representation of the different locations. Even if Euclidean inferences had to be made, the correlation between Euclidean and functional distances is high enough for the subjects to base their estimation in relation to the route travelled. This eventually leads us to the second reason and the fact that distances can be inferred on the basis of time. It is this temporal dimension, which is not evidently clear in the model tasks and nonexistent in the pointing task and that may have brought the scores of the MVI, SVI and blind groups closer to that of the sighted.

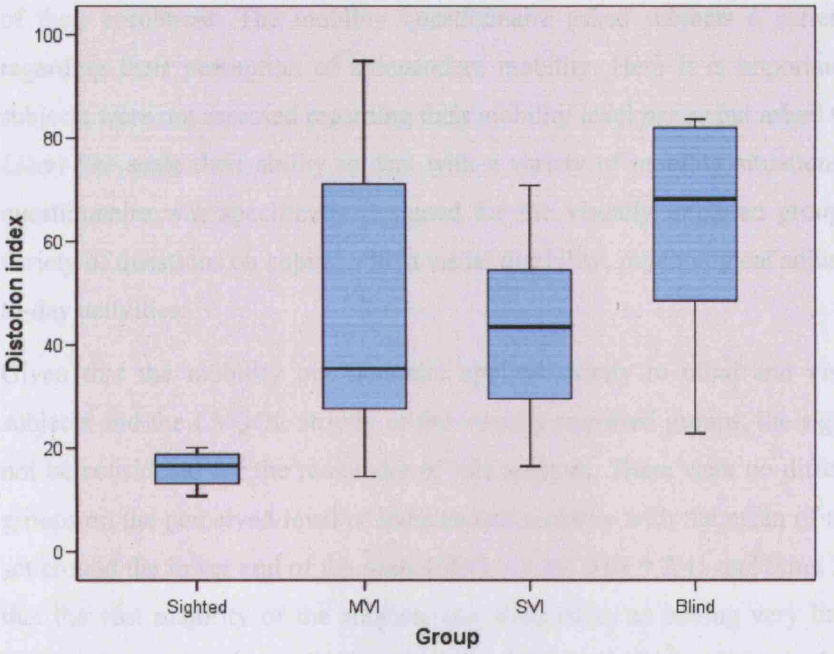
Figure 9.30 - Absolute Euclidean error box plot (RLSB)



9.7.3 Model construction: Distortion index and individual differences

Figure 9.31 presents the box plot for the model construction task. Results from the ANOVA indicated significant differences between the sighted and the other three groups and this is obvious when comparing the box plots. No significant differences were found between the MVI, SVI and blind groups but looking at the figure one notices the presence of good and bad performers in each of these groups. The MVI group has the lowest median (35.39) but its entire distribution is skewed to the right. As noted above, this group has a higher mean (48.44) than the SVI group and it houses both the best and the worst performers. The box plot for the SVI group is slightly skewed to the left as a result of the disparity between a low mean (42.78) and higher median (43.49). Here again we notice the presence of good and bad performers. The blind was the worst performing group but the distribution is also skewed to the left and the left whisker indicates that at least one subject performed at the level of the other three groups.

Figure 9.31 - Distortion index box plot (RLSB)



9.8 Visual acuity, mobility, quality of life and intelligence

The right and left skews observed in the previous sections ultimately lead to a very important question regarding the possible factor or combination of factors that may be causing this variation. In other words, what is it that is causing some individuals to perform better than others and why is there such variability between tasks? Results from a regression analysis revealed that visual acuity alone significantly predicted the accuracy of angle estimation, $\beta = .643$, $t(27) = 4.367$, $p < .001$ accounting for 39% of the variation (adjusted $r^2 = .392$, $F(1,27) = 19.071$, $p < .001$). Visual acuity also significantly predicted performance in the model construction task $\beta = .405$, $t(27) = 2.302$, $p = .029$ but unlike the pointing task, it could only account for 13% of the variation (adjusted $r^2 = .133$, $F(1,27) = 5.297$, $p = .029$). As expected, visual acuity did not significantly predict the accuracy of distance estimation, $\beta = .134$, $t(26) = .689$, $p = .497$.

9.8.1 Mobility and quality of life

It seems that there are other important factors influencing the accuracy in performance at least in the distance estimation and the model construction tasks. As noted at the beginning of this chapter, blind and visually impaired subjects were also asked to complete mobility and low-vision quality of life questionnaires (LVQOL) and this data was complemented by an intelligence assessment conducted by the RLSB at the moment of their enrolment. The mobility questionnaire asked subjects a variety of questions regarding their perception of independent mobility. Here it is important to stress that subjects were not assessed regarding their mobility level *per se* but asked to identify via a *Likert-like* scale their ability to deal with a variety of mobility situations. The LVQOL questionnaire was specifically designed for the visually impaired groups and asked a variety of questions on coping with a visual disability, psychological adjustment and day-to-day activities.

Given that the mobility questionnaire applied strictly to blind and visually impaired subjects and the LVQOL strictly to the visually impaired groups, the sighted group will not be considered for the remainder of this analysis. There were no differences between groups on the perceived level of independent mobility with the mean of the three groups set around the lower end of the scale (MVI = 2.19; SVI = 2.41 and blind 2.16) indicating that the vast majority of the subjects saw themselves as having very little difficulty in most mobility situations. This was a somewhat unexpected result especially for the SVI and blind groups considering many of the subjects were not independent travellers outside the RLSB campus. It is possible that subjects responded to the questionnaire with the RLSB campus in mind, the similarity of their mean scores indicating that for the most part these individuals reached a mobility threshold in a well-known environment. Significant differences were found regarding years of mobility training ($F_{2,21} = 5.451$, $p = .012$), a Tukey post hoc test revealing difference in means between the MVI (2.83) and the blind (9.29) with the mean for the SVI group (6.29) approaching that of the blind, supports the idea that although the blind and SVI might take longer to develop their mobility skills, these groups can reach the same level of perceived mobility as the MVI group in a well known environment.

In regard to the LVQOL questionnaire, a t-test revealed significant differences in the means of the MVI and SVI groups ($t = 2.244$, $DF = 15$, two tailed $p = .043$). As expected, subjects in the MVI group regarded themselves as having a higher quality of life ($M = 3.79$, $SD = .76$) than those in the SVI group ($M = 3.04$, $SD = .61$) although the average for both groups rested at the higher end off the scale. In addition, the scores for the two questionnaires were highly correlated ($r = -.904$, $n = 17$, $p < .001$) indicating that for the most part, subjects in the MVI and SVI groups that perceived themselves having a good level of mobility also regarded themselves as a having a good quality of life (the minus sign exists because the scales of the two questionnaires were reversed).

9.8.2 Intelligence

All students that enrol at Dorton College are assessed for their numeracy and literacy skills. Before 2004, students were asked to complete a separate numeracy and literacy test. After 2004, the RLSB changed its regulations and students were asked to complete a Foundations Skills Assessment (FSA), which was essentially a combination of the literacy and numeracy tests. A one-way ANOVA was conducted in order to determine if the MVI, SVI and blind groups differed in their numeracy, literacy or FSA scores. Results from the ANOVA revealed no significant differences between groups in the literacy ($F_{2,7} = .411$, $p = .678$), numeracy ($F_{2,7} = 1.382$, $p = .312$) and FSA ($F_{2,10} = .147$, $p =.865$). The scores of the literacy and numeracy tests were then combined and normalized along those of the FSA assessment in order to produce and overall intelligence score that applied to all subjects in the three groups. A one-way ANOVA was then conducted in order to determine if the MVI, SVI and blind groups different in their overall intelligence score. Results from the ANOVA revealed no significant differences between groups ($F_{2,20} = .440$, $p = .650$).

9.8.3 Factors influencing task performance

When the sighted group is excluded, visual acuity[75] alone is still a good predictor in the accuracy of angle estimation $\beta = .552$, $t(22) = 3.106$, $p = .005$ accounting for at least 27% of the variation (adjusted $r^2 = .273$, $F(1,22) = 9.645$, $p = .005$) but not a significant predictor of performance in the model construction task ($\beta = .186$, $t(22) = .888$, $p = .384$) and the distance estimation task ($\beta = -.011$, $t(22) = -.050$, $p = .960$). Given these results, a series of correlations were performed in order to verify whether a relationship existed between the perceived level of independent mobility, quality of life, and intelligence and performance in the three tasks. Table 9.12 presents the output of these correlations.

[75] In ophthalmology or when visual acuity is used for statistical calculations, it is preferable to use the logarithm of the minimum angle of resolution (logMAR). LogMAR converts the Snellen chart into a linear scale where positive values indicate visual loss and negative values indicate normal or better visual acuity. Individuals who are severely visually impaired and unable to read the chart at any distance are classified in terms of their ability to count figures (logMAR = 1.9), perception of hand motion (logMAR 2.3), and light or no light perception (logMAR 2.7). This Snellen method of assessment has several weaknesses. Critics note that letters get together as their size decreases and this can lead to some confusion while reading. Others have noted that there are large jumps in acuity levels between the rows making it hard to know the exact acuity. Nonetheless, the Snellen chart continues to be the most widely used medium for assessing visual acuity.

In relation to the angle estimation task a significant positive correlation was found for visual acuity (r = .552, DF = 22, p = .005) and for years of mobility training (r = .471, DF 22, p = .202). Individuals who had the longest amount of mobility training and lowest visual acuity (LogMAR) also had the highest error scores in the angle test. A *stepwise* multiple regression was performed in order to investigate if years of mobility training complement or substitute visual acuity as a significant predictor of performance in the angle estimation task. Using the *stepwise*[76] method, a significant result emerged whereby visual acuity continued to be a significant predictor of performance (β = .552, t(22) = 3.106, p = .005) accounting for at least 27% of the variation of performance in the angle estimation task. These results confirm what was discussed at the beginning of the chapter regarding the visual quality of this task and the difficulty faced by the blind and SVI groups.

Table 9.12 - Task performance, mobility, quality of life and intelligence (RLSB)

Task	Statistic	Visual Acuity (logMAR)	Intelligence	Mobility Score	Mobility years	LVQOL Score
Angle	Pearson r	.552(**)	-.054	.173	.471(*)	-.376
	Sig.	.005	.808	.419	.020	.137
	N	24	23	24	24	17
Distance	Pearson r	-.011	-.304	.184	.213	-.127
	Sig.	.960	.158	.389	.318	.627
	N	24	23	24	24	17
Model	Pearson r	.186	-.419(*)	-.020	.199	.053
	Sig.	.384	.047	.926	.352	.840
	N	24	23	24	24	17

*** Correlation is significant at the 0.05 level (2-tailed).**
**** Correlation is significant at the 0.01 level (2-tailed).**

No significant correlations were found for the distance estimation task. For the model task, a significant negative correlation was found between the amount of distortion (DI) committed and the level of intelligence. This was a somewhat expected result given that this particular task not only required the ability to mentally represent the relative position of different locations but also to transform and externalise this representation by putting

[76] In a *stepwise* regression, each variable is sequentially added and its value assessed. If a variable does contribute to the model, it is retained but all other variables are re-tested in order to see if they still contribute to the success of the model. If a variable no longer contributes to the model's significance, it is then removed. In this manner, the method ensures the smallest number of predictor variables. Ordering for the regression follows the significance level obtained in the correlations.

pieces together in a model much like a puzzle. Results from a regression revealed that the level of intelligence was indeed a significant predictor of performance (β = -.419 t(21) = -2.113, p = .047) accounting for 14% of the variation of performance in the model construction task (adjusted r^2 = .136, F(1,21) = 4.465, p = .047). These results are consistent with those from Fletcher (1981b) who found that intelligence level was significantly related to performance and particular Euclidean knowledge of objects inside a room.

The fact that no significant correlations were found regarding the perceived level of independent mobility and performance in the three tasks raises some important questions regarding the effectiveness of this questionnaire in the assessment of independent mobility, at least in well-known environments. It seems hard to believe that the level of mobility plays such a minor role the construction of mental representations. In the chapter that follows the effectiveness of the questionnaire is reassessed in relation to a novel and complex environment. Mobility is also considered as it occurs during exploration and navigation eliminating some of the bias inherent in the questionnaire. The analysis of movement patterns allows for a deeper understanding of the manner in which space and spatial relationships are coded in the total and partial absence of vision. By comparing the movement patterns and exploratory strategies used by the different groups to the accuracy in variety of spatial tasks, several conclusions will be made regarding the role of vision in the construction and manipulation of mental representations.

9.9 Summary

This chapter presented the results of the first experiment conducted at the RLSB. Subjects were classified into four groups according to their visual acuity and were asked to partake in three spatial tasks after having walked a route and learning the location of 10 different buildings and structures. Results from the pointing task revealed significant differences between groups with the sighted performing best followed by individuals in the MVI, SVI and blind groups. Vision played a particular role in the performance as obvious from the large differences between these groups. Results from the pointing task also revealed that the level of experience or familiarity with the environment could have important implications in the accuracy of judgements. Results from the within subject test in the analysis of variance revealed that all subjects were more accurate when pointing *to and from* locations in the *college area* of the campus – the area where these individuals live, work and study. This was also the case for landmarks where the accuracy of both the blind and visually impaired groups improved when asked to point to the Mansion House and Student Centre. At the same time, the accuracy of judgements was worse for locations that were not commonly frequented by the students (i.e., Shed). These results are consistent with those from Byrne and Salter (1983) where it was found that subjects were consistently better at pointing to locations they were familiar with. Given the central location of the Mansion House and the Student Centre, these results are also consistent with Lloyd (1989) where it was found that subjects were significantly more accurate when making judgements from centrally located reference points than from points located in the periphery. Accuracy of pointing judgements also decreased as a function of the complexity of the route taken in order to arrive at a destination. This was usually the case for A-block although these results are hard to generalise for the other locations. Subjects in the sighted group also took advantage of the visual perspective afforded by locations situated on higher ground (mansion area) to calibrate and improve the accuracy of their judgements.

Regarding the constant error for pointing judgements, it was found that the four groups shared a similar pattern of distortions when pointing *to and from* the different locations. It was argued that this similarity in clockwise or counter clockwise biases was evidence (despite differences in visual acuity, or in the case of the blind the total absence of vision) that the representations formed by the blind and visually impaired, constructed either through proprioception or the remainders of functional vision, shared many characteristics in common with those constructed by vision. It should also be noted that individual differences also existed within each of the four groups and these were made evident from the presence of large variable errors particularly in the MVI and SVI groups (variable error also tended to be lower for all groups at more familiar locations). This is further evidence of some of the problems inherent in the classification of individuals with similar acuity but who vary in the extent they use their functional vision.

In relation to the distance estimation task, no differences were found between groups in the accuracy of distance judgement although effect sizes revealed that vision still played an important role in the accuracy of estimations. As expected, subjects tended to be more accurate when estimating distances between locations in the *college* areas of the campus. Particularly interesting was the fact that the estimation of many subjects in the blind and visually impaired groups related more closely to the Euclidean baseline. These results directly contradict those found by Rieser et al. (1980) where it was shown that in the absence of guidance, the blind tend to estimate distances in relation to the routes traversed.

Results from the constant error analysis for the distance estimation task further support those from the pointing task regarding the similarity of representations between blind, visually impaired and the sighted. Here again, it was shown that despite differences in accuracy all groups tended to overestimate the distance between locations that were closer together and underestimate the distance between locations that are further apart. This similarity in distortion was also shown to exist through an in-depth analysis of the MDS output for the different groups. There it was found that irrespective of visual acuity distortions were a function of (a) the discrepancy between functional and Euclidean distances, (b) the order the location was visited and (c) the orientation of the front door of the building. Distortion also tended to occur between locations with similar relative distances (i.e., B-Block, ELJ and Thomas Lucas; Mansion House, Shed and School).

Results from the model construction task revealed significant differences between groups with the sighted considerably outperforming all the other groups. This was somewhat an expected result considering the task requirements (representation of configurational knowledge) and the motor skills needed to complete it. Of particular interest are the large variations in performance within the different groups. The fact that all groups had at least one very good and one very bad performer suggests that vision may not be a defining factor in the construction of mental representations. An analysis of distortions between and within groups confirmed the idea that the representation of top and bottom performers in the blind and visually impaired groups shared many characteristics in common with the sighted despite the fact that they were constructed in the total or partial absence of vision. Here again, distortions were smaller for familiar locations. In addition, it was found that despite the low accuracy in the blind group, all subjects still demonstrated good knowledge of the topological relationship between the locations.

Finally, results from the three tasks were analysed in relation to the participant's level of independent mobility, quality of life and intelligence. In relation to the pointing task, it was found that visual acuity was the only significant predictor of performance. No relationships were found between mobility, quality of life and intelligence for the distance estimation task. Significant correlations were found between intelligence and the accuracy of model construction and results from a regression revealed that for this particular task, intelligence was better predictor than visual acuity. The fact that no correlations were found between the level of mobility and quality of life and performance in any of the tasks suggests that these questionnaires may not be appropriate in situations where the individual is well acquainted with the environment. It seems hard to believe that mobility plays such a minor role in the construction of mental representations by individuals who are blind or visually impaired. To understand the role of mobility and confidence in the construction and accuracy of mental representations, we must consider it as it is manifested for the first time - while exploring a novel space.

Chapter 10
Experiment 2 – Exploratory strategies and mental representations in a complex and novel environment

10.1 Introduction: Familiar and novel environments

This chapter presents the results for the second experiment conducted with students from Dorton College in a maze constructed at the site of the Royal London Society for the Blind. The experiment was designed as an attempt to address some of the questions that were left unanswered in the previous chapter. In the previous experiment, subjects were tested in their college campus – an environment they had daily access to and were comfortable navigating around. Data collected through different spatial tasks allowed for several conclusions to be made regarding the content and accuracy of mental representations. Visual acuity was found to be a good predictor of accuracy for pointing judgements but less so for tasks that required subjects to estimate distances between different locations. Although the level of intelligence was found to significantly correlate with accuracy in model construction, no relationship was found between the level of mobility, quality of life and performance for all three tasks.

Testing in a well-known environment can masquerade some of the differences in the level of mobility between individuals. When tested in a familiar environment, the individual approaches the situation already equipped with an existent mental construct and relies to a lesser extent on information collected through movement. Yet careful observation of travel behaviour during the two years the author spent working and living at the RLSB indicated that subjects did vary in their ability to navigate independently and with confidence. In order to study the effect independent travel can have on the construction of mental representations, a novel environment was constructed that allowed the researcher control over a variety of variables that can affect acquisition and manipulation of spatial knowledge.

10.1.1 The maze: Design and construction

A maze was constructed at the site of the RLSB in an attempt to study the content and accuracy of mental representations in an environment that was both novel and complex. The maze experiment picks up from some of the weaknesses of the past experiment and goes a step further by looking at the development of these representations through the wayfinding strategies and spatial coding heuristics that are used when exploring space. Testing in a novel environment eliminates many errors associated with familiarity and experience that are often so hard to disentangle. At the beginning of the testing phase in a novel environment every subject is on par regarding their knowledge of the experimental space, giving the experimenter a chance to make stronger inferences regarding the relation between the design of the space, the exploratory strategies and the level of performance. The issue of a *mobility threshold* is also addressed, as the researcher is able to focus on the actual movement and exploratory patterns employed by each of the participants.

In an attempt to build on past experiments that have also examined exploratory strategies (particularly Hill et al. 1993), the size of the experimental space was considerably enlarged. Studies that require the capturing of movement are usually confined to laboratories or gyms where movement is often restricted to a few meters. In such situations, the spatial relationships among objects can often be grasped only from a single vantage point or can be inferred with relative ease after only a few minutes of exploration. Past studies have also tested subjects in empty environments with no obstacles or barriers and where movement around the body axis is only constricted by the boundaries of the space. Such situations are highly unrealistic and hard to generalize to real world city navigation. The maze is an attempt to bring such studies closer to real situations when the environment is both large and complex - where movement and exploration requires considerable body displacements and the integration of a variety of movements in a space that is both large and differentiated by open areas, long corridors and dead ends.

The maze was constructed on a football pitch at the back of the Mansion House at the RLSB. It consisted of a network of poles and plastic construction fences and occupied 45 X 30 meters. Six tables were strategically placed within it and labelled to represent six different locations in a city. Heft (1996) argues that navigation is goal oriented and has shown that that children perform fewer errors when learning a route to a functionally meaningful place than learning a route to places with no necessary labels or meaning. For this reason, subjects were always instructed to think of the maze as a city when exploring and performing the different tasks. The six tables were: Bank, Train Station, Coffee Shop, Police Station, Bakery and School. The entrance to the maze was labelled as the *starting point* and there were no other entrance/exists apart from it. All fences measured approximately 1.5 (5 feet) meters in height and 1 meter in width. They were meshed and suspended from two poles at 1.4 meters. Labels containing the name of each location were printed and stapled to each of the tables. Braille labels were also placed on each table. Given the small size of the Braille label, it was decided that the name of each location would be verbally communicated by the researcher each time the subject walked in front of the table. Figure 10.1 presents a detailed drawing of the maze with the dimensions for each of the, blocks, corridors and tables. Figure 10.2 presents an isometric drawing of the maze, the six locations and the starting point. Figure 10.3 presents some photographs of the actual maze.

Figure 10.1 - Maze and table dimensions

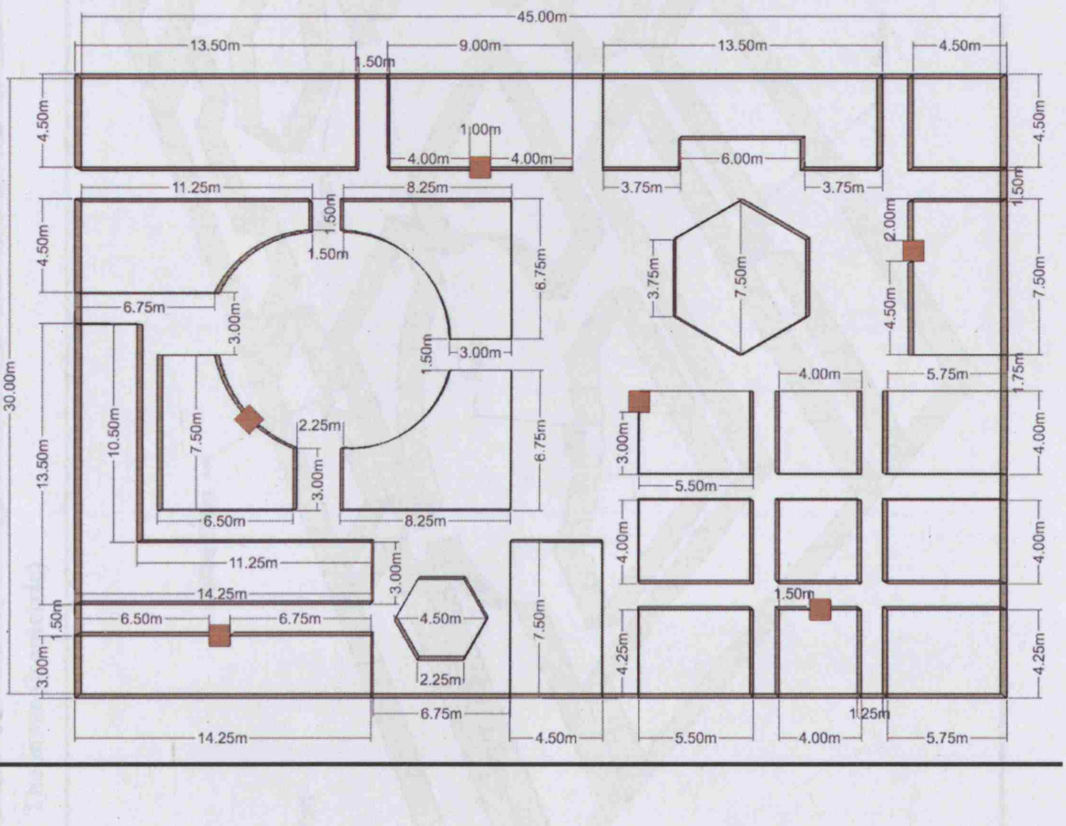


Figure 10.2 - The maze (isometric)

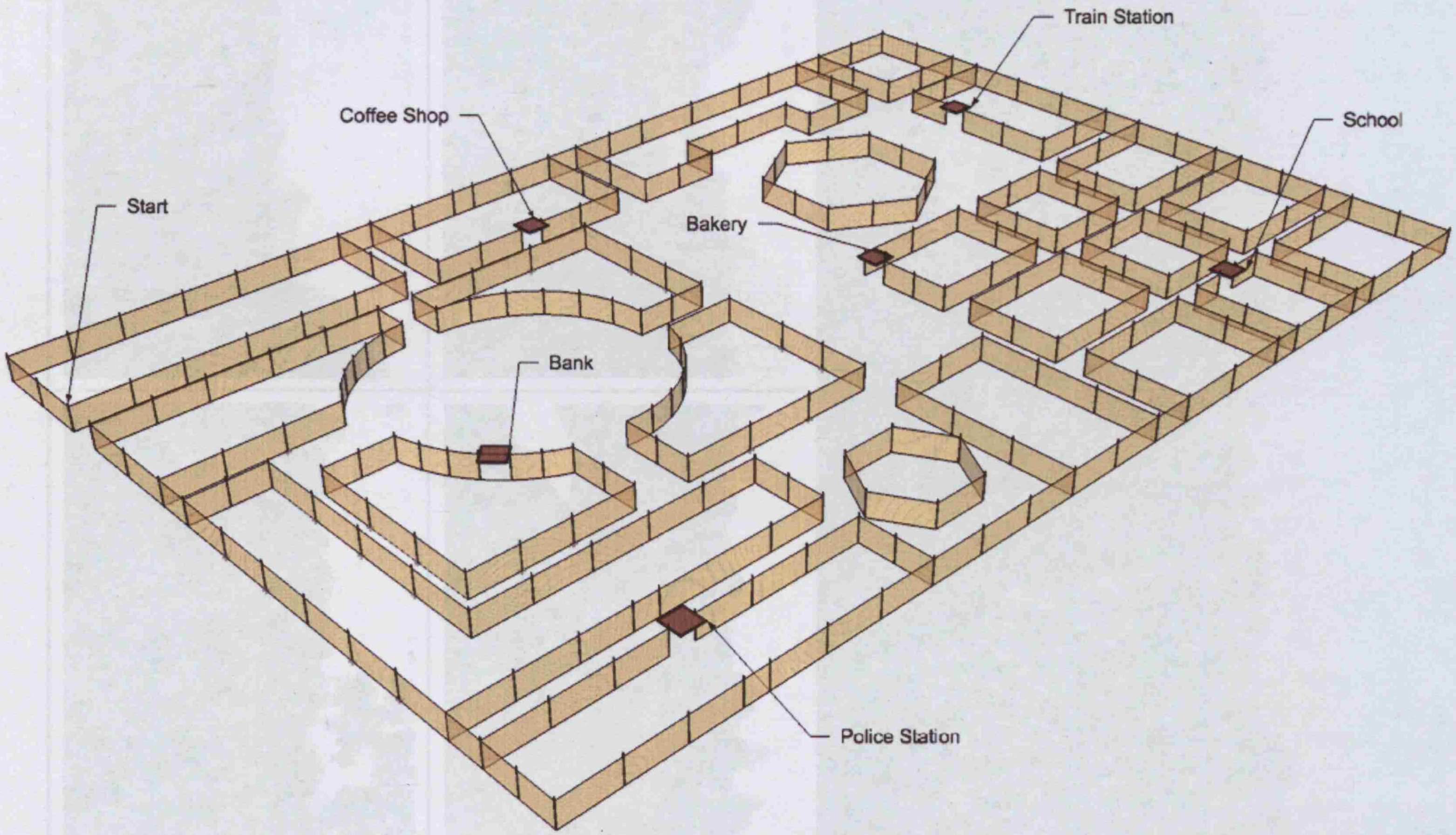
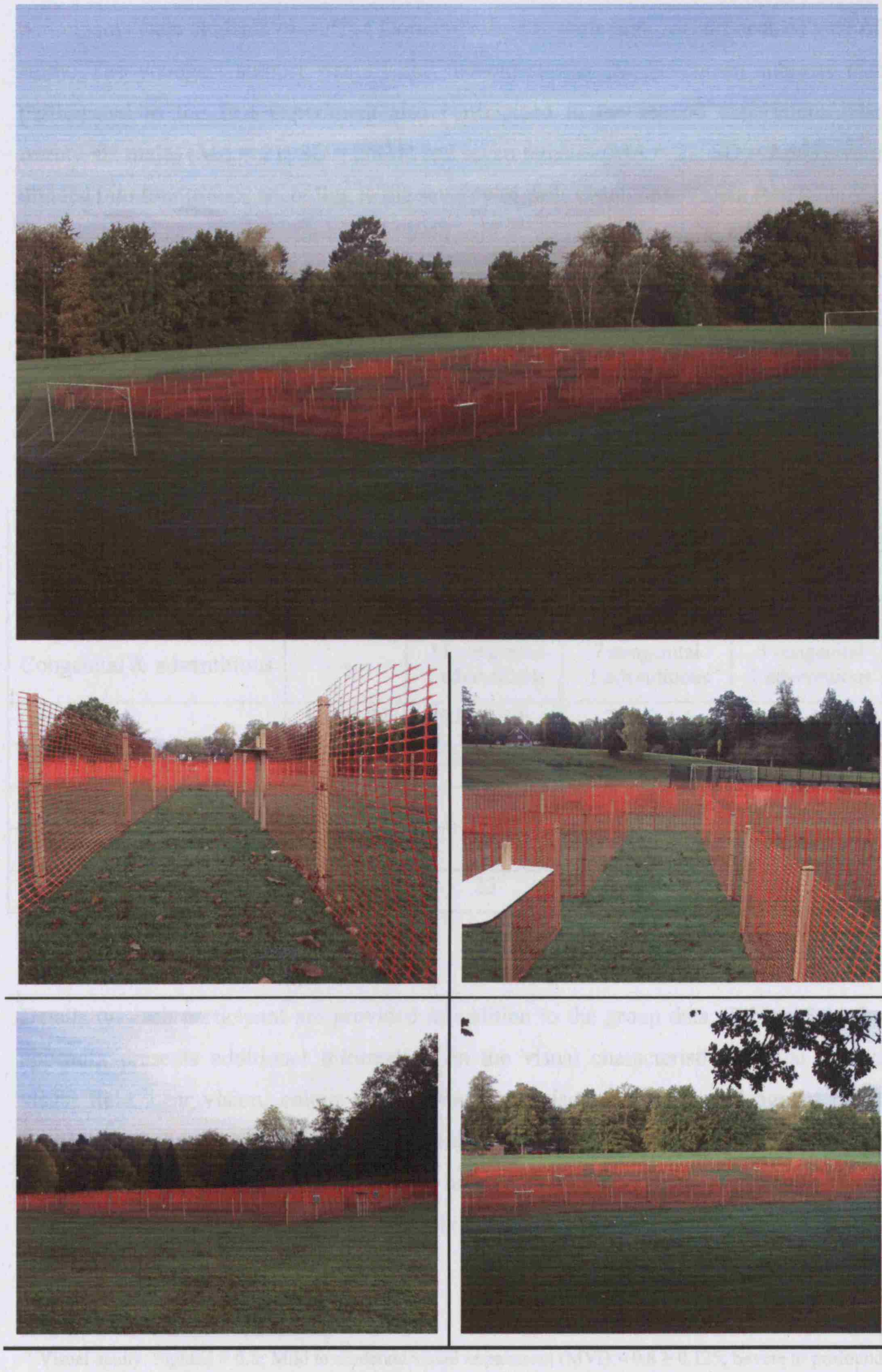


Figure 10.3 - The maze (photographs)



10.2 Participants' profile

A total of 33 subjects (MA = 21; SD = 2.74) participated in the second experiment. All participants were students or staff of Dorton College in their first, second or third year of study. The youngest subject was 17 and the oldest was 29. Seventeen subjects that participated in the first experiment also participated in the second experiment. The twenty-six males (MA = 21; SD = 2.831) and seven females (MA = 21; SD = 2.563) were divided into four groups according to the severity of their visual impairment (see table 9.1 in the previous chapter for more information on the *International Council of Ophthalmology's* Multiple Ranges of Vision Classification)[77]: Sighted, mild to moderate visual impairment (MVI), severe to profound visual impairment (SVI) and blind (congenital & adventitious). Table 10.1 presents how the acuity range classification was adapted for this experiment along with some of the characteristics of each group.

Table 10.1 - Group characteristics (experiment 2)

Group	Sighted	MVI	SVI	Blind
Number of subjects	7	12	8	6
Visual acuity	> 0.8	< 0.8 ≥ 0.125	< 0.125 ≥ 0.02	LP & no LP*
Congenital & adventitious	-	11 congenital 1 adventitious	7 congenital 1 adventitious	5 congenital 1 adventitious
Gender	5 M & 2 F	9 M & 3 F	7 M & 1 F	5 M & 1 F
Mean age (SD)	24 (3.155)	20 (1.730)	20 (2.722)	20 (1.643)
Median age	22	20	19	20
Minimum age	21	17	18	17
Maximum age	29	23	25	22

LP = Light perception

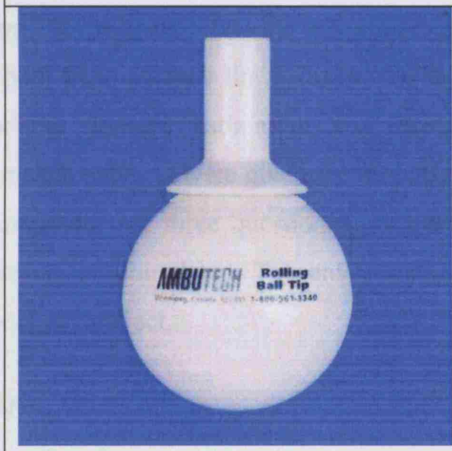
Details on each participant are provided in addition to the group data. Table A3 in the appendix presents additional information on the visual characteristics (visual acuity, visual field, near vision, colour vision, prescribed visual condition and age of onset impairment) and other characteristics (additional conditions or disabilities, years of mobility training and scores for literacy, numeracy or a combined foundations skills assessment) for each of the blind and visually impaired participants.

[77] Visual acuity: Sighted > 0.8; Mild to moderate visual impairment (MVI) < 0.8 ≥ 0.125; Severe to profound visual impairment (SVI) < 0.125 ≥ 0.02; Blind Light perception & No light perception.

10.3 Experiment 2: Maze exploration

The second experiment examined the relationship between the exploratory strategies used to locate and remember six locations within the maze and the performance on a variety of spatial tasks. Participants were given 45 minutes to explore the maze, locate and remember the position of six tables said to represent different locations in a city. They were placed at the starting point and told they could explore the space in any manner they wished. They were also encouraged to use a white cane that was modified with a rolling large ball tip in order to deal with the grassy and sometimes uneven condition of the ground (figure 10.4).

Figure 10.4 - Modified white cane tip



Subjects were told to take their time and go over the maze until they were confident they knew the position of the six different tables. They were followed at all times by the researcher who captured their every movement with a digital video camera. The researcher also called out the name of each location every time the subject was within an arm's reach of the table. The protocol for verbally indicating the position of the tables was established in order not to put the blind at any disadvantage during the exploration phase. Once the name was called out the subject was told to touch the table, locate and read the label. Once all tables were found and the subject was confident that he/she could (a) mentally represent the position of the six different locations and (b) navigate from one location to the other, the time was stopped and the subject was guided back to the starting point. At this time the subject was given one last chance to ask questions before the beginning of the testing phase.

10.3.1 Participant preparation

Before entering the maze the researcher sat down with each participant to describe and explain the experiment and the subsequent tasks they would be asked to complete. Most subjects had already participated in the first experiment and were already familiar with the tasks. Subjects were told to pay attention to the absolute and relative position between the different tables, as they would need to make pointing judgments, estimate distances and construct a model of the campus. All students were tested at approximately the same time of the day (between 10:00 a.m. & 3:00 p.m.) in order to keep the light levels consistent.

Tests were always conducted in the same order and began immediately after the 45 minutes expired or when the subjects declared that they had finished exploring and could remember the position of the six tables. For the pointing task, subjects were brought back to the starting point, handed the digital compass and guided towards the first location. All subjects followed the same circuit when making pointing judgements inside the maze. After the pointing task subjects were brought back to the Mansion House, offered a cup of tea and given five minutes to relax. The researcher then went over the distance estimation task and told participants that given the long nature of the task, they were allowed to ask for a break at any time they felt tired. After completing the distance questionnaire, subjects were given another five minutes to relax while the researcher set up the board for the model construction task. There were no time limits for any of the tasks, although test times were recorded for the distance estimation and model construction tasks. Finally, after completing the model, subjects were given the mobility, low-vision quality of life and debriefing questionnaires. All three questionnaires were presented verbally and took less than 30 minutes to be completed. The entire testing procedure took between two and two-and-half hours per subject.

10.4 Direction task (pointing judgment)

Subjects made a total of thirty pointing judgments (five from each location in the maze) using a SILVA NOMAD© digital compass. They were instructed to place the compass on the palm of their hand and to extend and aim their arm/hand towards the location called by the researcher. After finishing all pointing judgements from a location, subjects were told the name of the place they were heading towards. Subjects started at the home base (but made not pointing judgements from this location) and followed a specific order/route around the maze (Coffee Shop, Train Station, School, Bakery, Police Station and Bank). Testing began directly after the subject finished exploring the maze. The pointing task lasted between 10 to 15 minutes per subject.

10.4.1 Pointing judgement: Regression

Estimated angles were converted to conform to a circular logic so that the difference between the estimated and objective values was kept under 180°. The estimated angles were regressed onto the objective angles for the four groups. Results from the regression indicate a positive linear relationship between the two data sets: Sighted Y' = -1.39 +

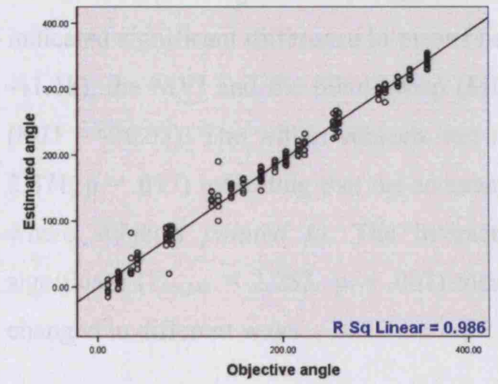
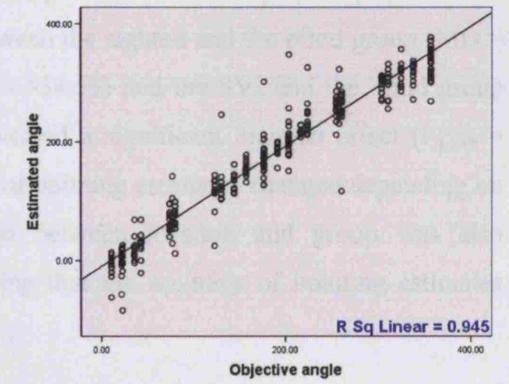
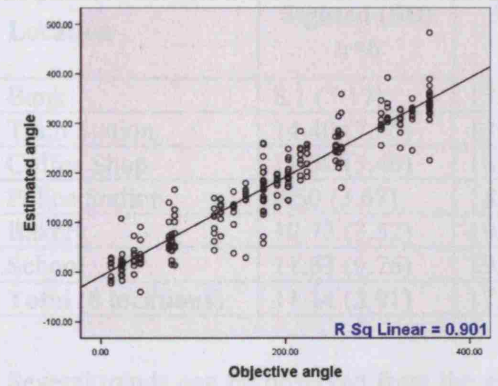
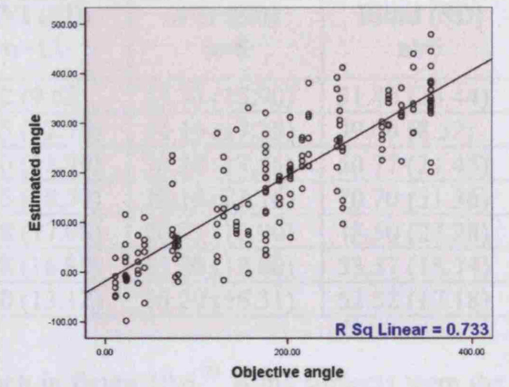
(.97X); MVI Y' = -10.04 + (1.02X); SVI Y' = -8.04 + (1.00X) and blind Y' = -18.07 + (1.05X). Figure 10.5 presents scatter plots of the regression along with the degree of variance (r^2) between the estimated and the real angles for the four groups.

Looking at the four scatter plots we notice that similar to the first experiment the sighted had the highest degree of fit followed by the MVI, SVI and blind groups (sighted r^2 = 0.99; MVI r^2 = 0.95; SVI r^2 = 0.90; blind r^2 = 0.73). Interestingly, the degree of fit for all groups was higher than those from the first experiment conducted in a well-known environment. Although the second experiment was conducted in a novel and complex environment, the actual experimental space was considerably smaller which must surely have given an advantage to the sighted and some subjects in the MVI and SVI groups. These subjects could take advantage of their sight or residual vision to calibrate their pointing judgments. In the case of the blind, the size of the space may have also facilitated the integration of piecemeal information gathered through the exploration.

10.4.1.1 The issue of blindfolds

Subjects were not blindfolded at any time during the experiment. In examining the advantages of vision in the construction of mental representation, we are not only concerned with the sighted but also with the manner in which individuals who are visually impaired can employ what remains of their vision during exploration. Placing a blindfold on a sighted or an individual who has a mild or severe visual impairment puts them at a disadvantage as these individuals are forced to manipulate spatial information in a manner they are not accustomed to do. In chapter 3 we discussed the importance of residual vision and how the visually impaired should be encouraged to make use of it. The purpose of this research is to produce practical and realistic results. Anyone who has worked with the blind and subsequently puts a blindfold on a sighted or visually impaired subject knows that although movement is restricted, it does not simulate blindness. The individual is not only restricted as result of the lack of vision but the *lack of experience* operating without vision. In this manner, the study of the effect of vision in mental representation requires a control group that not only has full vision but that also is able to effortlessly operate with it. The use of a blindfold on the distance estimation and model building tasks is not an issue as these tasks were conducted away from the maze inside the researcher's apartment.

Figure 10.5 - Regression between estimated and objective angles (maze)

Regression sighted: Y' = -1.39 + (.97X)	Regression MVI: Y' = -10.04 + (1.02X)
	
Regression SVI: Y' = -8.04 + (1.00X)	Regression blind: Y' = -18.07 + (1.05X)
	

10.4.2 Pointing judgment: Absolute error

Repeated measures ANOVAS were conducted in order to further investigate the results from the pointing task. Similar to the first experiment, accuracy was considered in relation to locations *pointed to* and locations *estimated from*. In the first experiment it was hypothesized that familiar and more frequented locations could offer a more precise or stable frame of reference for individuals to base their estimations. This logic does not apply for this experiment considering subjects did not know the position of any of the locations prior to exploring the maze. Similar to Dodds et al. (1982) it was hypothesized that for the maze experiment, tables situated in complex locations in relation to the starting point would offer the greatest challenge. Figures 10.6 and 10.7 present the mean absolute error for the six locations that were *pointed to* or *estimated from*. These figures are complemented by tables 10.2 and 10.3 where the mean absolute error and standard deviation for each of these locations are presented.

10.4.2.1 Absolute error: Locations pointed to

Results from the between groups test for locations *pointed to* revealed a significant effect of vision in pointing accuracy ($F_{3,28}$ = 11.018, p < .001). A Tukey HSD post hoc test indicated significant difference in means between the sighted and the blind group (MD = -41.18), the MVI and the blind group (MD = -34.53) and the SVI and the blind group (MD = -26.03). The within subjects test revealed a significant location effect ($F_{5,140}$ = 2.871, p = .017) indicating that the accuracy of pointing estimates changed depending on where subjects *pointed to*. The interaction between location and group was also significant ($F_{15,140}$ = 2.253, p = .007) meaning that the accuracy of pointing estimates changed in different ways.

Table 10.2 - Mean absolute error for locations pointed to in the maze

Location	Sighted (SD) n=6	MVI (SD) n=12	SVI (SD) n=8	Blind (SD) n=6
Bank	8.1 (5.17)	13.32 (9.63)	23.33 (15.90)	51.40 (23.44)
Train Station	14.40 (7.06)	19.05 (12.78)	14.40 (17.25)	39.00 (8.32)
Coffee Shop	12.50 (5.46)	16.90 (12.99)	30.20 (17.55)	50.77 (21.45)
Police Station	9.50 (3.67)	18.35 (18.59)	30.10 (23.16)	70.70 (31.36)
Bakery	10.73 (3.52)	19.18 (17.08)	26.75 (16.90)	48.50 (27.28)
School	11.63 (9.76)	19.98 (16.80)	23.20 (12.80)	53.57 (18.74)
Total (6 locations)	11.14 (3.91)	17.80 (13.12)	26.29 (16.31)	52.32 (17.18)

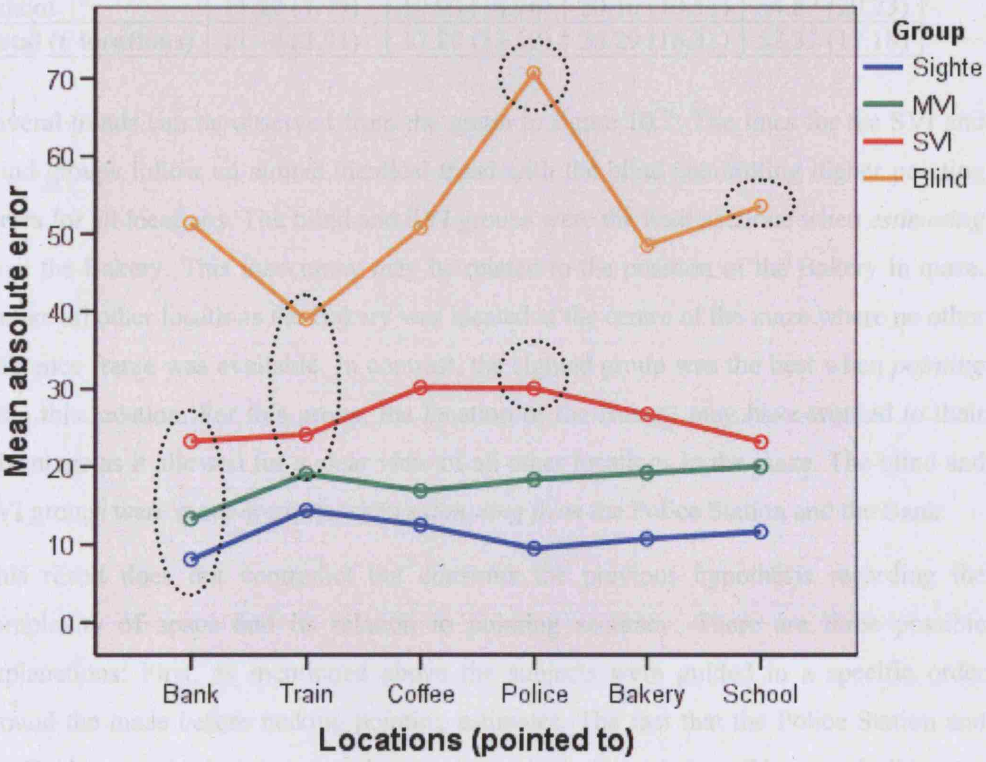
Several trends can be observed from the graph in figure 10.6.[78] Blind subjects were the least accurate when *pointing to* the Police Station and School. It should also be noted that the high pointing error of the blind group (70.70°) is also accompanied by a relatively high standard deviation. The Police Station was also a problematic position for the SVI group although their error (30.10) was not nearly as high. The blind and SVI groups were the most accurate when *pointing to* the Train Station. This is probably related to the position of this table given that it was facing the home base and locating it did not require any turns. This is also true for the Coffee Shop although the actual orientation differed from that of the home base and Train Station. The sighted, MVI and SVI groups were more accurate when *pointing to* the Bank. The Bank was the closest location from the home base.

Together these results seem to indicate that for the SVI and blind groups, pointing error is influenced by the number of turns necessary to reach a particular destination. Unlike the

[78] As noted in the previous chapter, the digital compass carries an error between 5 and ten degrees. This is of particular relevance when looking at the error scores for the sighted group considering that subjects in this group were able to see all locations before pointing should approach zero.

other locations in the maze, the route to both the Police Station and the School required at least two right angle turns from the starting point. In contrast, the Train Station is easily reached by walking a straight line. These two groups also had problems when *pointing to* the Coffee Shop. This is an interesting result considering that the Coffee Shop was just a few meters away from starting point. Here it is possible that the orientation of the table may have confused these individuals, many of which explored the maze by trailing one of the walls.

Figure 10.6 - Mean absolute angle error for locations pointed to in the maze



10.4.2.2 Absolute error: Locations estimated from

Subjects made the same number of pointing estimates for each location. In this manner the mean absolute error *for each group* is the same for locations *pointed to* and *estimated from*. What differs is the error score for each individual location. Regarding the accuracy for locations *estimated from,* results from the within test revealed a significant location effect ($F_{5,140}$, = 4.004, p = .002) indicating that the accuracy of pointing estimates varied from where the subjects made their pointing estimation. The interaction between location and group was also significant ($F_{15,140} = 1.985$, $p = .020$) meaning that the accuracy of pointing judgements changed depending on the location but changed in different ways.

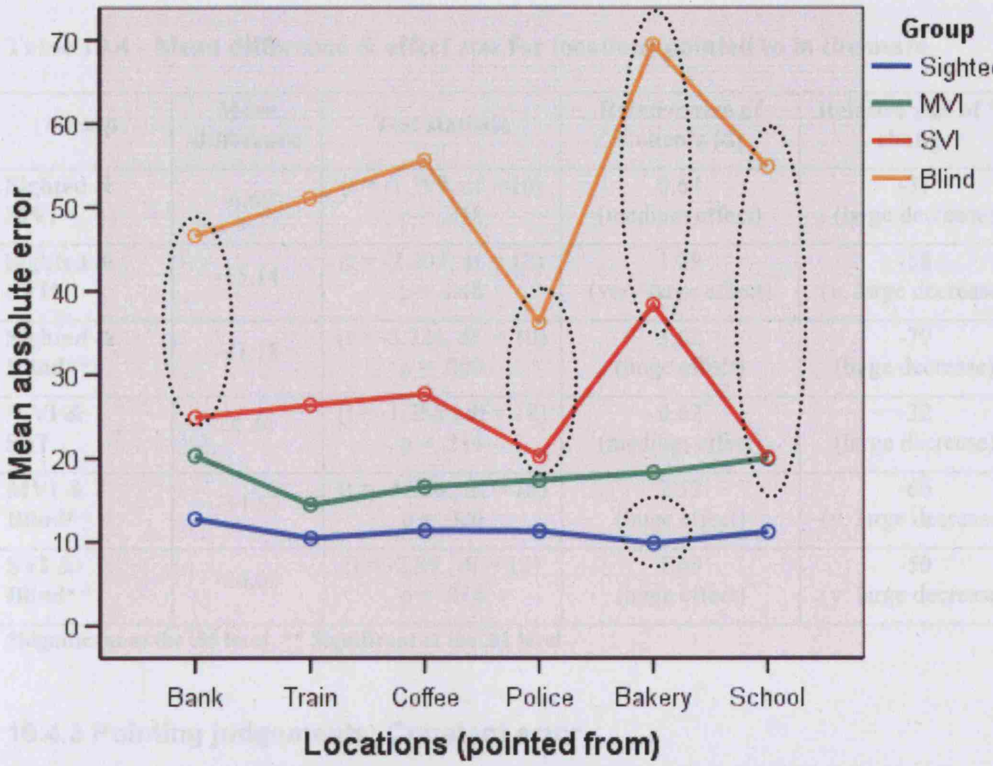
Table 10.3 - Mean absolute error for locations estimated from in the maze

Location	Sighted (SD) n=6	MVI (SD) n=12	SVI (SD) n=8	Blind (SD) n=6
Bank	12.73 (4.51)	20.27 (15.58)	24.90 (19.29)	46.63 (18.44)
Train Station	10.43 (6.71)	14.42 (16.64)	36.38 (17.19)	51.06 (28.11)
Coffee Shop	11.37 (6.82)	16.55 (8.53)	27.70 (22.38)	55.63 (13.78)
Police Station	11.30 (6.44)	17.35 (13.89)	20.30 (7.75)	36.27 (20.63)
Bakery	9.83 (3.20)	18.27 (15.88)	38.35 (30.60)	69.47 (28.36)
School	11.20 (7.77)	19.93 (18.76)	20.10 (10.51)	54.87 (29.23)
Total (6 locations)	11.14 (3.91)	17.80 (13.12)	26.29 (16.31)	52.32 (17.18)

Several trends can be observed from the graph in figure 10.7: The lines for the SVI and blind groups follow an almost identical trend with the blind committing higher pointing errors for all locations. The blind and SVI groups were the least accurate when *estimating from* the Bakery. This inaccuracy may be related to the position of the Bakery in maze. Unlike all other locations the Bakery was located at the centre of the maze where no other reference frame was available. In contrast, the sighted group was the best when *pointing from* this location. For this group, the location of the Bakery may have worked to their advantage as it allowed for a clear view of all other locations in the maze. The blind and SVI groups were more accurate when *estimating from* the Police Station and the Bank.

This result does not contradict but confirms the previous hypothesis regarding the complexity of space and its relation to pointing accuracy. There are three possible explanations: First, as mentioned above the subjects were guided in a specific order around the maze before making pointing estimates. The fact that the Police Station and the Bank were the last two locations to be visited allowed the subjects to build more accurate representations (correcting errors from their previous representations) of all the locations in the maze. Second, the position of the Police Station and the Bank are almost vertically aligned with that of the home base and this may have acted as a form of reference facilitating their pointing estimation. Third, the standard deviation for these two locations approaches 20 degrees and is evidence for the presence of good and bad performers. In this case, the actual complexity of the space may have worked to the advantage of good performers who found the Police Station and the Bank and used their position as salient landmarks.

Figure 10.7 - Mean absolute angle error for locations estimated from in the maze



10.4.2.3 Effect sizes: Absolute error

A series of independent sample t-tests were conducted for each pair of groups for locations *pointed to*. These are presented in table 10.4 along with the effect size, and the relative percent change.

The table confirms the trend observed in the analysis of variance with the sighted group performing the best followed by the MVI, SVI and the blind group. Results from the t-test, indicate statistically significant differences between the sighted and the SVI, and between the blind and the other three groups. According to Cohen's interpretation of effect sizes, the mean difference for these three groups and the blind is considered "huge." This is clear by looking at the relative size of percent change where there is at least a 50% difference between the estimates of these groups and the blind. Vision was a great aid during the pointing task and this is clearly reflected in the performance of the sighted, MVI and SVI groups. The performance of the MVI and SVI groups particularly aided by the size of the space where unlike the first experiment, some of the locations could not be located by sight alone. Although the overall performance of the blind was better in the second experiment it was still lower when compared to the other groups.

Table 10.4 - Mean difference & effect size for locations pointed to in the maze

Group	Mean difference	Test statistic	Relative size of Cohen's (d)	Relative size of % change
Sighted & MVI	-6.65	(t = -1.199, df =16) p = .248	0.64 (medium effect)	-37 (large decrease)
Sighted & SVI*	-15.14	(t = -2.207, df= 12) p = .048	1.29 (very large effect)	-58 (v. large decrease)
Sighted & Blind**	-41.18	(t = -5.724, df = 10) p = .000	3.62 (huge effect)	-79 (huge decrease)
MVI & SVI	-8.49	(t = -1.288 , df= 18) p = .214	0.62 (medium effect)	-32 (large decrease)
MVI & Blind**	-34.52	(t = -4.758 , df= 16) p = .000	2.52 (huge effect)	-66 (v. large decrease)
SVI & Blind**	-26.03	(t = -2.89 , df= 12) p = .014	1.69 (huge effect)	-50 (v. large decrease)

***Significant at the .05 level ** Significant at the .01 level**

10.4.3 Pointing judgements: Constant error

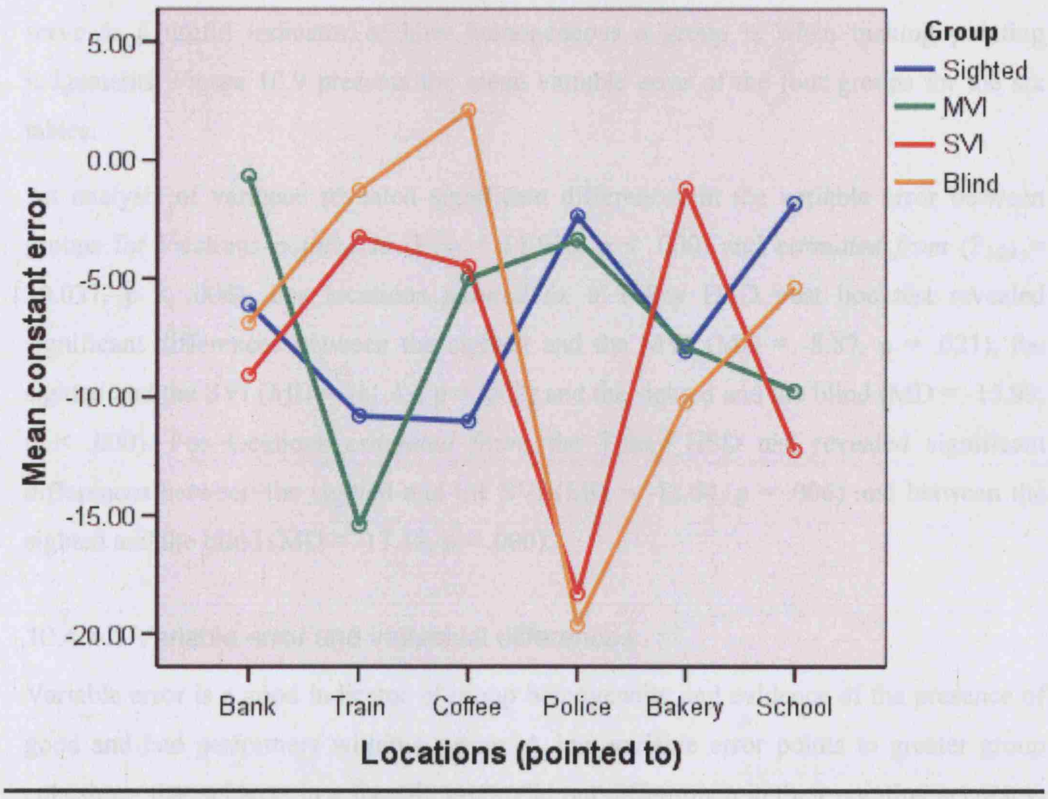
Mean constant error was calculated in order to identify any directional bias when *pointing to* the different locations in the maze. Figure 10.8 on the following page displays the mean constant error for the six tables in the maze. Errors scores higher than zero indicate a clockwise bias while scores lower than zero indicate a counter clockwise bias. Like in the previous analysis, we are particularly interested in the pattern of distortions across groups. That is, if subjects consistently overestimate or underestimate the direction of a location or a set of locations.

Results from the repeated measures ANOVA for locations pointed to revealed no significant differences between groups ($F_{3,28}$ = .030, p = .993). In addition, no significant differences were found for the within subjects test ($F_{5,140}$ = .637, p = .672), and the interaction between locations and groups was also not significant ($F_{5,140}$ = 2.473, p = .123). More interesting is the fact that all subjects had a counter clockwise bias when *pointing to* the six tables (slight exception for the blind when *pointing to* the Coffee Shop).

10.4.3.1 Constant error and the similarity of distance distortions

It is hard to identify the exact reason(s) for this underestimation (counter clockwise bias) but it is possible that the subjects were influenced by the position of the Mansion House located on the east side of the maze. All subjects met with the experimenter at the Mansion House, which was the last reference building visited prior to walking to the open field where the maze was constructed. Although the maze was at a considerable distance from the Mansion House, it is still possible that subjects used its relative salient position as a reference frame from which they could make their pointing judgements. The fact that the starting point had the same orientation and was parallel to the Mansion House also suggests that some of the subjects may have also used it as a reference frame.

Figure 10.8 - Mean constant error for locations pointed to in the maze



Looking at the graph, we notice that the blind and the SVI groups tend to follow a similar pattern of underestimation that differs from the one followed by the MVI and sighted groups. These differences however, were not significant - all subjects having a counter clockwise bias. In the previous chapter, we showed that all groups tended to follow a similar pattern of distortions (see figure 9.13 and 9.14) when *pointing to* locations around the RLSB campus. Although in some cases the magnitude of the distortion varied, all groups followed a similar pattern of clockwise and counter clockwise biases. The magnitude of counter clockwise distortions also varied between groups for the maze experiment but the fact that all subjects had a counter clockwise bias supports the idea that the representations of the blind and visually impaired although not as accurate, share some characteristics in common with those that are constructed mainly on the basis of vision. What remains to be seen, is whether like in the first experiment, the pattern of distortions will be similar across groups in the distance estimation and model construction tasks.

10.4.4 Pointing judgements: Variable error

Variable error when pointing *to and from* the six locations in the maze was also calculated for the four groups. As mentioned in the previous chapter, variable error can serve as a useful indicator of how homogeneous a group is when making pointing judgements. Figure 10.9 presents the mean variable error of the four groups for the six tables.

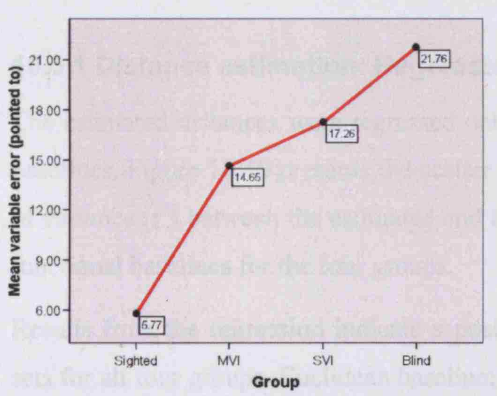
An analysis of variance revealed significant differences in the variable error between groups for locations *pointed to* ($F_{3,23}$ = 11.910, p < .000) and *estimated from* ($F_{3,23}$ = 10.037, p < .000). For locations *pointed to,* a Tukey HSD post hoc test revealed significant differences between the sighted and the MVI (MD = -8.87, p = .021), the sighted and the SVI (MD = -11.49, p = .002) and the sighted and the blind (MD = -15.99, p < .000). For locations *estimated from,* the Tukey HSD test revealed significant differences between the sighted and the SVI (MD = -12.04, p = .006) and between the sighted and the blind (MD = -17.18, p < .000).

10.4.4.1 Variable error and individual differences

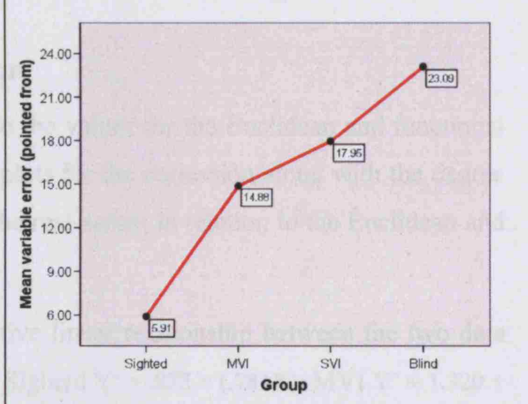
Variable error is a good indicator of group homogeneity and evidence of the presence of good and bad performers within a group. A low variable error points to greater group cohesion - that subjects in a specific group did not differ much in their pointing accuracy. Looking at figure 10.9a and 10.9b we note that this is mainly the case for the sighted group but also somewhat true for the MVI group. In figure 10.9c, we see that the blind and visually impaired groups were the most variable when *pointing to* the Police Station. This variability is evidence of the presence of good and bad performers in each of these groups. We also note that the Train Station, the location where the blind had the lowest absolute error, is also the place where the variable error was lowest. The sighted had the highest variable error when pointing *to* and *from* the School and this may be related to the relatively isolated position of this location. This error however, is still low when compared to those committed by the blind and visually impaired groups. Finally, looking at figure 10.9d, we note that the blind and SVI group had the highest variable error when *estimating from* the Bakery. As noted above, the Bakery was located at the centre of the maze, which may have facilitated the pointing from the sighted and MVI groups but confused those from SVI and blind groups.

Figure 10.9 - Mean variable error for locations pointed to and from in the maze

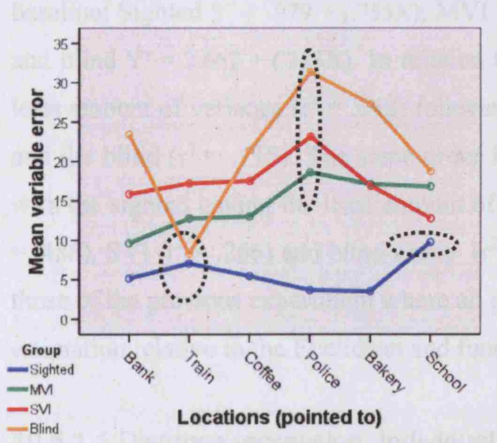
(a) Variable error by group (pointed to)



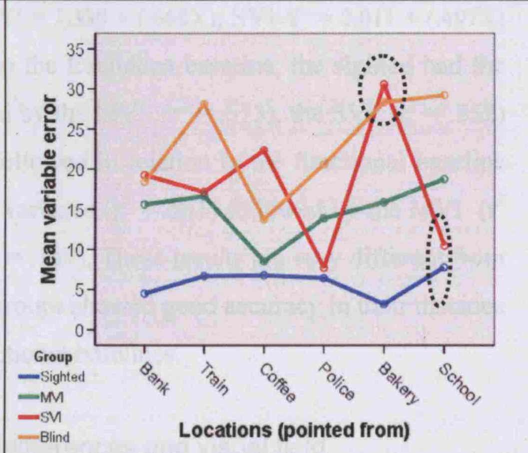
(b) Variable error by group (estimated from)



(c) Variable error by area (pointed to)



(d) Variable error by area (estimated from)



10.5 Distance estimation

The distance estimation task took place after all pointing judgments were completed. Knowledge of the relative distance between the six locations in the maze was tested with the method of triadic comparisons. A questionnaire with thirty triads was created and subjects estimated the distance between each possible pair of locations. For each triad, subjects were asked to estimate which two locations were the closest together and which two were the furthest apart. The pair judged closest was given a score of "0", the pair judged furthest a score of "2", and the remaining pair a score of "1". The scores of these four judgements were combined to give an overall value ranging from 0 to 8 for each pair of locations. Again, participants were not specifically instructed to estimate straight line or route distances. Two sets of values, for the Euclidean baseline and for the functional baseline were generated using the exact cartographic metrics in *ArcMap*. Two error scores, relative to the Euclidean (Eu) and functional (Fu) baselines, were calculated for each subject by subtracting the mean estimated value from each of the baseline values.

10.5.1 Distance estimation: Regression

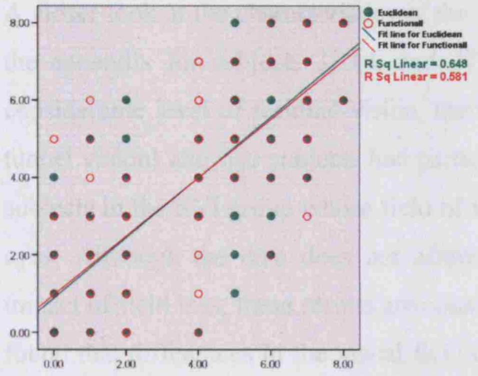
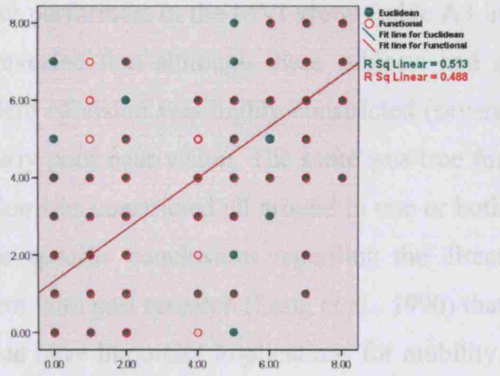
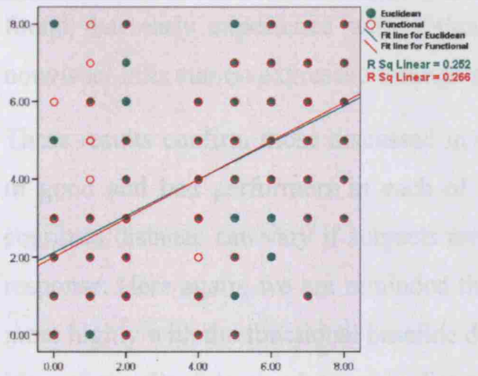
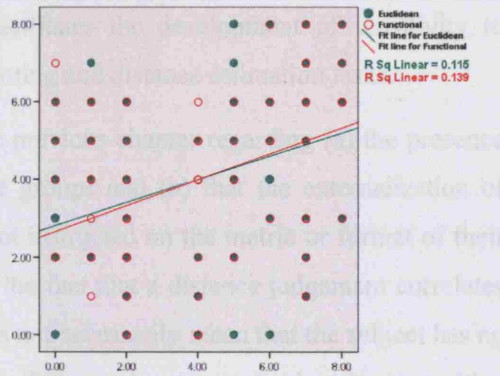
The estimated distances were regressed onto the values for the Euclidean and functional baselines. Figure 10.10 presents the scatter plots for the regression along with the degree of variance (r^2) between the estimated and the real values in relation to the Euclidean and functional baselines for the four groups.

Results from the regression indicate a positive linear relationship between the two data sets for all four groups. Euclidean baseline: Sighted Y' = .875 + (.781X); MVI Y' = 1.320 + (.670X); SVI Y' = 2.107 + (.473X) and blind Y' = 2.810 + (.298X). In relation to the functional baseline: Sighted Y' = .979 + (.755X); MVI Y' = 1.330 + (.668X); SVI Y' = 2.011 + (.497X) and blind Y' = 2.667 + (.333X). In relation to the Euclidean baseline, the sighted had the least amount of variance (r^2 = .648) followed by the MVI (r^2 = .513), the SVI (r^2 = .252) and the blind (r^2 = .115). The same order followed in relation to the functional baseline with the sighted having the least amount of variance (r^2 = .581) followed by the MVI (r^2 = .488), SVI (r^2 = .266) and blind group (r^2 = .139). These results are very different from those of the previous experiment where all groups showed good accuracy in their distance estimation relative to the Euclidean and functional baselines.

10.5.1.1 Distance regression: Individual differences and visual field

Rank order correlations were calculated for every participant in order to determine if the estimated values conform more closely to the Euclidean or functional baselines. As mentioned above this is an important step in the analysis as it identifies individual differences that are often masked by group analysis. Table A4 in the appendix presents the correlation coefficient and significance level for each participant in relation to the Euclidean and functional baselines (higher correlations are marked by a star).

Figure 10.10 - Regression of estimated distances in relation to (Eu) and (Fu) - Maze

Sighted (a)	MVI (b)
	
Regression Euclidean: Y' = .875 + (.781X) Regression functional: Y' = .979 + (.755X)	Regression Euclidean: Y' = 1.320 + (.670X) Regression functional: Y' = 1.330 + (.668X)
SVI (c)	**Blind (d)**
	
Regression Euclidean: Y' = 2.107 + (.473X) Regression functional: Y' = 2.011 + (.497X)	Regression Euclidean: Y' = 2.810 + (.298X) Regression functional: Y' = 2.667 + (.333X)

The distance judgements of all but one subject in the sighted group correlated more highly with the Euclidean baseline. Results also revealed the presence of a particularly bad performer in this group. The correlation coefficient for *subject 30* (see table A3 in the appendix) was low and not statistically significant with either the Euclidean or the functional baselines. In the case of the MVI and SVI groups, three subjects in each group tended to make judgements that correlated more highly with the functional baseline. These two groups also housed three very poor performers each (MVI subjects: 3, 14, 27; SVI subjects: 2, 8, 21) whose correlation coefficient was low and not statistically significant. Out of the six blind subjects, the distance judgements of only one subject (subject 11) correlated more highly with the Euclidean baseline. The judgements of one other subject correlated more highly with the functional baseline (subject 25). The rest of the group however, had very low correlation coefficients that were not statistically significant with either the Euclidean or the functional baseline.

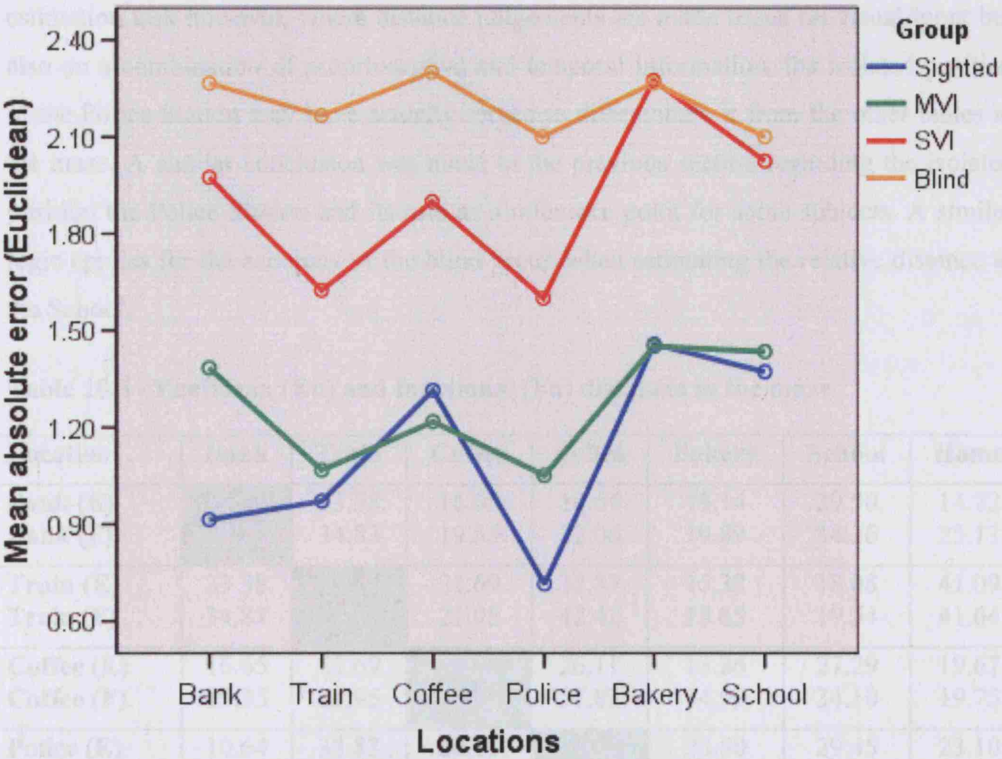
A closer look at the characteristics of the poor performers in the MVI group (table A3 in the appendix for subjects 3, 14, and 27) revealed that although these subjects had a considerable level of residual vision, their field of vision was highly constricted (severe tunnel vision) and two subjects had particularly poor near vision. The same was true for subjects in the SVI group whose field of vision was constricted all around in one or both eyes. Although the data does not allow for specific conclusions regarding the direct impact of field loss, these results are consistent with past research (Long et al., 1990) that found that differences in the visual field could have important implications for mobility. In the case of the blind subject, a closer look at the data revealed that the subject who was correlated more highly with the Euclidean baseline (subject 11) was also the only adventitiously blind subject in the group. This is consistent with Rieser et al. (1992) who found that early experience with vision facilitates the development of sensitivity to nonvisual information expressed through pointing and distance estimation tasks.

These results confirm those discussed in the previous chapter regarding (a) the presence of good and bad performers in each of the groups and (b) that the externalization of cognized distance can vary if subjects are not instructed on the metric or format of their response. Here again, we are reminded that the fact that a distance judgement correlates more highly with the functional baseline does not necessarily mean that the subject has no idea of the Euclidean relationship between different locations. A significant positive relationship between Euclidean and functional distances ($r = .896$, $DF = 493$, $p < .001$) was also found for the maze experiment.

10.5.2 Distance estimation: Absolute error

A repeated measures ANOVA was conducted in order to further investigate the effect of vision on distance estimation relative to the Euclidean baseline. Figure 10.11 presents the mean absolute error relative to the Euclidean baseline for the four groups broken down for the six locations in the maze. Results from the between group test revealed significant differences between groups in the accuracy of distance estimation ($F_{3,29} = 4.869$, $p = .007$). A Tukey post hoc test revealed significant differences in means for the sighted and the blind ($MD = -1.08$, $p = .022$) and for the MVI and the blind ($MD = .93$, $p = .028$). The sighted group was the most accurate followed by the MVI, SVI and the blind group. The within subject test revealed a significant location effect ($F_{5,145} = 3.785$, $p = .003$) but the interaction between location and group was not significant ($F_{15,145} = .545$, $p = .911$).

Figure 10.11 - Mean absolute distance error for tables in the maze



10.5.2.1 Distance estimation: Making sense of accuracy errors

Looking at figure 10.11, we note a similar pattern of accuracy in distance estimation for all four groups. We also note that the performance of the MVI tends to resemble more closely the one of the sighted while the performance of SVI resembles that of the blind. All groups had the highest error when estimating the relative distance of the Bakery. This may be related to the fact that Bakery is located at the centre of the maze where the distance to all other locations are relatively similar (see table 10.5) and consequently harder to differentiate. All subjects were more accurate when *pointing to* the Police Station. This result is somewhat at odds with those from the pointing task which revealed that the Police Station was one of the locations subjects (particularly the SVI and the blind) were the least accurate when *pointing to*. However, what may have confused subjects in the pointing task may have actually worked to their advantage in the distance estimation task. The higher accuracy when *pointing to* the Police Station may be related to the somewhat isolated position of this table in relation to others in the maze. Given that pointing is mainly a visual task, the isolated position of the Police Station may have confounded the judgements of the partially sighted subjects, who were making estimations on the remains of their vision or the blind subjects, many of which had problems finding this table, losing their orientation in the process. In the distance estimation task however, where distance judgements are made based on visual input but also on a combination of proprioceptive and temporal information, the isolated position of the Police Station may have actually served to differentiate it from the other tables in the maze. A similar conclusion was made in the previous section regarding the isolated position the Police Station and its role as a reference point for some subjects. A similar logic applies for the accuracy of the blind group when estimating the relative distance to the School.

Table 10.5 - Euclidean (Eu) and functional (Fu) distances in the maze

Locations	Bank	Train	Coffee	Police	Bakery	School	Home
Bank (E) **Bank (F)**		33.58 34.83	16.65 19.35	10.64 22.06	19.14 19.89	29.50 34.26	14.22 25.13
Train (E) **Train (F)**	33.58 34.83		21.69 21.95	38.83 42.42	15.32 15.65	18.08 19.54	41.09 41.64
Coffee (E) **Coffee (F)**	16.65 19.35	21.69 21.95		26.11 37.83	13.86 14.99	27.29 34.10	19.67 19.75
Police (E) **Police (F)**	10.64 22.06	38.83 42.42	26.11 37.83		23.50 24.77	29.45 33.40	23.10 43.32
Bakery (E) **Bakery (F)**	19.14 19.89	15.32 15.65	13.86 14.99	23.50 24.77		13.48 18.29	29.49 33.77
School (E) **School (F)**	29.50 34.26	18.08 19.54	27.29 34.10	29.45 33.40	13.48 18.29		41.90 51.10
Home (E) **Home (F)**	14.22 25.13	41.08 41.64	19.67 19.75	23.10 43.32	29.49 33.77	41.90 51.10	

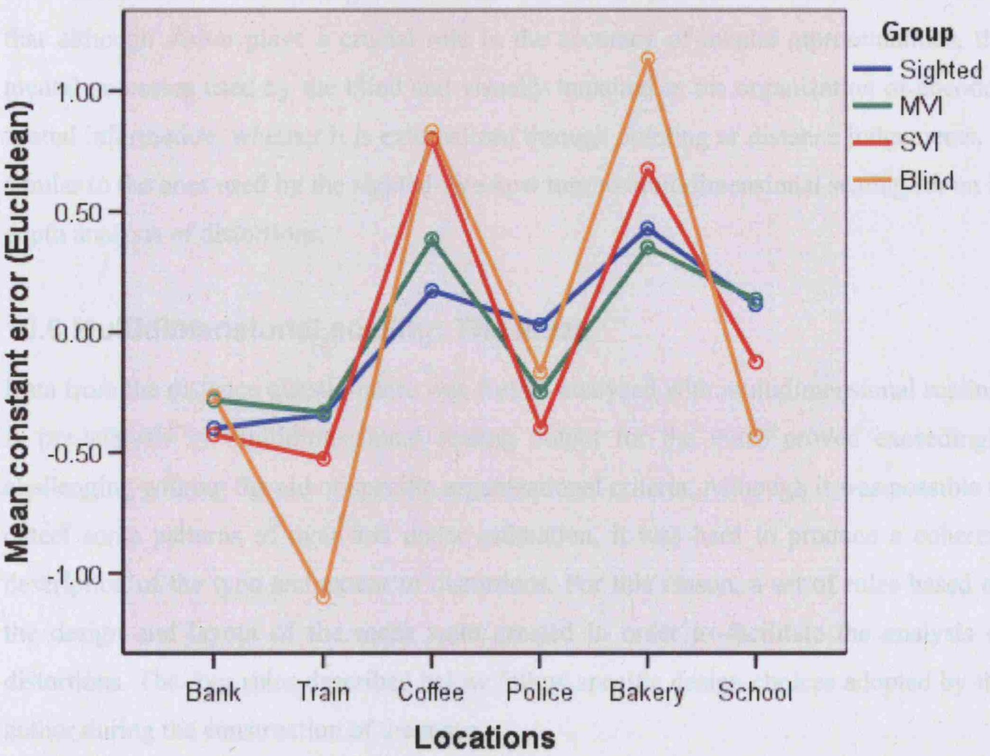
10.5.2.2 Distance estimation: Difference in accuracy between experiments

Two reasons may be attributed to the lower performance of all groups but particularly of the blind and visually impaired when compared to the first experiment. First, unlike the RLSB campus, the maze was a novel environment where the accuracy of representations was strictly based on a first trial exploration that lasted up to 45 minutes. The higher performance of the sighted and MVI groups is further evidence of the facilitating and calibrating effect of vision in the construction of mental representations. It seems that in a short period of time, vision was able to give the sighted and partially sighted subjects an advantage by providing spatial information that in the absence of sight requires more time to compile. Second, the small size of the maze may have confounded the estimation for all groups given that the variation in the relative distance for all locations was smaller. Locations in the maze were bunched together in a smaller space making it harder to differentiate in a triad, which two locations are the closest together and which two are further apart (see table 10.5). We will discuss this point in more detail when looking at the results from the multidimensional scaling analysis.

10.5.3 Distance estimation: Constant error

Mean constant error was also calculated in order to investigate the type of bias the different groups may have when estimating distances for the six locations in the maze. Figure 10.12 presents the mean constant error relative to the Euclidean baseline for the four groups broken down for the six locations in the maze.

Figure 10.12 - Mean constant error by locations in the maze



Results from the within subject test in a repeated measures ANOVA revealed a significant location effect ($F_{5,145} = 22.948$, $p < .000$). The interaction between locations and group was also significant ($F_{15,145} = 2.051$, $p = .016$). Looking at the graph, we see that all groups followed a similar trend of overestimation and underestimation and this varied depending on the location.

10.5.3.1 Constant error and the similarity of distance distortions

The similarity in distortions across groups provides convincing evidence that the blind (even the congenitally blind) are able form and manipulate mental representations of space constructed with the aid of proprioception and sensory modalities other than vision. Although large differences exist between groups in the accuracy of distance estimations, figure 10.12 makes it evidently clear that distortions in the mental representation of distances follows a similar trend of over and under estimation across groups. Much like the conclusions drawn from figures 9.14 and 9.18 in the previous chapter, it is now clear that although vision plays a crucial role in the accuracy of mental representations, the mental processes used by the blind and visually impaired in the organization of encoded spatial information, whether it is externalized through pointing or distance judgements, is similar to the ones used by the sighted. We now turn to multidimensional scaling for an in depth analysis of distortions.

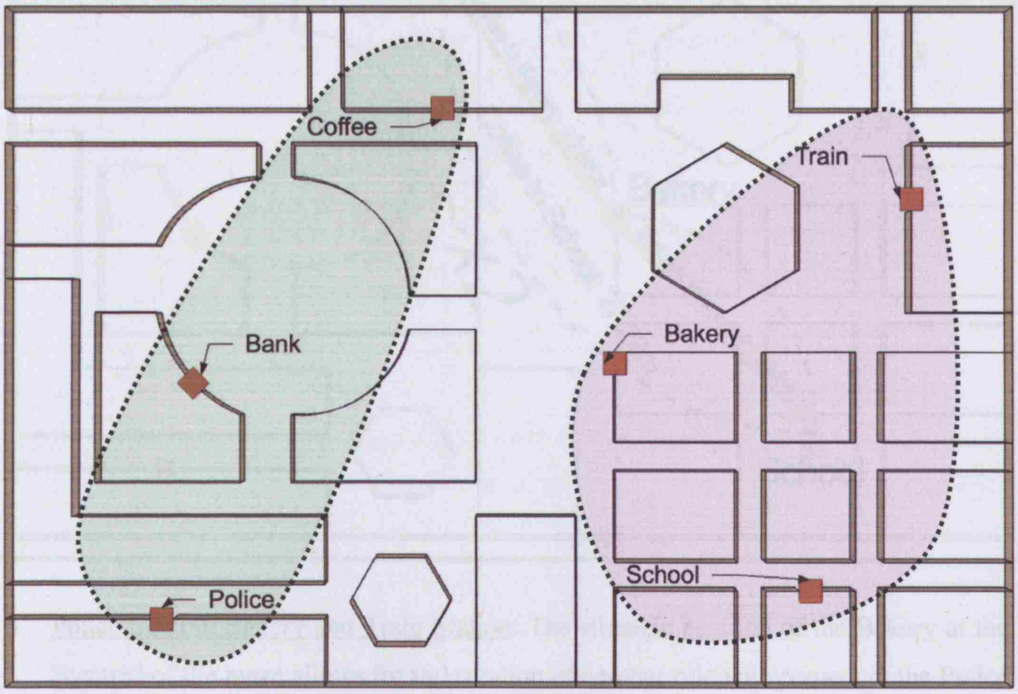
10.6 Multidimensional scaling: The maze

Data from the distance questionnaire was further analysed with multidimensional scaling. A pre-analysis of multidimensional scaling output for the maze proved exceedingly challenging without the aid of specific organizational criteria. Although it was possible to detect some patterns of over and under estimation, it was hard to produce a coherent description of the type and extent of distortions. For this reason, a set of rules based on the design and layout of the maze were created in order to facilitate the analysis of distortions. The four rules described below follow specific design choices adopted by the author during the construction of the maze.

1. <u>Maze areas</u>: The maze was designed with the idea of giving subjects the feeling that they were walking inside a city. They were instructed to think of the maze as a city and the tables were given specific names of shops, and services that are typically found in cities. It was decided that two areas would be created (see figure 10.13). The first area (green cluster) consisted of the Coffee Shop, Bank and Police Station and was designed as a relative open area with no specific regularities. The second area

(pink cluster) consisted of the Train Station, Bakery and School, and followed a stricter pattern of organization – the south-eastern part specifically designed as a grid. These areas are further distinguished by an empty space at the centre of the maze. Although a table from a cluster may be closer to another from a different cluster (i.e., Coffee Shop and Bakery), it was expected that if distances were estimated correctly, these two clusters would be visible through the MDS output. This was confirmed for the MDS output calculated with the Euclidean baseline (see figure 10.17c).

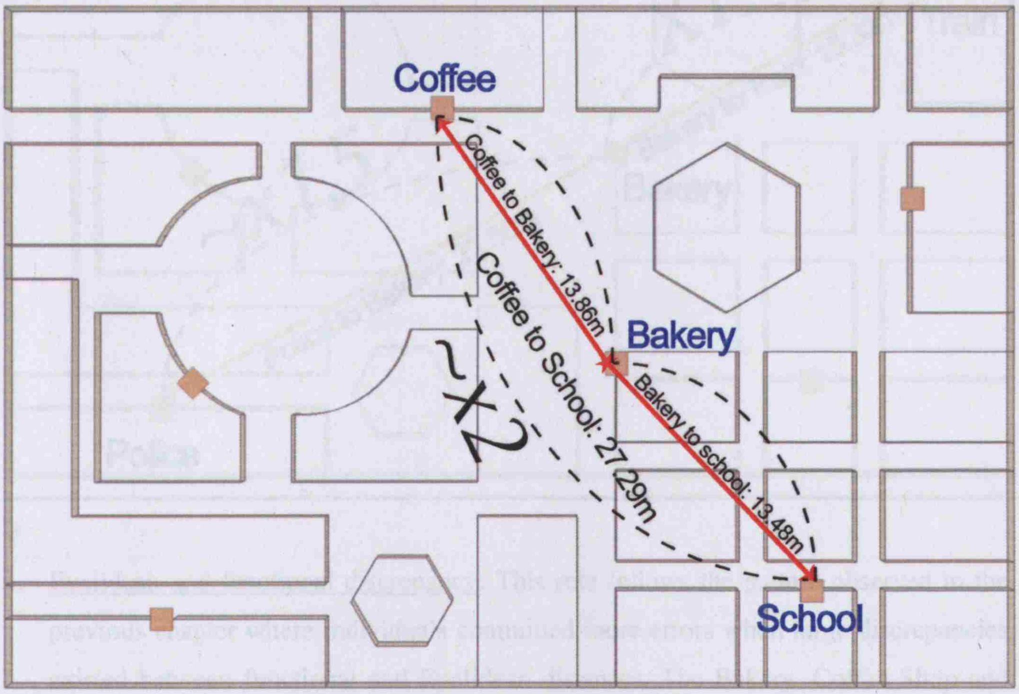
Figure 10.13 - Maze areas (rule #1)



2. Bakery at the Centre: The Bakery was strategically positioned at the "centre" of the maze with an equal distance to the Coffee Shop and the School. Looking at figure 10.14, we see that the Euclidean straight-line distance from the Bakery to the Coffee Shop is 13.86 meters and the distance from the Bakery to the School is 13.49 meters. Although there is a minor discrepancy between the distances of these two locations and the Bakery, we are reminded that distances were calculated to the centre of the table and that each table occupied one square meter. This rule allows for the specific evaluation of the MDS output in terms overestimation and underestimation from these two locations in relation to the Bakery. No matter what sort of configuration is produced by the MDS algorithm, the Bakery should always be located at an equal

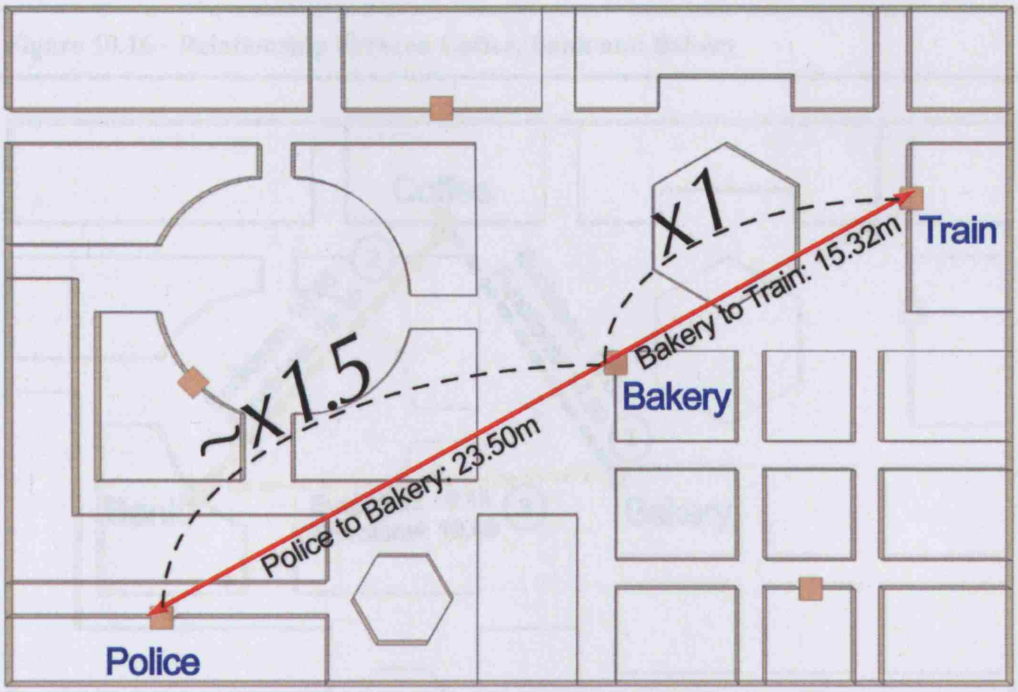
distance from the Coffee Shop and the School. In addition, it was hypothesized that the distance between the Bakery and School would often be overestimated given the discrepancy between the Euclidean and functional distances resulting from the grid-like design in the south-eastern area of the maze.

Figure 10.14 - Relationship between the Bakery, School and Coffee (rule #2)



3. Police Station, Bakery and Train Station: The strategic position of the Bakery at the "centre" of the maze allows for the creation of another rule with respect to the Police Station and the Train Station. Figure 10.15 presents this relationship. This rule follows a similar logic as the previous one except that instead of being located at the middle point between two locations, the Bakery is located 1.5 times further away from the Police Station than to the Train Station. Looking at the figure, we note that the distance from the Bakery to the Train Station is 15.32 while the distance from the Bakery to the Police Station is 23.50. Here again we are reminded that the small discrepancy is the result of distances being calculated to the centre of each table. Similar to the previous rule, this relationship should be evident from the MDS output and distortions may be evaluated in terms of over and under estimations.

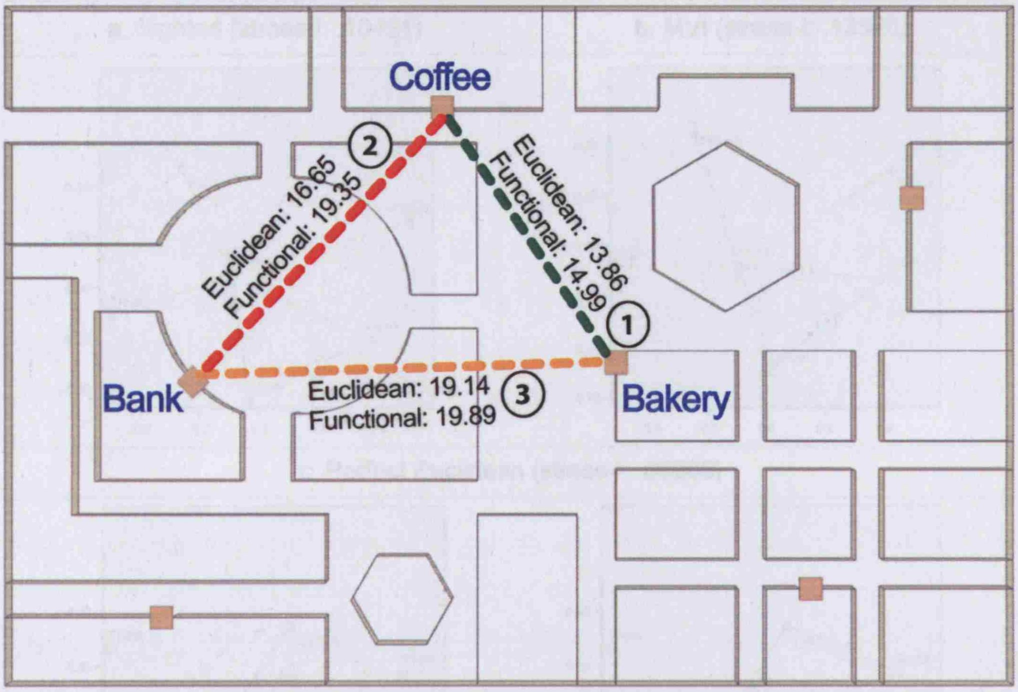
Figure 10.15 - Relationship between Police Station, Bakery and Train (rule #3)



4. Euclidean and functional discrepancy: This rule follows the pattern observed in the previous chapter where individuals committed more errors when large discrepancies existed between functional and Euclidean distances. The Bakery, Coffee Shop and Bank were positioned so that although they seem to be at an equal distance from each other, the Euclidean distance from the Coffee Shop to the Bank (16.65 meters) is 3 meters longer than the Euclidean distance between the Coffee Shop and the Bakery (13.86 meters) and 3 meters shorter then the distance between the Bank and the Bakery (19.14 meters). This is not the case for the functional distance whereby the shortest route continues to be that from Coffee Shop to the Bakery (14.99 meters) while the functional distance from the Coffee Shop to the Bank (19.35 meters) and from the Bank to the Bakery (19.89 meters) is equal. Given the almost straight-line route between the Bank and the Bakery, it was hypothesized that the Euclidean distance between these two locations would be underestimated. At the same time, the Euclidean distance between the Coffee Shop and Bank would be overestimated as a result of the route subjects were forced to cover in order to reach these tables. Figure 10.16 above presents the Euclidean relation between these tables with a triangle. The numbers next to each leg of the triangle characterize the Euclidean relationship – the

lowest number representing the shortest leg. The Euclidean and functional distances for each pair of locations are also presented.

Figure 10.16 - Relationship between Coffee, Bank and Bakery

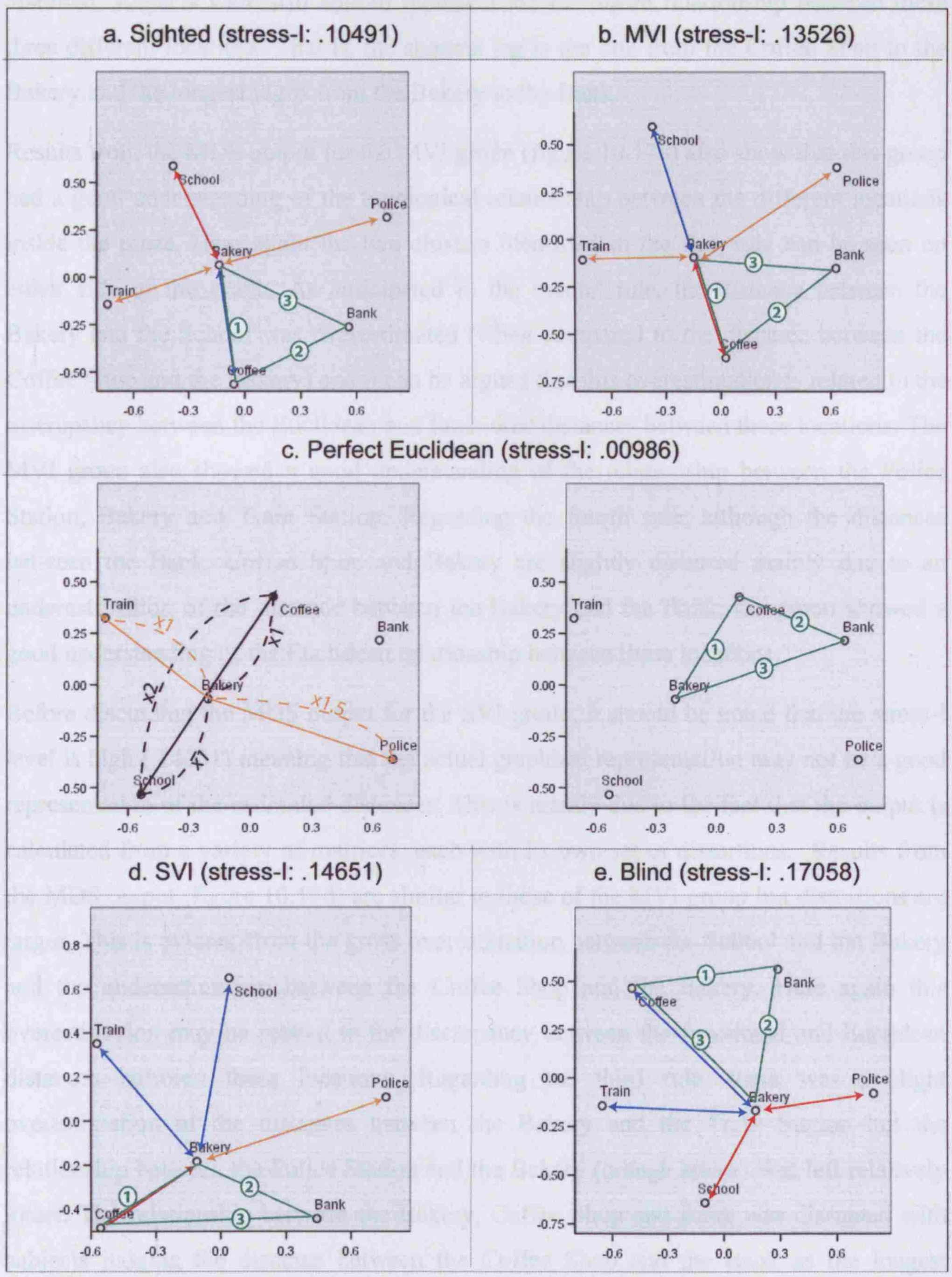


10.6.1.1 MDS output: Group distortions

Figure 10.17 on the following page presents the MDS output for the four groups. Given the extent of some distortions, the two clusters identified by the first rule will be considered but will not be graphically represented. Distortions relative to rules #2 and #3 will be represented with arrows. Red arrows indicate underestimations while blue arrows indicate overestimations. Orange errors are used when distortions were very small or inexistent. The fourth rule will be represented by a green triangle with numbers along each leg.

Results from the MDS output for the sighted group (figure 10.17a) revealed only minor distortions relative to the Euclidean baseline (10.17c). The two clusters (Coffee Shop, Bank, Police Station & Train Station, Bakery, School) identified can be easily spotted on either side of the graph. With regard to the second rule, there is only a slight underestimation between the School and the Bakery, and a corresponding overestimation between the Coffee Shop and the Bakery. The Bakery however, is still well centred between these two locations.

Figure 10.17 - Distortions relative to Euclidean baseline



The relationship between the Trāin Station, Bakery and the Police Station is also relatively intact with the Euclidean distance between the Police Station and the Bakery being around 1.5 times longer than the distance between the Bakery and the Train Station. Finally, although the distances between the Coffee Shop, Bank and Bakery are slightly distorted, subjects were still able to represent the Euclidean relationship between these three different locations. That is, the shortest leg is the one from the Coffee Shop to the Bakery and the longest leg is from the Bakery to the Bank.

Results from the MDS output for the MVI group (figure 10.17b) also show that this group had a good understanding of the topological relationship between the different locations inside the maze. Here again the two clusters identified in the first rule can be seen on either side of the graph. As anticipated in the second rule, the distance between the Bakery and the School was overestimated (when compared to the distance between the Coffee Shop and the Bakery) and it can be argued that this overestimation is related to the discrepancy between the Euclidean and functional distances between these locations. The MVI group also showed a good understanding of the relationship between the Police Station, Bakery and Train Station. Regarding the fourth rule, although the distances between the Bank, Coffee Shop and Bakery are slightly distorted mainly due to an underestimation of the distance between the Bakery and the Bank, the group showed a good understanding of the Euclidean relationship between these locations.

Before discussing the MDS output for the SVI group, it should be noted that the stress-I level is high (.14651) meaning that the actual graphical representation may not be a good representation of the estimated distances. This is mainly due to the fact that the output is calculated from a variety of matrices, each with its own set of distortions. Results from the MDS output (figure 10.17d) are similar to those of the MVI group but distortions are larger. This is evident from the gross overestimation between the School and the Bakery and the underestimation between the Coffee Shop and the Bakery. Here again this overestimation may be related to the discrepancy between the functional and Euclidean distances between these locations. Regarding the third rule, there was a slight overestimation of the distances between the Bakery and the Train Station but the relationship between the Police Station and the Bakery (orange arrow) was left relatively intact. The relationship between the Bakery, Coffee Shop and Bank was disrupted with subjects judging the distance between the Coffee Shop and the Bank as the longest followed by the distance between the Bank and the Bakery. Again this may be related to the fact that although the functional distances between the Coffee Shop and the Bank and between the Bank and the Bakery are similar, the route from the Bank to the Bakery is relatively straight. Overall it seems that as a group, subjects tended to place the Bakery closer to the Bank and the Coffee Shop rather than to the Train Station and School. In fact, a look at the graph in figure 10.17d shows that in contrast to the first rule, the two clusters are: 1- Coffee Shop, Bakery and Bank; 2- Train Station, School and Police Station. Figure 10.17e presents the MDS output for the blind group. Unfortunately, the stress value is too high (.17058) in order for conclusions to be made about the group's distortions. Results from blind group will be analysed individually in the next section when we look at distortions committed by the bottom performers in each group.

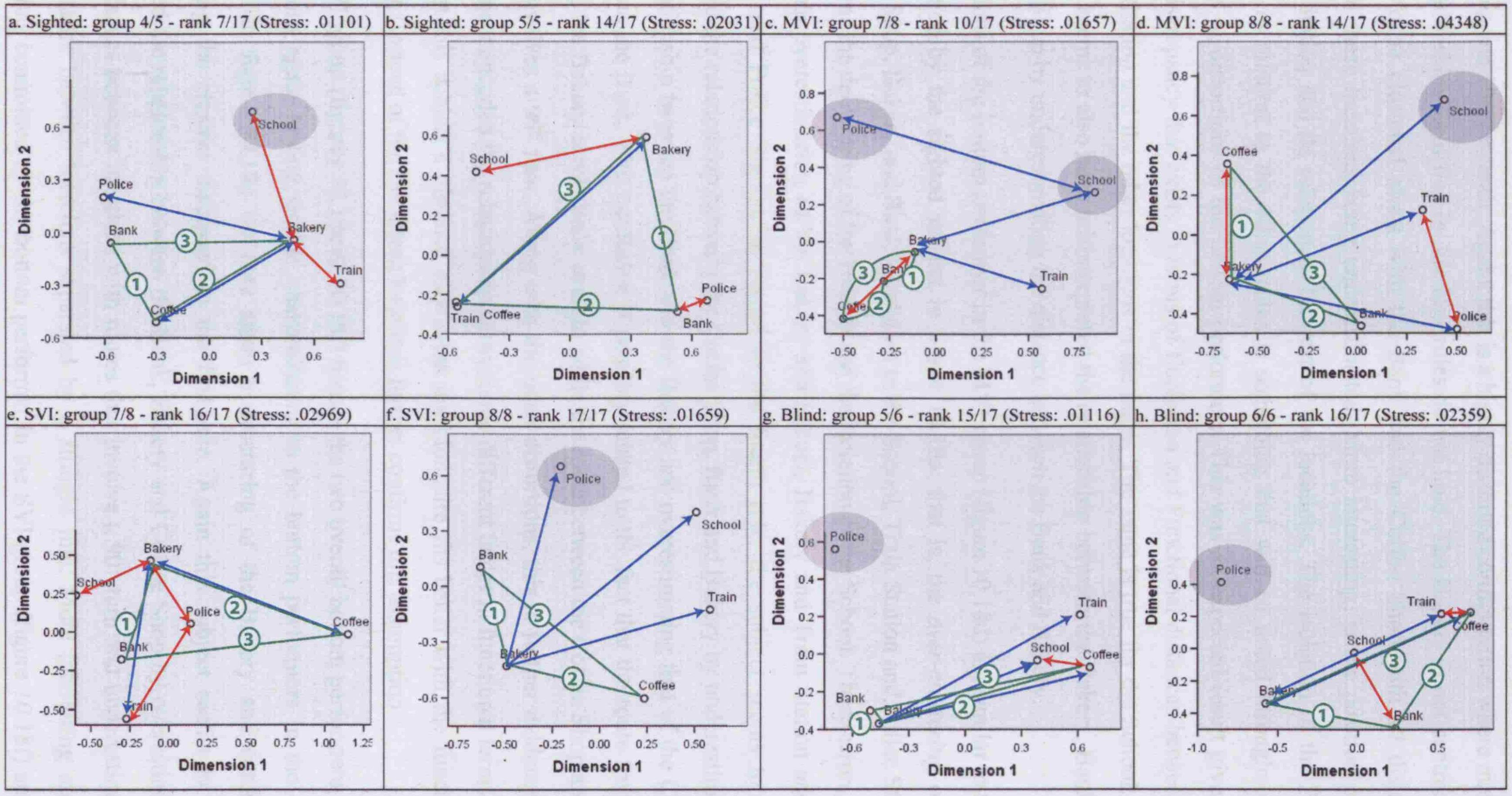
10.6.1.2 MDS output: Bottom performers

Figure 10.18 presents the MDS output for the two bottom performers in each group. Results are analyzed according to the rules established above. This section is important as it highlights the fact that irrespective of visual condition, the bottom performers of the different groups shared similar distortion patterns.

Figure 10.18a presents the MDS output for the sighted subject who ranked last but one in the group and 7/17 overall. Looking at the figure, it is evident that although the subject seems to have partitioned the maze according to the two clusters discussed in the first rule, this eventually led to a de-centring of the Bakery and an underestimation of the distance between the Bakery and the School and between the Bakery and the Train Station. This large differentiation between the two areas also led to an overestimation of the Bakery and Police Station and the Bakery and Coffee Shop.

Figure 10.18b presents the MDS output for the bottom performer in the sighted group. This is a highly distorted representation and not common to subjects with vision. The main error is related to the gross de-centring of the Bakery in relation to the other locations leading to a large overestimation between the Bakery and the Coffee Shop and between the Bakery and the Train Station. The relationship between the Bakery, Coffee Shop and Bank is also highly distorted with the distance between the Bakery and the Bank being treated as the shortest. At first, it was thought that this large distortion was the result of a mnemonic difficulty or confusion between the names of the different locations. This however cannot be the case given that the subject ranked 6/32 in the angle estimation and 12/32 in the model building – two tests that also require the association between names and locations.

Figure 10.18 - Distortion for bottom performers



⇒ = Underestimate ⇒ = Overestimate ⇒ = No distortion

Figure 10.18c, presents the MDS output for the MVI subject who ranked last but one in the group and 10/17 overall. Again, this is a highly distorted configuration where many of the relationships identified by the four rules do not hold. The Bakery is not centred and seems to be clustered along with the Bank and the Coffee Shop with all distances between these locations being underestimated. More interesting, is the position of the Police Station and its relation to the rest of the locations. The isolation of the Police Station in relation to the other tables is something that will be noted throughout the analysis of distortions of the bottom performers. This was an expected result given the large discrepancy that exists in terms of Euclidean and Functional distances between the Police Station and the other locations in the maze. The same is true for the School. This subject seems to also have misinterpreted the relationship between the Bakery, Bank and Coffee Shop by underestimating the distance between the Bank and Bakery.

Distortions of the bottom performer in the MVI group (figure 10.18d) are similar to those committed by the sighted subject in figure 10.18a; that is, the *over-clustering* of the Coffee Shop, Bakery and Bank in relation to the School, Train Station and Police Station as well as the de-centring of the Bakery and the isolation of the School. These errors have led to an overestimation of the Bakery and School, Bakery and Train Station and the Bakery and Police Station. In regard to the fourth rule, the subject seems to have confused the relationship between the Coffee Shop, Bank and Bakery by underestimating the relationship between the Bank and the Bakery and overestimating that of the Coffee Shop and the Bank. This confusion is possibly related to the fact that the route from the Bank to the Bakery is relatively straight while the route between the Coffee Shop and the Bank involves a 90° turn. Along with the other distortions, this is further evidence that this subject encoded the relationship between the different tables in functional terms. The fact that this subject's distance estimation questionnaire fits better with the functional baseline (instead of the Euclidean baseline) further confirms this assumption.

The SVI group (figures 10.18e & 10.18f) houses the two overall bottom performers, their distortions again having similar characteristics to the bottom performers in the other groups. In figure 10.18e we note again a decentring of the Bakery and confusion regarding the clusters discussed in the first rule. Again this subject seems to have confused the relationship between the Bank, Bakery and Coffee Shop by overestimating the distances between locations with routes that involve a 90° turn and underestimating the distance between locations separated by a straight line. More interesting are the distortions committed by the bottom performer in the SVI group (figure 10.18f) and the fact that they are almost identical with those committed by the bottom performer in the MVI group (figure 10.18d). This is evident from the isolation of the Police Station and School, the de-centring of the Bakery and the confusion caused by right-angled turns in the relationship between the Bank, Bakery and Coffee Shop.

Distortions by the bottom performers in the blind group are also quite extreme (see figures 10.14g & 10.14h). In both cases, we note an isolation of the Police Station in relation to the other locations. Both subjects seem to have also misinterpreted the relationship between the Bank, Bakery and Coffee Shop underestimating the distance between locations separated by a straight line (Bank and Bakery) and overestimating those that involve a right angle turn.

10.7 Model building

The final task consisted of completing a cued model of the maze. Seven magnetic pieces representing a scaled version of the six tables and the starting point were created and three (Bakery, Police Station and the starting point) were fixed in their real cartographic location on a gridded (1 cm X 1cm) magnetic white board similar to the one used in the previous experiment. Subjects were asked to position the remaining four pieces in relation to the fixed ones in order to reconstruct the position of all tables in the maze. They were told to ask for the pieces (in no particular order), which were handed to them by the researcher. There was no time limit although students were told that they would be timed. They were also told that they could position all locations first and later move them. The board was not fixed allowing each subject to vary its orientation during the task.

10.7.1 Bidimensional regression

The position of the estimated locations was calculated using a coordinate system (x, y) provided by the actual margins of the white board which was also tabbed by wood strips, the bottom left grid-square representing (x1, y1). After the four magnetic pieces were placed, the investigator stopped the time and collected the coordinates for each location. Results from the model were analysed via bidimensional regression and a distortion index was calculated for each subject. Table 10.6 presents the results for the model task along with the minimum and maximum values for each group.

As it can be observed in the table, the sighted was the best performing group followed by the MVI, SVI and blind groups. The minimum and maximum distortion index scores also point to large variations in performance (red highlight). This is particularly the case for the MVI, SVI and blind groups, each containing at least a very good and a very bad performer.

Table 10.6 - Bidimensional regression (r^2) and distortion index (DI) for maze

Group (n)	r^2 (SD)	Distortion index (SD)	Min DI	Max DI
Sighted (7)	.98 (.01)	12.44 (4.00)	8.65	17.42
MVI (12)	.91 (.17)	23.18 (19.64)	**10.09**	**76.24**
SVI (8)	.74 (.33)	40.57 (31.38)	**9.30**	**99.66**
Blind (6)	.72 (.26)	46.34 (27.72)	**17.90**	**78.55**

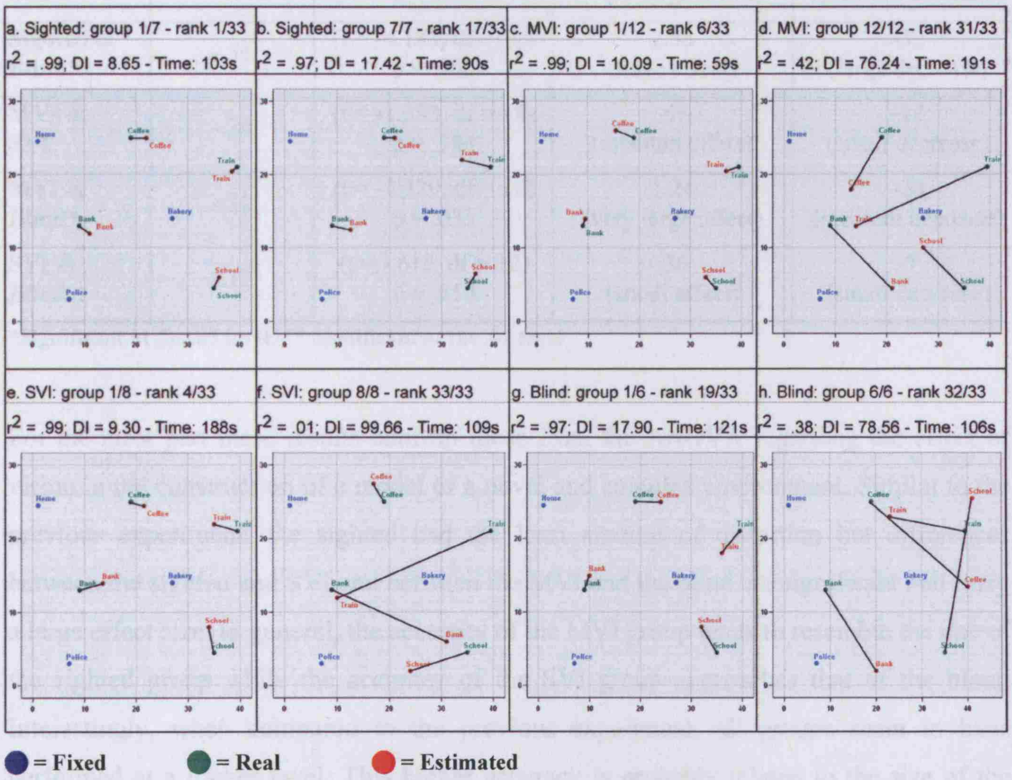
10.7.1.1 Individual differences: Top and bottom performers

In order to further investigate these individual differences, subjects were ranked on the basis of their distortion index in relation to group and overall performance. Distortions of the top and bottom performers for each of the groups were isolated and these are presented in figure 10.19 on the following page. In the figure, the blue circles represent the fixed locations, while the green and red circles represent the real and estimated locations respectively. The black lines that connect the real and estimated locations indicate the direction and magnitude of the shift.

Similar to the experiment in the RLSB campus, the distortion index for the top performers in the MVI, SVI and blind groups (10.19c, 10.19e and 10.19g) was relatively low. Despite differences in visual acuity, and in the case of the blind, the total absence of vision, subjects were still able to construct accurate models and represent the spatial relationship between the different locations in a novel environment after exploring it within a limited amount of time. Once again, vision does not seem to be a defining factor in the construction of mental representations as suggested by the deficiency and inefficiency theories. The top performers in the MVI and SVI groups fall within the top ten overall performers and although the top blind performer is ranked 19/33, the distortion index for this subject is still relatively small (DI = 17.90).

With regard to the bottom performers, the MVI, SVI and blind contain the three overall bottom performers. However, despite their large distortions, vision cannot be considered the only factor involved in the ability (or lack of) to represent space during exploration given that these subjects were outperformed by others, in the same or different groups, with inferior visual acuities. The distortion index for the bottom performer in the SVI group (subject 8) is extremely high (99.66%), yet it is hard to believe that this subject could not represent at least one location in the entry to maze (the Coffee Shop was only a few meters away in a straight line from the entry of the maze). It seems that this low performance is more the result of a testing artefact rather than the ability to mentally represent space.

Figure 10.19 - Distortions top and bottom performers (maze)



10.7.1.2 Bidimensional regression and group differences

Given this large variation in performance, it was no surprise that Levene's test of homogeneity of variance was violated (.009). In order to make use of the data, the original distortion index values were converted to logarithms to correct for the assumption in the ANOVA where the variance is the same across all data (see chapter 9). After the logarithmic conversion, Levene's test for the homogeneity of variance was not violated (.078). Results from a one-way ANOVA revealed a significant effect of vision in the construction of the cued model ($F_{2,29} = 4.383$, $p = .012$). A Tukey HSD post hoc test revealed that significant differences only exist between the sighted and the blind group ($p = .014$) although the mean difference between the sighted and the SVI group approached significance ($p = .051$). Effect sizes were also calculated using the logarithmic transformed distortion index and these are presented in table 10.7 below.

Table 10.7 - Effect size for distortion index (DI) in model for the maze

Group	Mean difference	Test statistic	Relative size of Cohen's (d)	Relative size of % change
Sighted & MVI	-.20	(t = -1.847, df = 17) p = .082	0.93 (large effect)	-16 (medium decrease)
Sighted & SVI*	-.40	(t = -2.576, df = 13) p = .023	1.43 (very large effect)	-27 (medium decrease)
Sighted & Blind**	-.51	(t = -4.183, df = 11) p = .002	2.53 (huge effect)	-32 (large decrease)
MVI & SVI	-.20	(t = -1.383, df = 18) p = .184	.67 (medium effect)	-14 (small decrease)
MVI & Blind*	-.32	(t = -2.329, df = 16) p = .033	1.24 (very large effect)	-20 (medium decrease)
SVI & Blind	-.12	(t = -.615, df = 12) p = .550	.36 (small effect)	-7 (small decrease)

***Significant at the .05 level ** Significant at the .01 level**

For the most part these results confirm those from the ANOVA regarding the effect of vision in the construction of a model of a novel and complex environment. Similar to the previous experiment, the sighted had the least amount of distortion but differences between the sighted and SVI and between the MVI and the blind are significant and carry a large effect size. In general, the accuracy of the MVI group tends to resemble the one of the sighted group while the accuracy of the SVI group approaches that of the blind. Interestingly, when compared to the previous experiment, all groups seem to have performed at a higher level. This higher accuracy is probably related to the size of the space and the fact that subjects only had to place 4 pieces instead of seven. Unlike the previous experiment however, the SVI group did not perform better that the MVI group. There it was argued that the SVI had an advantage in model construction given that they were more accustomed in dealing with tactile and visual information. However, given the size of the maze and the fact that many of the MVI subjects could simultaneously see and integrate the position of different tables, this trained aptitude for motor tasks was still no match for the accuracy of representations that were mainly built with the help of vision. Finally, there was no difference between groups in the time taken to construct the model although the results did approach significance ($F_{3,29}$ = 2.780, p = .059). This difference however was not a function of visual acuity as the sighted were the quickest to complete the model (78s) followed by the MVI (138s), blind (152s) and the SVI (179s). The relationship between time taken to construct the model and accuracy was also not significant.

10.7.1.3 Bidimensional regression and the similarity of distortions

Results from the bidimensional regression also allow us to look at the type of distortions committed by the different groups as well as specific individuals within these groups. This is an important step in the analysis, given that the degree of fit does not distinguish between the types of distortions. That is, the overall degree of fit for different groups of subjects may be similar but the distortion committed may vary in terms of translation ($\alpha 1$ & $\alpha 2$), scale and angle (θ) displacements. Table 10.8 presents a summary of the distortions for each of the groups.

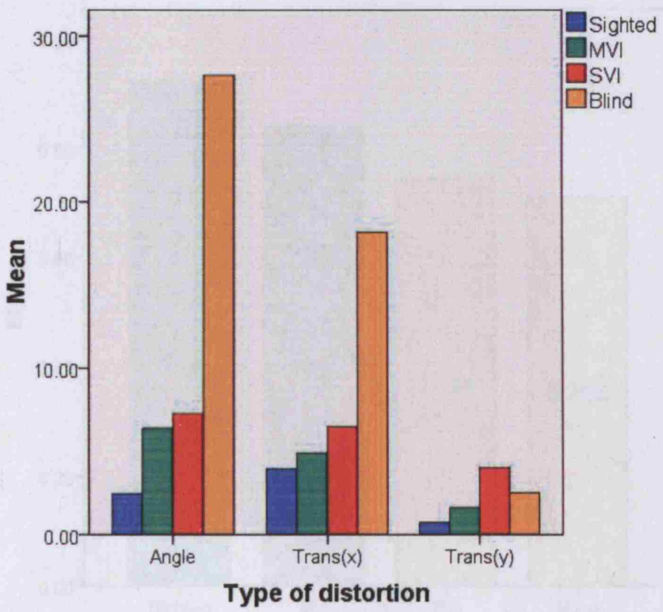
Table 10.8 - Mean differences and effect size for distortions in models (maze)

Group	Alpha 1 (x) (d)	Alpha 2 (y) (d)	Angle (d)	Scale (d)
Sighted vs. MVI	-.92 .22 (small)	-.90 .28 (small)	-3.93 .26 (small)	.08 .50 (medium)
Sighted vs. SVI	-2.53 .48 (medium)	-3.29 .82 (large effect)	-4.82 0.21 (small)	.18 .82 (large)
Sighted vs. Blind	-14.24* 1.56 (huge)	-1.79 .58 (medium)	-25.19 1.17 (v. large)	.21** 1.92 (huge)
MVI vs. SVI	-1.61 .27 (small)	-2.40 .58 (medium)	-.89 .04 (negligible)	-.10 .40 (medium)
MVI vs. Blind	-13.32* 1.53 (huge)	-.90 .25 (small)	-21.26 .90 (large)	.13 0.71 (medium)
SVI vs. Blind	-11.71 1.15 (v. large)	1.50 .34 (small)	-20.36 .65 (medium)	.04 .15 (small)

***Significant at the .05 level ** Significant at the .01 level**

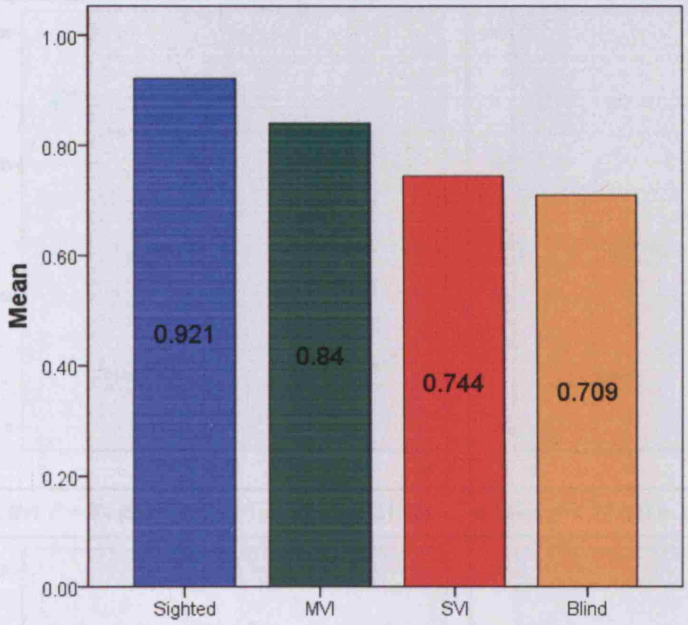
Looking at the table 10.8, one notices that significant differences exist between the sighted and the blind and between the MVI and the blind in relation to east/west translation. Significant differences also exist between the sighted and the blind in relation to scale. The sighted generated the least amount of distortion, followed by the MVI, SVI and blind (a slight exception exists for the blind group regarding north-south translations). Nonetheless, a quick glance at the charts in figure 10.20 and 10.21 make it clear that although there are differences in the magnitude of the distortion, (distortions were higher for the MVI, SVI and blind groups), all groups follow a similar pattern of distortions. That is, despite differences in the accuracy of models (differences in DI between groups), all groups tended to commit the same type of distortions in relation to translation, angle and scale shifts.

Figure 10.20 – Angle and translation distortions (maze)



As noted in the chapter 8, translation, angle and scale values indicate how much change is needed to produce the best-fit shape between the cognitive and the real configurations (Kitchin & Blades, 2002). Regarding east/west translations we note that all subjects had a tendency to distort the configuration towards the east, this tendency increasing as visual acuity decreased. The same is true for north/south distortions where all subjects tended to distort the configuration towards the north. Once again, higher distortions occurred as visual acuity decreased with a small exception for the blind group. Regarding angle distortions, positive values indicate that a counter clockwise rotation is necessary in order to produce the best fit. Looking at figure 10.20, we note that all subjects tended to distort their configuration in clockwise fashion – once again the degree of shift varying as a function of visual acuity with the blind committing considerably high angle distortions. Scale values less than 1 indicate that the variant configuration needs to be contracted to produce the best fit while values higher than 1 indicate that the configuration needs to be expanded. Looking at the chart in figure 10.21 we notice that all groups had scale values above 1 and that the amount of contraction also varied as a function of visual acuity, this time the blind committing the least amount of distortions.

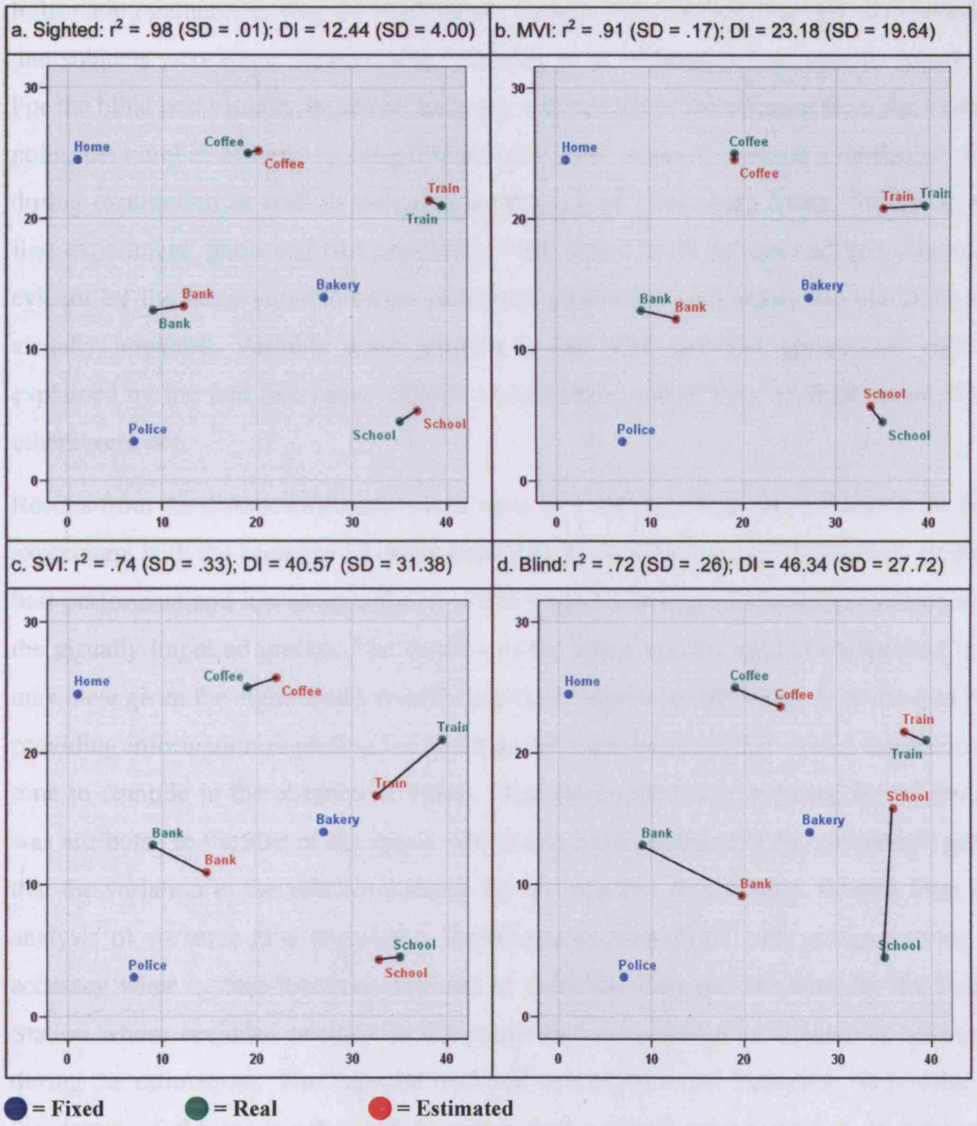
Figure 10.21 – Scale distortions (maze)



In general these results support the notion that the blind and visually impaired are able to construct mental representation from information that is not necessarily collected nor assembled through vision, and that they are able to manipulate this spatial information in a similar fashion to the sighted when asked to reproduce the overall configuration between elements in an environment.

Figure 10.22 in the following page is a scatter plot representing the results of the model task for the four groups. The figure allows us to visualize the extent of the similarity of distortions between the different groups. The east and north distortion are clearly visible for the sighted group (figure 10.22a) as these were accompanied by a very small clockwise distortion. We also note that the entire configuration has been contracted towards the centre (Bakery). The same is true for the MVI and SVI groups (figures 10.22b and 10.22c) but distortions are accompanied by a greater clockwise angle error. We also note that that both configurations are contracted towards the centre. In regard to the blind group (figure 10.22d), the high angle error makes it hard to isolate the relative low east and north distortions. The blind group had particular difficulties with the position of the School and the Bank. Once again the entire configuration seems to be contracted towards the centre.

Figure 10.22 - Group distortions and magnitude shift (maze)



10.8 Summary: Accuracy and distortions

Results from the maze experiment confirmed many of the hypotheses put forward in the previous chapter regarding the accuracy and distortions of mental representation constructed in the partial or total absence of vision. Results from the pointing test revealed significant differences between the different groups with the sighted performing best followed by the MVI, SVI and blind groups. In general, all subjects performed better when compared to the first experiment but vision remained an important factor in performance. The better results by the blind and the visually impaired can be attributed to the smaller size of the space, which allowed subjects to (a) use what remained of their vision when making the pointing judgments or (b) to better integrate piecemeal spatial information gathered during the exploration. Results from the pointing task also revealed that subjects were more accurate when *pointing to* or *estimating from* specific locations. For the blind and visually impaired, accuracy was related to the distance from the starting point, the number of turns or complexity of the route required to reach a particular table during exploration as well as the presence/absence of a reference frame. Similar to the first experiment, good and bad performers were found in all groups and this was made evident by the large variable errors (standard deviations) particularly for the blind and visually impaired. Variable errors present in the MVI and SVI groups can also be explained by the fact that some subjects were making use of their residual vision while others were not.

Results from the distance estimation task were very different from those found in the first experiment with the accuracy of estimation of all groups decreasing. The sighted were the best performers and it was argued that vision played a crucial role in the performance of the visually impaired groups. The novelty of the space and the limited exploration time may have given the sighted and visually impaired subjects an advantage over the blind by providing information regarding the distance between locations that would require more time to compile in the absence of vision. Here again, the lower accuracy for all groups was attributed to the size of the space, which may have confounded the estimations given that the variation in the relative distance for all locations was smaller. Results from the analysis of variance also revealed a significant location effect with groups varying in accuracy when certain locations featured in the triad. This was the case for the Police Station whose secluded position in the maze may have served as a frame of reference during the estimations. The opposite occurred in relation to the Bakery as its position in the centre of the maze often led to errors with subjects representing it as relatively equidistant to all other locations.

Results from the distance estimation task also made evident that even in a novel and complex environment blind and visually impaired subjects are able to understand and represent the Euclidean relationship among objects. As seen through the rank order correlations, the estimation of at least one subject in each group was significantly correlated to the Euclidean baseline. The total or partial absence of vision does not necessarily force individuals to think in terms of routes although the blind and visually impaired had a greater tendency to do this. Large individual differences in the ability to accurately estimate distances were also observed within each of the groups. All groups had at least one subject whose estimations were very distorted and did not conform to either baseline.

Results from the model construction task revealed that all groups were more accurate in representing the locations of the tables in the maze when compared to the buildings in the college campus. Although these results are not directly comparable, the high accuracy of some subjects in the blind and visually impaired groups is further evidence that these subjects can combine piecemeal information collected during navigation into a coherent configuration. Here again, the better performance may be attributed to the relative small size of the space and the fact that individuals were mentally manipulating fewer objects in their representation. The sighted was the best performing group but large individual differences were also found within each of the groups. Looking more closely at the effect size of distortions, it was found that vision also played an important role in the construction of mental representations with the performance of the MVI resembling the one from the sighted and the SVI being closer to that of the blind.

In relation to the distortions committed it was found that despite differences in accuracy and in some cases the magnitude of these distortions, all groups shared similar biases in their mental representation of the locations inside the maze. This was made evident by comparing the pattern of distortion observed when these representations were externalised. In relation to the pointing task, an analysis of constant error revealed that all groups shared counter clockwise biases when *pointing to* the tables. In relation to the distance estimation task, it was found that all groups had similar patterns of over and underestimation that varied according to the location featured in the triad. Results from multidimensional scaling analysis showed that for the most part, these distortions were the result of discrepancies between the Euclidean and functional distances between a set of locations. This was clearly seen from the distortions committed when estimating the distance between the Bakery, School and Coffee Shop with the grid pattern at the bottom of the maze forcing individuals to follow a specific route, which led them to overestimate the distance between the Bakery and the School. Distortions also occurred as a result of the subjective partitioning of space whereby subjects could not accurately represent the centre point (Bakery) as they though it to be equidistant to the other locations. In relation to the model task, a similar pattern of distortion was found relative to east-west and north-south translation, angle displacements and scale contraction. Models for all groups were distorted to the north and east. There was also a tendency contract the configuration by positioning tables towards the centre of the maze closer to the Bakery.

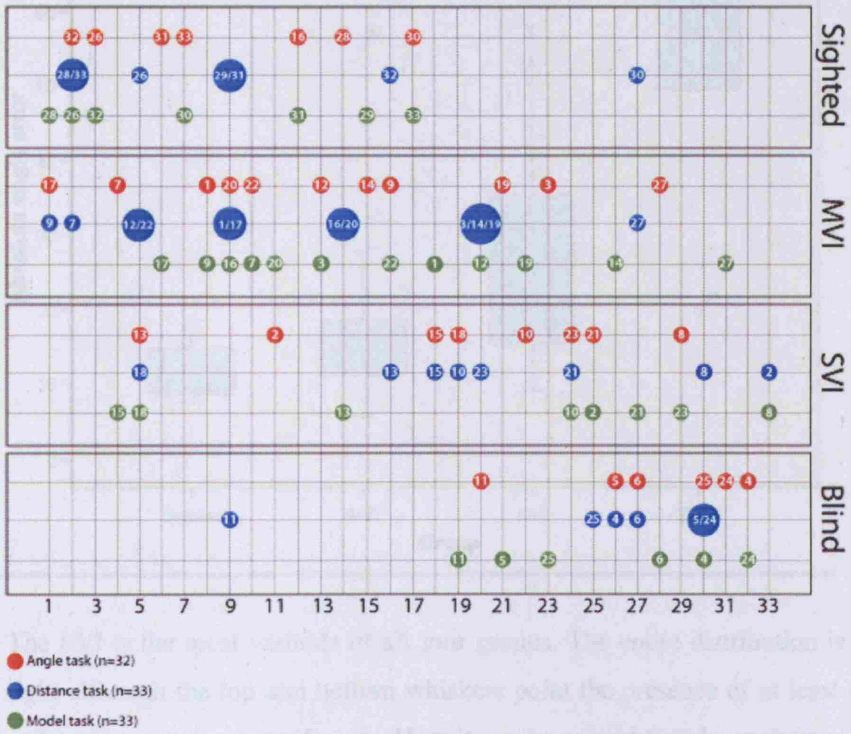
Given this striking similarity in distortions, it was argued that that although vision plays a crucial role in the accuracy of mental representation, the mental processes used by the blind and visually impaired in the organization of encoded spatial information, whether it is externalized through pointing, distance judgements or a model, is similar to the ones used by the sighted. Blindness and visual impairment, congenital or adventitious, does not prevent the construction of mental representations. Information collected through proprioception and the other sensory modalities, although not as accurate still allows for the collection of spatial information and the integration of this information into a coherent representation.

10.9 Interpreting the results

Results from the maze experiment confirm those discussed in the previous chapter regarding the role of vision in the accuracy of mental representations. At the same time, it has been shown with considerable success that although the accuracy of representations diminishes as visual acuity decreases, the format of representations assessed by differences in the type of distortions committed tends to remain relatively similar across groups. It was also found that considerably large individual differences exist within each of the four groups. That is, good and bad performers are present in all groups for all tasks but that bigger differences exist within the MVI, SVI and blind groups. Figure 10.23 summarizes these differences using a dot diagram to classify performance ranks for the three tasks with lower ranks indicating better performance.

Clusters indicate group cohesion while long spreads indicate the presence of good and bad performers. Looking at the figure, we notice that similar to the first experiment, there is greater group cohesion for the sighted and the blind in the angle task (sighted performing very well while the blind performing poorly) while there are large variations for the MVI and SVI groups. In the distance estimation task, we notice a greater cohesion although all groups have at least one or two very good and very poor performers. We also notice that the best overall performer is in the MVI group and not the sighted group and that one blind subject performed particularly well in this task. Regarding the model task, we notice once again, greater cohesion among the sighted and blind groups but very large variations in the MVI and SVI groups with the worst overall performers located in the SVI group. Here it is also interesting to note that one sighted subject also had considerable difficulties with this task. In the sections that follow we look at each of these tasks in more detail. The numbers inside each circle indicate the actual subject number and allows for an individual comparison of performance in all three tasks. For example subject 11 in the blind group ranked first in all three tasks. As we shall see, this was the only adventitiously blind subject in the group whose performance resembled that of the visually impaired and sighted subjects further confirming the importance of vision in the formation of mental representations.

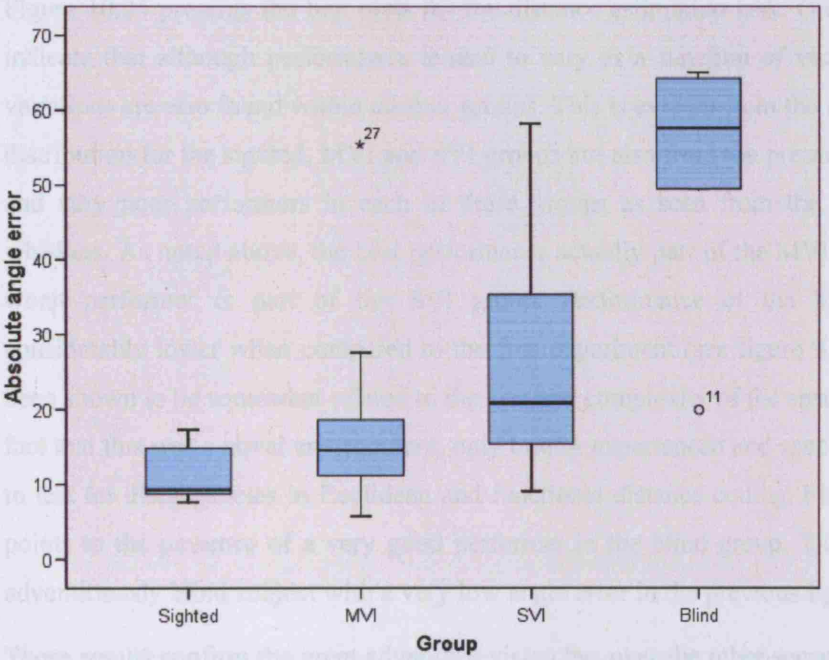
Figure 10.23 - Subject ranks (maze)



10.9.1 Pointing judgments: Angle error and individual differences

Figure 10.24 below presents a box plot detailing the performance of the four groups in the pointing task (locations pointed to). Looking at the box plot we notice the large difference in performance between the blind and the rest of the groups. Although performance did vary, the distribution is slightly skewed to the right, the accuracy of all sighted subjects is high and this is due to the fact that these subjects could actually see the position of the tables prior to making their pointing judgments. The performance of the MVI group resembles very closely the one of the sighted and this can also be attributed to the fact that most subjects in this group could use what remained of their vision when making the pointing estimation. Interestingly, the same subject that was an outlier in the previous experiment is now the extreme case. As noted in the previous chapter, it was found that apart form a visual acuity of 1/6 (both eyes) the subject had an additional disability (Lawrence Moon Biedl Syndrome), one year of mobility training and a low score in the intelligence assessment.

Figure 10.24 - Absolute angle error box plot (maze)



The SVI is the most variable of all four groups. The entire distribution is skewed to the right although the top and bottom whiskers point the presence of at least one very good and another very poor performer. Here it can be argued that the variation in performance is related to differences in visual acuity considering that the SVI group housed individuals with various acuities ($< .125 \geq .02$). However, no significant correlation was found between visual acuity and performance in the pointing task for the entire SVI group ($r = -.481$, $n = 8$, $p = .227$).

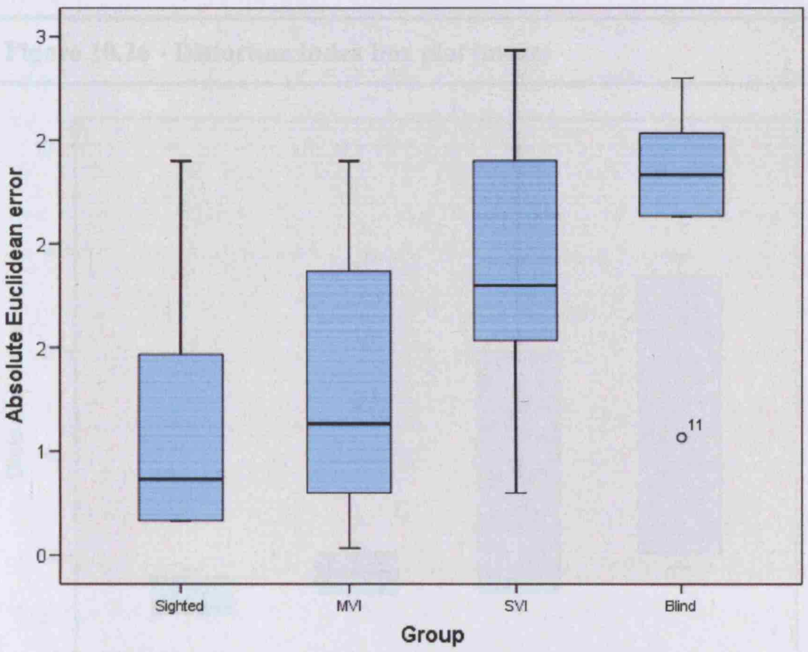
Looking at the box plot for the blind group we notice that the median is considerably high (57.63), and the distribution is slightly skewed to the left. More interesting is the presence of a very good performer (subject 11) with an angle error of only 20 degrees. Looking at the details of this subject in appendix A3 we notice that this was the only adventitiously blind subject, having lost his sight at the age of 17. As we shall see, this subject was also the best performer in the distance estimation (look at outlier in figure 10.25) and the model construction task. In general, results from the pointing task seem to confirm those previously discussed regarding the fact that pointing is an action that is greatly aided by vision, even if sight is no longer present. It is also a task that must be carefully administered and analysed as it puts the blind at a considerable disadvantage.

10.9.2 Distance estimation: Euclidean error and individual differences

Figure 10.25 presents the box plots for the distance estimation task. Once again, results indicate that although performance tended to vary as a function of visual acuity, large variations are also found within all four groups. This is evident from the right skew in the distribution for the sighted, MVI and SVI groups but also from the presence of very good and very poor performers in each of these groups as seen from the top and bottom whiskers. As noted above, the best performer is actually part of the MVI group while the worst performer is part of the SVI group. Performance of the blind group was considerably lower when compared to the first experiment (see figure 9.30) and this has been shown to be somewhat related to the size and complexity of the space but also to the fact that this was a novel environment, only briefly experienced and specifically designed to test for discrepancies in Euclidean and functional distance coding. Finally, the outlier points to the presence of a very good performer in the blind group. This was the same adventitiously blind subject with a very low angle error in the previous figure.

These results confirm the great advantage vision has over the other senses when it comes to the quick assimilation of information. Unlike the first experiment, subjects could not use any previous experience or mental schema to calibrate their estimations. They were forced to operate on a representation that was quickly put together from proprioceptive inputs as well as information received from the other senses. Although these representations were functional, they were also laden with errors particularly in situations when there was a discrepancy between the Euclidean and functional distances. Vision allowed for a better (and quicker) understanding of these relationships for not only were these subjects *seeing* the distance relationship between the different tables, they were also correcting any Euclidean and functional discrepancies by walking around the maze. In this manner, the underperformance <u>of all groups</u> relative to the first experiment can be understood as a lack of experience – of deductions being made on basis of a newly created mental representation. The substantial underperformance of the <u>SVI and blind</u> groups can be seen as the results of the lack of experience coupled with the absence of sufficient converging inputs necessary for the formation of accurate representations.

Figure 10.25 - Absolute Euclidean error box plot (maze)

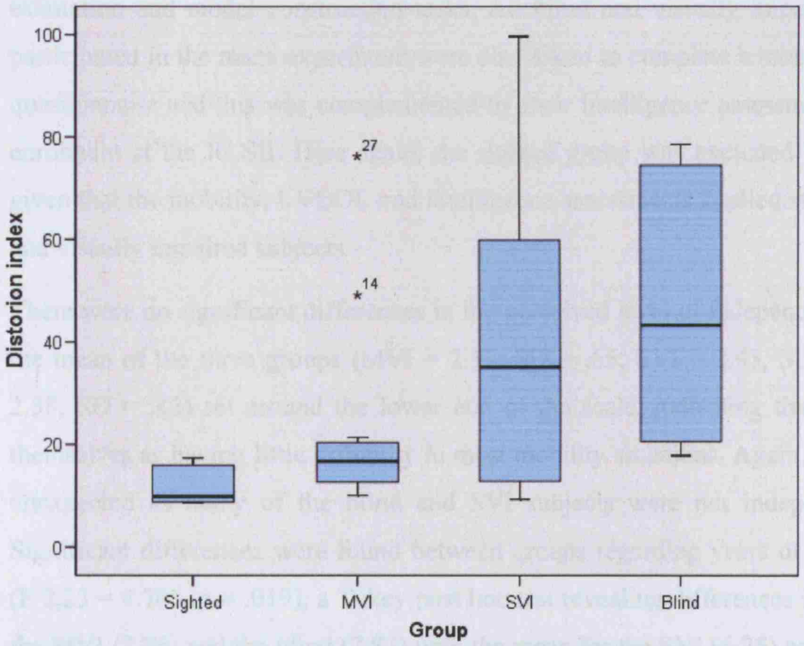


10.9.3 Model construction: Distortion index and individual differences

Figure 10.26 presents the box plot for the model construction task. Although results from the ANOVA only revealed significant differences between the sighted and blind, the distributions for the MVI, SVI and blind groups are considerably skewed, pointing to the presence of very good and very poor performers. This is particularly the case for the MVI group where two extreme cases are present. Case 27 as we have already seen for the angle estimation task, is the subject with Lawrence Moon Biedl Syndrome, very little mobility training and a low score in the intelligence test. Case 14 on the other hand did not have any other additional disabilities, had at least six years of mobility training but did not have a particularly high intelligence score (FSA 20/45).

In the previous chapter we saw that intelligence can play a determining role in the performance in the model construction task. It remains to be seen whether intelligence is a critical factor in environments that have not been previously experienced. Performance for the blind group was unexpectedly higher when compared to the first experiment. As argued before this is probably related to the smaller scale of the space and the fact that subjects were only asked to position 4/7 pieces instead of 7/10. Once again, the adventitiously blind subject was the group's best performer and this is represented by the bottom skew in the figure.

Figure 10.26 - Distortion index box plot (maze)



10.10 Mobility, quality of life and intelligence

At the end of last chapter, we asked an important question regarding the factor or combination of factors behind differences in accuracy and the large variation in performance within the visually impaired and blind groups for the three tasks. This question is now revisited for the maze experiment. Results from a regression analysis revealed that visual acuity alone significantly predicted the accuracy of angle estimation, $\beta = .682$, $t(30) = 5.104$, $p < .001$ accounting for 47% of the variation in performance ($r^2 = .465$, $F(1,30) = 26.047$, $p < .001$). Unlike the previous experiment, visual acuity was also a good predictor of accuracy in the distance estimation task, $\beta = .507$, $t(31) = 3.276$, $p = .003$ accounting for 26% of the variation in performance ($r^2 = .257$, $F(1,31) = 10.729$, $p = .003$). These results further confirm the idea that in a smaller environment, vision holds an important advantage over the other senses regarding the quick and accurate calibration of distance and heading relationships. Regarding the model construction task, visual acuity was also a significant predictor of performance, $\beta = .399$, $t(31)$, $= 2.424$, $p = .021$ accounting for 16% of the variation in performance ($r^2 = .159$, $F(1,31) = 5.878$, $p = .021$).

10.10.1 Mobility and quality of-life

That vision plays an important role in the formation and accuracy of mental representations was clearly shown in the results of the regression for the angle estimation task. Yet, it is still possible that other factors are influencing performance in the distance estimation and model construction tasks. All blind and visually impaired subjects that participated in the maze experiment were also asked to complete a mobility and LVQOL questionnaire and this was complemented by their intelligence assessment at the time of enrolment at the RLSB. Here again, the sighted group was excluded from the analysis given that the mobility, LVQOL and intelligence assessments applied strictly to the blind and visually impaired subjects.

There were no significant differences in the perceived level of independent mobility with the mean of the three groups (MVI = 2.30, SD = .65; SVI = 2.45, SD = .63 and blind 2.38, SD = .42) set around the lower end of the scale, indicating that the groups saw themselves as having little difficulty in most mobility situations. Again, this is somewhat unexpected as many of the blind and SVI subjects were not independent travellers. Significant differences were found between groups regarding years of mobility training ($F_{2,23} = 4.765$, $p = .019$), a Tukey post hoc test revealing differences in means between the MVI (2.76) and the blind (7.83) with the mean for the SVI (6.25) approaching that of the blind.

In regard to the LVQOL questionnaire, results from a t-test revealed significant differences in means between the MVI and the SVI groups ($t = 2.254$, $DF = 18$, two tailed $p = .037$). Here again, subjects in the MVI group perceived themselves as having a higher quality of life (M = 3.65, SD = .63) than those in the SVI group (M = 3.02, SD = .58) although the average for both groups rested at the higher end of the scale. Finally, the scores for the two questionnaires was also highly correlated ($r = -.824$, $n = 20$, $p < .001$)[79] indicating that for the most part, subjects who perceived themselves as having a good level of independent mobility, also regarded themselves as having a good quality of life.

10.10.2 Intelligence

Blind and visually impaired subjects were also assessed for their level of intelligence through the literacy and numeracy test or through an overall Foundation Skills Assessment. A one-way ANOVA was conducted in order to determine if the MVI, SVI and blind groups differed in their literacy, numeracy or FSA scores. Similar to the

[79] The minus sign in the correlation is the result of the scales for the two questionnaires being reversed.

previous experiment, no significant differences were found between groups for literacy ($F_{2,15}$ = .094, p = .911), numeracy ($F_{2,15}$ = .025, p = .975) and FSA ($F_{1,5}$ = .697, p = .442). The scores for the literacy and numeracy tests were then combined and normalised along with those of the FSA assessment in order to produce an overall intelligence score that applied to all subjects in the three groups. A one-way ANOVA was then conducted in order to determine if the MVI, SVI and blind groups differed in their overall intelligence score. Results from the ANOVA revealed no significant differences between the groups ($F_{2,22}$ = .340, p = .716).

10.10.3 Factors influencing task performance

When the sighted group is excluded from the analysis, visual acuity alone is still a significant predictor of accuracy in angle estimation, β = .626, t(24) = 3.928, p = .001 accounting for at least 37% of the variation in performance (adjusted r^2 = .366, F(1,24) = 15.426, p = .001). Unlike the previous experiment, visual acuity was also a significant predictor of accuracy in the distance estimation task, β = .458, t(24) = 2.522, p = .019 accounting for 18% in the variation in the performance (adjusted r^2 = .177, F(1,24) = 6.362, p = .019) but was not able to significantly predict accuracy in the model construction task, β = .262, t(24) = 1.330, p = .196.

Table 10.9 - Task performance, mobility, quality of life and intelligence (maze)

Task	Statistic	Visual Acuity (logMAR)	Intelligence	Mobility Score	Mobility years	LVQOL Score
Angle	Pearson r	.626(**)	-.435(*)	.399(*)	.545(**)	-.585(**)
	Sig.	.001	.030	.044	.004	.007
	N	26	25	26	26	20
Distance	Pearson r	.458(*)	-.454(*)	.373	.459(*)	-.594(**)
	Sig.	.019	.023	.061	.018	.006
	N	26	25	26	26	20
Model	Pearson r	.262	-.461(*)	.589(**)	.400(*)	-.578(**)
	Sig.	.196	.020	.002	.043	.008
	N	26	25	26	26	20

***Correlation is significant at the 0.05 level (2-tailed).**
**** Correlation is significant at the 0.01 level (2-tailed).**

Given these results, a set of correlations were performed in order to verify whether any relationship existed between the perceived level of independent mobility, quality of life and intelligence, and the performance in the three tasks. Table 10.9 above presents the relationship between the different tasks, visual acuity, intelligence, level of independent mobility, years of mobility training and quality of life.

10.10.3.1 Pointing judgement: Intelligence, mobility and quality of life

In relation to the angle estimation task a significant positive relationship was found for visual acuity (LogMAR), mobility score and mobility years for the MVI, SVI and blind groups. A negative correlation was found between pointing error and intelligence score for the MVI, SVI and blind groups and pointing error and LVQOL score for the MVI and SVI groups. These results are considerably different from those in the first experiment where only visual acuity was found to positively correlate with pointing error. It seems that intelligence, the perceived level of independent mobility and in particular the years of mobility training can also affect performance in this task, albeit in different degrees. The fact that the LVQOL questionnaire is also highly correlated to the performance of subjects in the MVI and SVI, further confirms much of what has been said in chapter 3 regarding the role confidence and self-esteem can have on successful mobility, wayfinding, exploration and the overall construction of mental representations.

A *stepwise* multiple regression was performed in order to investigate if any of these variables (the ones that were found to significantly correlate with performance) complement or substitute visual acuity as significant predictors of performance in the angle estimation task. Using the *stepwise* method a significant model emerged whereby visual acuity and intelligence were found to be significant predictors of performance in the angle estimation task ($F_{2,22}$ = 15.412, p < .001), adjusted r^2 = (.546). Table 10.10 presents the significant variables.

Table 10.10 - Regression model for the angle estimation task

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	11.038	5.666		1.948	.064
	Acuity LogMAR	13.827	3.614	.624	3.826	.001
2	(Constant)	33.736	8.544		3.948	.001
	Acuity LogMAR	13.927	3.051	.628	4.565	.000
	Intelligence	-34.945	10.899	-.441	-3.206	.004

a Dependent Variable: Absolute angle error

When scores for the LVQOL questionnaire are included (with blind and sighted group removed from the analysis), a significant result emerges in which the importance of visual acuity and intelligence as a predicting variables is forfeited to the perceived level of quality of life (β = -.584, t(17) = -2.965, p = .009) which accounts for 30% of the variation (adjusted r^2 = .302, F(1,17) = 8.792, p = .009). In general, it seems that when all groups are considered, visual acuity is the main predictor of performance. However, when the sighted are excluded from the analysis, the interplay of intelligence and visual acuity are the main predictors of performance. Finally, the perceived level of quality of life is the main predictor of performance for the visually impaired groups (MVI and SVI).

10.10.3.2 Distance estimation: Intelligence, mobility and quality of life

For the distance estimation task positive significant correlations were found between Euclidean error and visual acuity (LogMAR) and Euclidean error and mobility years for the MVI, SVI and blind groups. Significant negative correlations were found between Euclidean error and intelligence for the MVI, SVI and blind groups and between Euclidean error and quality of life for the MVI and SVI groups. Here again, results are very different from the ones found in the previous experiment were none of the factors were correlated with performance in the distance estimation task. Much like in the angle estimation task, it seems that intelligence and the years of mobility training are related to performance for the MVI, SVI and blind groups. The same is true for the perceived level of quality of life for the MVI and SVI groups.

A *stepwise* multiple regression was performed in order to investigate if any of these variables (the ones that were found to significantly correlate with performance) complement or substitute visual acuity as significant predictors of performance in the distance estimation task. Using the *stepwise* method a significant model emerged whereby mobility years and intelligence were found to be significant predictors of performance in the distance estimation task (F 2,22 = 6.788, p = .005), adjusted r^2 = (.325).

When scores for the LVQOL questionnaire are included (with the blind and sighted group removed from the analysis) a significant result emerges in which the importance of all other variables as predictors are forfeited for the level of quality of life (β = -.600, t(17) = -3.088, p = .007) which accounts for 32% of the variation (adjusted r2 = .322, F(1,17) = 9.539, p = .007). Here again, it seems that when all groups are considered, visual acuity is the main predictor of performance. However, when the sighted are excluded from the analysis, the interplay between the years of mobility training and the level of intelligence becomes the main predictors of performance. Once again, the level of quality of life is the main predictor of performance for visually impaired groups (MVI and SVI). Table 10.11 presents the significant variables.

Table 10.11 - Regression model for the distance estimation task

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	1.319	.216		6.100	.000
	Mobility years	.076	.033	.431	2.292	.031
2	(Constant)	2.137	.365		5.856	.000
	Mobility years	.074	.030	.419	2.498	.020
	Intelligence	-1.235	.468	-.443	-2.639	.015

a Dependent Variable: Absolute Euclidean error

10.10.3.3 Model construction: Intelligence, mobility and quality if life

For the model construction task, we found that visual acuity was the only significant predictor of performance when the sighted group was included in the analysis. Looking at table 10.9 above, we note a significant positive relationship between the level of distortion (DI), mobility score and years of mobility training for the MVI, SVI and blind groups. A significant negative relationship is found between intelligence and the level of distortion for the MVI, SVI and blind groups and for quality of life and level of distortion for the MVI and SVI groups. These results are also considerably different from the ones in the first experiment where a significant relationship was only found between intelligence and the level of distortion. Overall these results indicate that there are several other factors influencing the performance of the blind and visually impaired groups in the model construction task with the perceived level of independent mobility among the most dominant.

A *stepwise* multiple regression was performed in order to investigate which of these variables (the ones that were found to significantly correlate with performance) can significantly predict performance in the model construction task. Using the *stepwise* method a significant model emerged in which the importance of all variables (even intelligence) is forfeited for the level of independent mobility (β = .585, t(23) = 3.457, p = .002) which accounts for at least 31% of the variation in performance (adjusted r^2 = .313, F(1,23) = 11.949, p = .002). The level of independent mobility continues to be the main predictor even when the scores for the LVQOL questionnaire are included (β = .541, t(17) = 2.650, p = .017), accounting for at least 25% of the variation in performance for subjects in the MVI and SVI- groups. It seems that visual acuity is only a good predictor of performance when the sighted group are considered in the analysis. Performance for the blind and visually impaired groups in the model construction task seems to depend much more on the perceived level of independent mobility.

10.10.4 Summary: Factors affecting performance

It is now clear that apart from visual acuity, there are a variety of other factors that are affecting the performance of the blind and visually impaired in the three spatial tasks. Contrary to the first experiment conducted in a well-known environment where only the level of intelligence seems to have significantly predicted performance for one of the tasks (model construction), we now find that in a novel and complex environment where the construction of mental representations is also limited by a timed exploration, the interplay of a variety of other factors such as perceived level of mobility, years of mobility training, quality of life (confidence) and intelligence, act as significant predictors of performance (many times acting as stronger predictors than visual acuity alone). This was the case in the angle estimation task where results from the multiple regression uncovered a significant model where intelligence and visual acuity were found to be significant predictors, in the distance estimation task where mobility years and intelligence were the significant predictors and in the model construction task where perceived level of independent mobility was the only predictor. Quality of life also played a significant role in predicting the performance of the MVI and SVI for the angle and distance estimation tasks. We now turn to the final section of this thesis where we will look at what aspects of mobility are affecting performance.

Chapter 11
Performance and exploratory strategies

11.1 Introduction

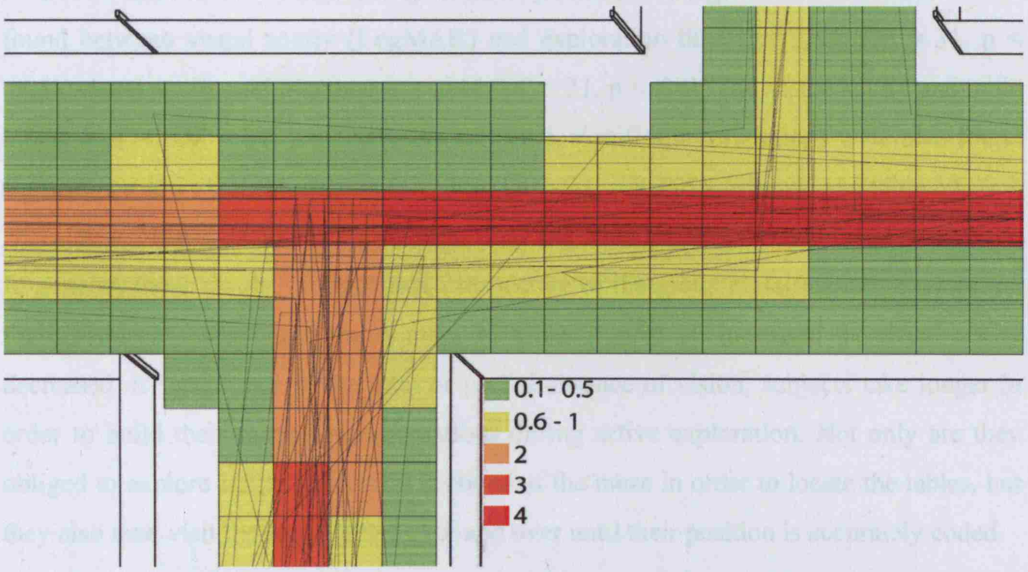
Tracking analysis was conducted in order to obtain a better understanding regarding the aspects of spatial exploration that are directly affecting the construction of accurate mental representations. The chapter takes an in depth look at the movement patterns and exploratory strategies used by the subjects while attempting to locate the six tables in the maze. The chapter begins by presenting the methods for the capturing, decoding and analysis of movement patterns and how these were incorporated into Geographic Information Systems (GIS) for the analysis of dynamic data. Differences in the exploratory patterns of the sighted, visually impaired and blind groups are presented and discussed in relation to distances covered, exploration time, table contacts (hits) and overall activity inside the maze. The exploratory strategies for each subject are then isolated and classified with the aid of the *Tracking Analyst* extension in *ArcMap*. The chapter concludes by relating the performance in the different spatial tasks to the type and frequency of strategies employed by the subjects during their exploration of the maze.

11.2 Tracking analysis

Movement inside the maze was captured using a digital video camera by the investigator who followed the subjects as they explored the maze in an attempt to locate and remember the position of the six tables. The video data (exploratory pattern) for each subject was entered into ArcMap as polylines in a database that also contained information regarding the duration of exploration and the number of times each table was visited (table hits). In order to get an idea of the activity patterns in the different areas of the maze, the polylines for subjects in the same group (sighted, MVI, SVI and blind) were merged together and a grid made up of polygons was overlaid on top of the corridors of the maze, each grid square occupying .25 meters.[80] The polylines for each group were then superimposed over the grid polygons. Activity for the four groups in the different areas of the maze was calculated from the intersection of polylines (subject tracks) and polygons (grid squares) after the two layers were joined.

In order for group comparisons to be made, intersection counts for each grid were then averaged over the number of subjects in each of the groups. Here again, we are not only interested in the absolute frequency of use but the similarity/difference in movement and exploratory patterns by the different groups. Figure 11.1 is an example of how activity was calculated using subjects in the SVI group. The figure presents a section of the maze (a corridor) with the polylines superimposed on the polygons. The different colours of the polygons indicated the intensity of activity at a particular area of the maze. In this case, the areas in red or orange at the centre of the corridor are the most frequented. As we shall see, this activity pattern is typical of the sighted and MVI groups who did not trail the walls of the maze during exploration, their navigation guided by visual information.

Figure 11.1 - Polygon & polyline pattern calculation



11.2.1 Tracking analysis: Duration, distance and table hits

Table 11.1 below presents a summary of tracking for the 4 groups. Looking at the table, we notice that the sighted group was the quickest to explore and locate the tables followed by the MVI, SVI and blind groups. The same is true for the distance walked inside the maze where the sighted did the least amount of walking followed by the MVI,

[80] The size of the grid was chosen in order to account for even the smallest movement and white cane strides.

SVI and blind groups. The sighted and the MVI groups also had the least amount of table hits. The SVI group averaged a slightly higher number of table hits when compared to the blind.

Table 11.1 - Tracking results

Group (n)	Exploration (seconds) (SD)	Distance (meters) (SD)	Table hits (SD)
Sighted (7)	173.57 (36.33)	177.14 (48.42)	6.86 (1.22)
MVI (12)	787.83 (767.74)	547.56 (352.05)	20.00 (12.19)
SVI (8)	1673.88 (1025.49)	1050.50 (537.41)	28.63 (14.63)
Blind (6)	2542.83 (291.88)	1024.62 (280.17)	25.17 (9.91)

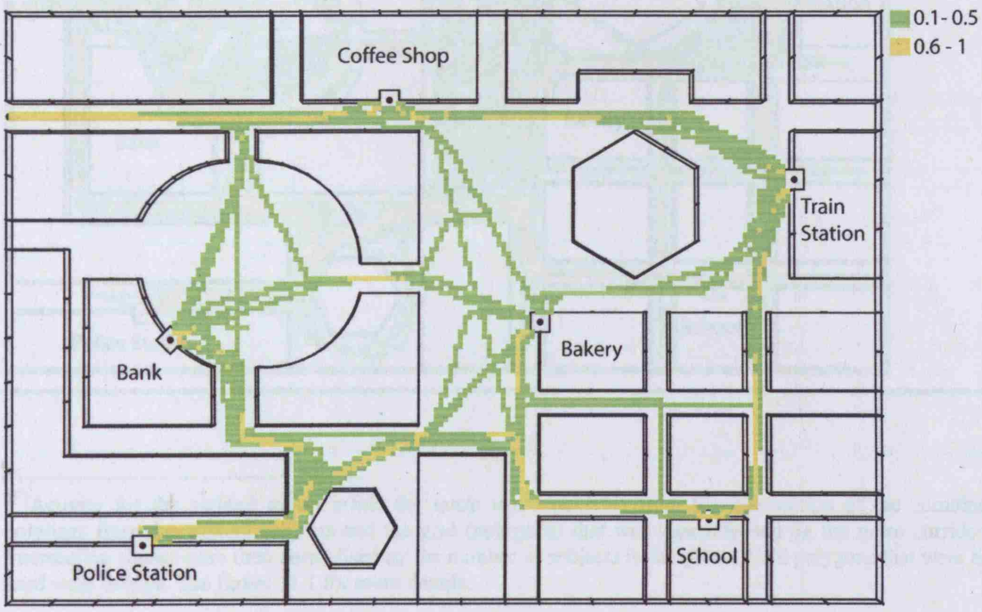
It was hypothesized that the groups and particularly the blind and SVI would significantly differ from the MVI and sighted regarding the duration, distance and number of table hits during the maze exploration. However, given the large standard deviations present in the MVI and SVI groups, Levene's test of homogeneity of variance was violated for the duration ($p < .001$), distance ($p = .016$) and number of table hits ($p = .020$) making the results of the ANOVA highly improbable. Nonetheless, significant correlations were found between visual acuity (LogMAR) and exploration time ($r = .799$, $DF = 31$, $p < .001$), visual acuity and distance ($r = .644$, $DF = 31$, $p < .001$) and visual acuity and table hits ($r = .474$, $DF = 31$, $p = .005$). As expected, significant correlations were also found for distance and exploration time ($r = .848$, $DF = 31$, $p < .001$), distance and table hits ($r = .927$, $DF = 31$, $p < .001$) and exploration time and table hits ($r = .700$, $DF = 31$, $p < .001$). In general, these results indicate that irrespective of the group classification, exploration time, distance walked and the number of tables visited all increased as visual acuity decreased. It seems that in the total or partial absence of vision, subjects take longer in order to build their mental representations during active exploration. Not only are they obliged to explore larger (different) sections of the maze in order to locate the tables, but they also tend visit the same tables over and over until their position is accurately coded.

The large standard deviations in the MVI and SVI groups indicate that some subjects had particular difficulties in constructing accurate mental representations of the position of the different tables inside the maze. It may be that some of them simply had problems locating the tables during exploration and this eventually led to longer walks, more time spent in the maze and repetitive table hits. This is confirmed above by the significant correlations between time, distance and table hits. However, it is also possible that the large variations are also the result of differences in mobility and quality of life (confidence) - two factors previously found to be related to performance in spatial tasks. Significant correlations were in fact found between distance and mobility years ($r = .570$, $DF = 18$, $p = .009$), exploration time and mobility years ($r = .616$, $DF = 18$, $p = .004$) and exploration time and quality of life ($r = -.573$, $DF = 20$, $p = .008$) further emphasizing the role of quality of life and level of independent mobility not only in the accuracy but also during the construction of these representations. It now seems that subjects that took longer to explore the maze either because they were moving slower or walking back-and-forth, did so because they had less confidence and inferior independent travelling skills. Here again, more years of mobility training does not necessarily translate into better independent mobility. In fact, it actually means the opposite. Given that most of the subjects were congenitally impaired, a significant correlation between mobility performance, distance or exploration time is an indicator that these subjects are still struggling with some of the skills necessary for independent mobility.

11.2.2 Activity patterns and the construction of mental representations

Results from the tracking analysis also allow us to look in more detail at the manner in which mental representations were constructed. Figure 11.2 presents the activity pattern for the sighted group. Here we are reminded that activity was normalised by the number of subjects in each of the groups.

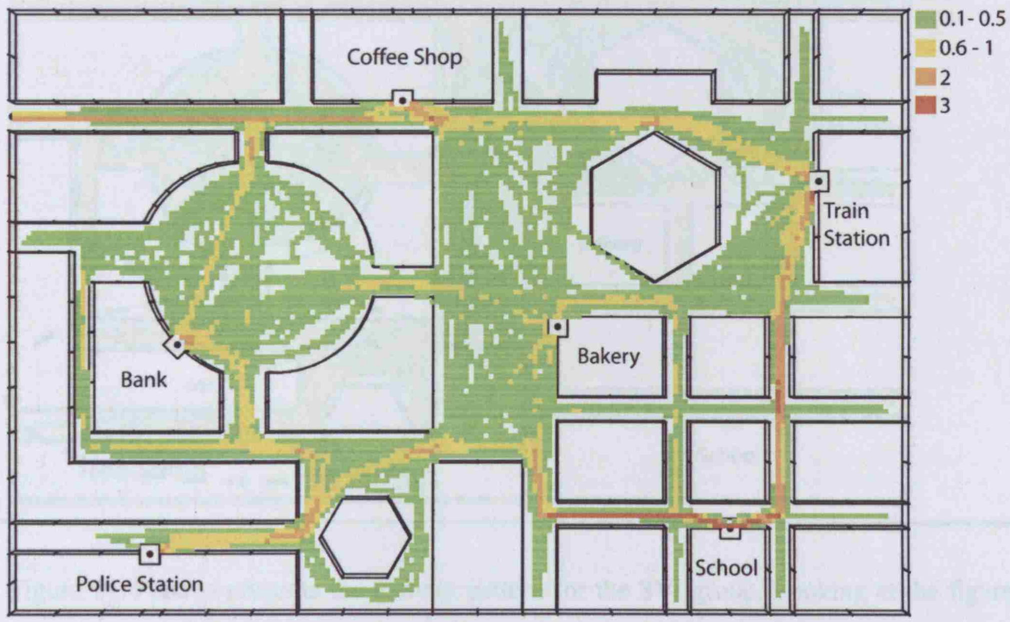
Figure 11.2 - Sighted track



Looking at the figure, we notice that the main areas of activities[81] are concentrated in the corridors adjacent to the tables. This was an expected result given that exploration was guided by vision. Subjects were able to move directly from one table to the other without walking into any dead-ends or making any unnecessary detours. There is very little movement in the middle of the maze although some subjects chose to stand there and look around while double-checking that they could remember the position of the different tables. Movement also seems to be concentrated in the southern part of the maze particularly between the School and the Police Station.

Figure 11.3 presents the activity pattern for the MVI group.[82] Given the small size of the experimental space, it was expected that this group would spend less time exploring the maze (also walk around less) than what can be observed from the figure. Although it is true that many of the subjects were not able to see two or more tables simultaneously, it was still expected that they would be able to efficiently organize and coordinate their actions with minimal movements.

Figure 11.3 - MVI track



[81] Activity for the sighted group inside the maze was calculated from the intersection of the combined polylines from the sighted subjects and the grid (polygons) that was superimposed on the maze corridors. Intersection counts were then normalised by the number of subjects in the group. Grid polygons that were not used were deleted. See figure 11.1 for more details.

[82] Activity for the MVI group was also calculated from the intersection of polylines and polygons (grid) normalised by the number of subjects in the group. This was also the case for the SVI and blind groups.

Unlike the pattern observed in the previous figure, we notice that the MVI group covered pretty much all areas of the maze although activity in the dead ends or areas without tables is lower. There is also considerable movement in the middle of the maze but like the sighted group, activity is concentrated adjacent to the tables and particularly around the School, Police Station and the Train Station. For the most part, exploration still seems to have been guided by vision with the vast majority of subjects travelling around specific corridors that link the different tables (yellow lines). There are however some subjects that required much more careful exploration walking back-and-forth between areas or corridors that did not lead to any tables. It should be noted that in the total or partial absence of vision, this type of perimeter or gridline exploratory pattern provides valuable information in respect to the overall dimensions (shape and size) of the experimental space.

Figure 11.4 - SVI track

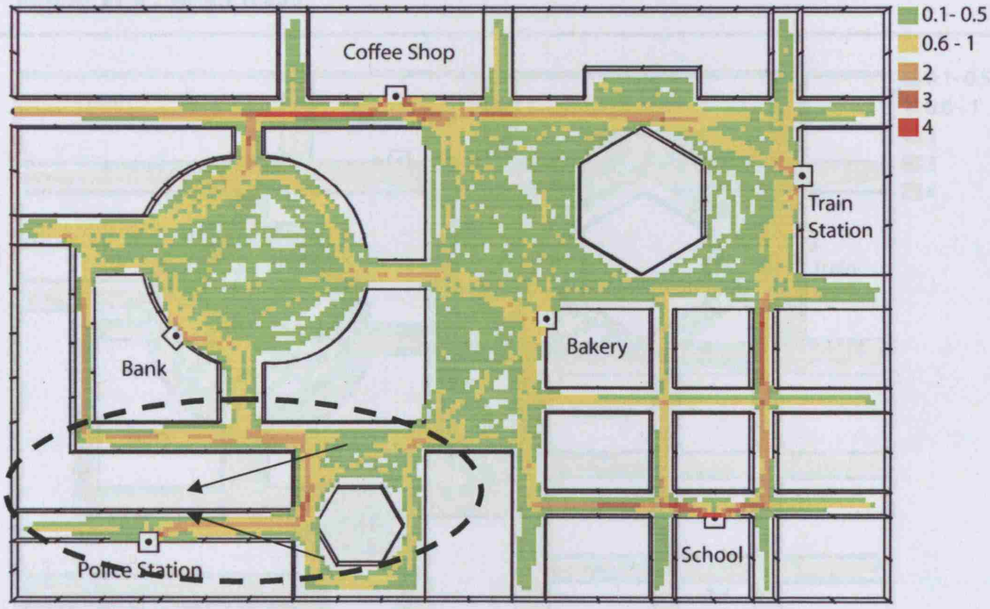


Figure 11.4 above presents the activity pattern for the SVI group. Looking at the figure, we notice that the intensity of activity is increased in all areas of the maze. Of particular interest is the increase in activity in the corridors that lead to dead ends. In conjunction with the video data it was observed that unlike the sighted or MVI groups, several subjects in the SVI group either trailed the wall or walked around the perimeter of the maze as a first strategy to locate the tables. Yet, despite the intensity within the dead-end corridors and several random movements in the middle of the maze, we observe the same

intensity of activity (a) adjacent to the six tables (particularly within the School, Police Station and Train Station and (b) along the corridors that lead directly to a table.

A good example of the effect that vision can have on the movement patterns is illustrated in the south-western area of the maze next to the Police Station. If we look back at figures 11.2 and 11.3, we notice that when the majority of sighted and MVI subjects reach the hexagon they can already see the location of the Police Station and consequently approach it from the northern part. This is the case for the sighted subjects but less for the MVI group. In figure 11.4, we note that the intensity of activity in the northern and southern part of the hexagon is very similar and related to the fact that many of the subjects were trailing the wall from School at the south side or the Bank at the northern side. Looking closely at the figure, we also notice that some of the subjects actually walked diagonally from the Bakery by crossing the open space and later following the corners of the hexagon.

Figure 11.5 - Blind track

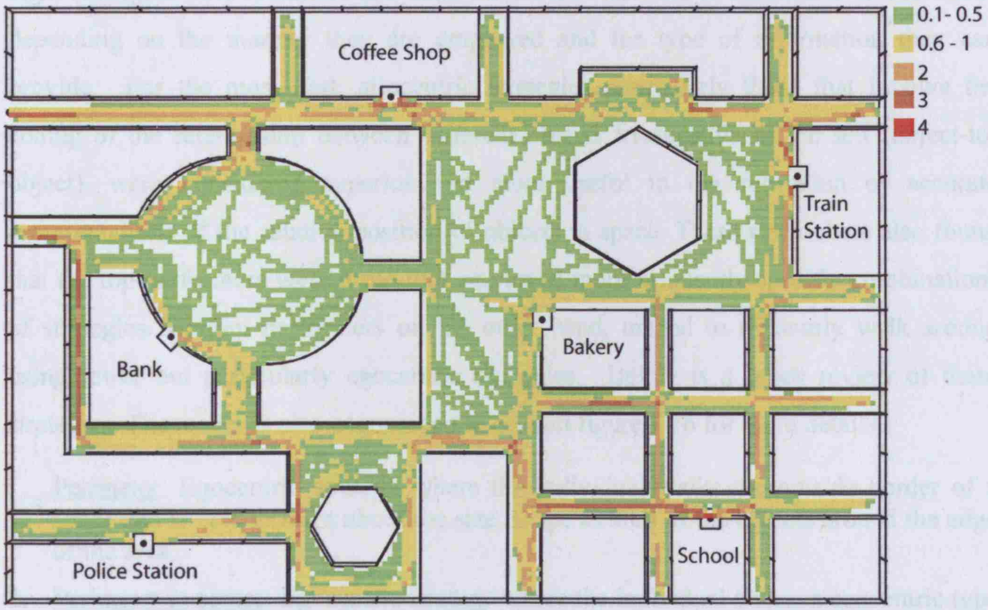


Figure 11.5 above presents the activity pattern for the blind group. The vast majority of subjects in this group trailed the wall either with their hands or with the help of the white cane. This can be observed by the high intensity of activity along the entire perimeter of the maze. This can also be seen by looking at the corridors that lead to dead ends and the relative low activity at the centre of the maze and northern hexagon. Trailing the wall from the starting point, subjects either followed the northern wall in direction of the

Coffee Shop, Train Station, and School or the southern wall in direction of the Bank and Police Station. Subjects could not trail the wall to get to the Bakery and this is consistent with many of the accuracy errors discussed at the beginning of the chapter. Similar to all other groups, the areas adjacent to the six tables, in particular the Train Station, School and Police Station, have the highest level of activity.

11.2.3 Uncovering the strategies

The final question asked in this thesis is whether any relationship exists between the strategies used by the different subjects to explore the maze and the accuracy of performance in the three tasks. At the end of chapter 7, we reviewed three studies that dealt specifically with the role of exploratory strategies on the construction of mental representation. Using a video camera to record movement, researchers (Thinus-Blanc & Gaunet, 1999; Gaunet & Thinus-Blanc, 1996; Hill et al., 1993; Tellevik, 1992) have successfully isolated a series of exploratory strategies employed by the blind and visually impaired in object location or reaction to change studies in small open spaces. A total of eight strategies were identified and these have been classified as egocentric or allocentric depending on the manner they are employed and the type of information they can provide. For the most part, allocentric strategies particularly those that involve the coding of the relationship between different objects irrespective of the self (object-to-object), were considered superior and more useful in the formation of accurate representations of the relative position of objects in space. These researchers also found that the top performers were those that employed more frequently specific combinations of strategies. Bottom performers on the other hand, tended to randomly walk around using fewer but particularly egocentric strategies. Below is a quick review of these strategies. The reader is also encouraged to consult figure 7.16 for more details.

1. Perimeter: Egocentric strategy where the individual walks the outside border of a space and is able to learn about the size, shape as well as the objects around the edge of the area.
2. Perimeter to centre: Egocentric strategy where the individual makes a concentric type of movement moving from the perimeter to the centre of the space. This strategy may be useful for open spaces but can be difficult to employ in a maze situation where movement is restricted.
3. Gridline: Egocentric strategy where the individual investigates the internal features of an area by systematically walking straight-line paths from one side to the other. Again this strategy may be particularly difficult to employ in spaces that are not completely open.
4. Perimeter to object: Allocentric strategy where the individual codes the position of an object by walking back-and-forth between the perimeter of the area and the object.

Here it is important to note that to be effective, the individual must relate the position of all the different objects after having coded their position relative to the perimeter.

5. Home-base to object: Allocentric strategy similar to the *reference point* strategy identified by Hill and Ponder (1976) where the subject uses an object (or location) as an anchor or home-base from where straight line movements or direct routes can be made to several other objects. Here again, the individual must relate the position of all different objects after having coded their position relative to the anchor.
6. Object to object: Allocentric strategy where the individual walks back-and-forth in a straight line or over a direct route between two objects. This strategy is identical to the back-and-forth strategy identified by Gaunet and Thinus-Blanc (1996).
7. Cyclic: Egocentric strategy that involves successively visiting all locations within an experimental space and then returning to the first object visited.
8. Imaginary: Imagining a geometrical form, pattern or object (triangle, rectangle, Braille cell) that approximates the spatial arrangement of the target objects (this strategy was discarded from the analysis given the difficulties associated in coding it).
9. Random: This is not a strategy *per se* but will be used to classify movement with no particular logic.

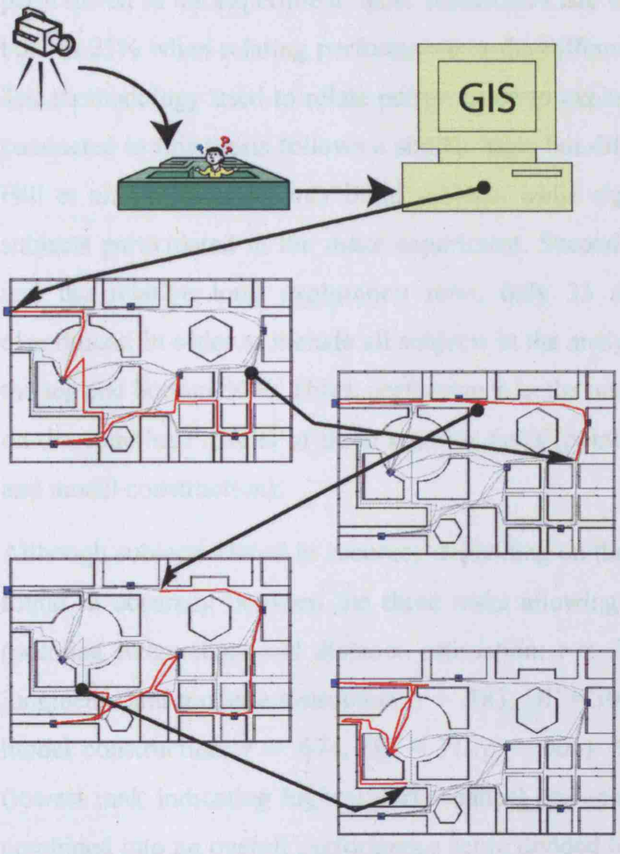
11.2.4 Strategy coding

Past studies have used video analysis in order to code the different types of strategies used by individuals during exploration. The majority of these experiments were conducted in small open spaces where the relatively short exploration time allowed researchers to disentangle movement by simply watching the captured video. Hill et al. (1993) for example gave subjects a total of seven minutes to explore the space and separated their exploratory pattern at each minute. Given the size and relative complexity of the maze, subjects were given a maximum of 45 minutes to explore and locate the different tables. Subjects were also given the opportunity to stop their exploration once they were confident they could remember the position of the different tables. Considering that subjects did in fact vary in their exploration time it was decided, for the sake of analysis, that all captured tracks would be divided in 7 equal intervals relative to the total exploration time - in the sense that if a subject explored the maze for a total time of 42 minutes, each tracking interval would detail what this person did at every six minutes. The diagram in figure 11.6 illustrates[83] the process involved in the coding of strategies. First, movement inside the space is captured by the researcher using a video camera. The exploratory pattern of each subject is then divided into 7 equal pieces depending on the time taken to explore, locate and remember the position of the different tables. Finally,

[83] This figure is simply used to illustrate the process of strategy coding and details are given for only the first four intervals of exploration. The exploratory pattern of each subject was broken down into seven intervals.

each piece is separately entered as a polyline in ArcGIS, which if combined make up the entire exploratory pattern for the subject. Red polylines indicate movement for the particular interval while green lines indicate the remainder of the exploratory pattern.

Figure 11.6 - Strategy analysis



The *tracking analyst* extension in ArcMap was then used to animate and playback the different sections of the exploration allowing for greater accuracy when identifying the strategies. Looking at figure 11.6, we notice that during the first and second intervals, the subject walked along the perimeter of the maze coming back to the starting point. We also notice that in the first interval the subject deviated from the perimeter by walking a diagonal line from the Police Station to get to the Bakery. In the fourth interval the subject began to employ a grid strategy by systematically walking straight lines. As a result this subject was classified as using the perimeter and cyclic strategies. The next section will use examples from top performers in the four groups in order to further illustrate the process of strategy coding.

11.2.5 Relating performance to exploratory strategies

In Hill et al. (1993) subjects were asked to make a series of pointing judgements between the objects found during their seven-minute exploration. A total of 65 subjects participated in the experiment and these were divided into two groups according to the their performance in the pointing task. Given the high number of subjects that participated in the experiment, these researchers had the luxury of separating the top and bottom 25% when relating performance to the different identified exploratory strategies. The methodology used to relate performance to exploratory strategies in the experiment conducted in this thesis follows a similar logic but differs in three important ways. First, Hill et al. (1993) used only blind subjects while sighted, visually impaired and blind subjects participated in the maze experiment. Second, given the availability of subjects and the relative long exploration time, only 33 subjects participated in the maze experiment. In order to include all subjects in the analysis, subjects were divided between the top and bottom 50%. Third, performance in the maze experiment was measured based on the combined results of three separate tasks (pointing estimation, distance estimation and model construction).

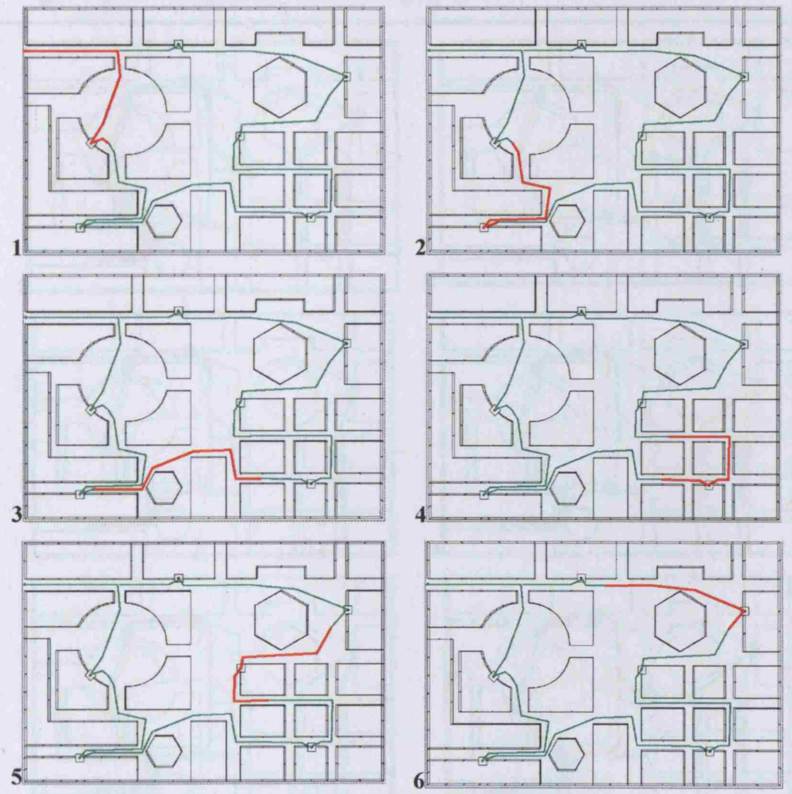
Although subjects varied in accuracy depending on the task, significant correlations were found in accuracy between the three tasks allowing for results to be pooled together (pointing judgements and distance estimation: $r = .715$, $DF = 30$, $p < .001$; pointing judgments and model construction: $r = .783$, $DF = 30$, $p < .001$; distance estimation and model construction: $r = .674$, $DF = 31$, $p < .001$). Subjects were ranked for each test (lowest rank indicating highest performance) and ranks from the three tasks were then combined into an overall performance score divided between the top and bottom 50% of performers. Ties were allowed during the ranking transformation and as a result, although 33 subjects participated in the maze experiment, subjects were ranked out of 23. Table B1 in appendix B presents the accuracy, rank and performance for each task as well as the overall rank and performance for all subjects. Table B2 in appendix B presents the same ranking transformations for all but the sighted subjects. Table B3 presents the ranking transformations for the SVI and blind subjects only.

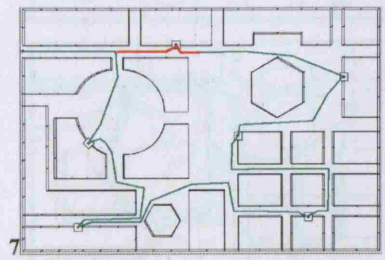
11.2.5.1 Strategy coding: Top performers

Performance was considered in relation to both the type of exploratory strategies implemented as well as frequency of use. Before presenting the results however, it is worth looking at some examples from top performers as a way of illustrating how the strategies were extracted from the overall exploratory patterns. The exploratory patterns and isolated strategies for all subjects can be found in the last section of appendix B.

Figure 11.7 presents the exploratory pattern of a top performer with a rank of 2/23. The subject belongs to the sighted group and this is evident from the movement patterns. Looking at the 7 intervals we notice that this subject took very little time to explore the maze moving directly from one table to the other. Movement in this case is predominantly guided by vision and the subject is classified as having adopted the cyclic strategy visiting all the tables and returning to the starting point.

Figure 11.7 - Exploratory strategies (sighted)

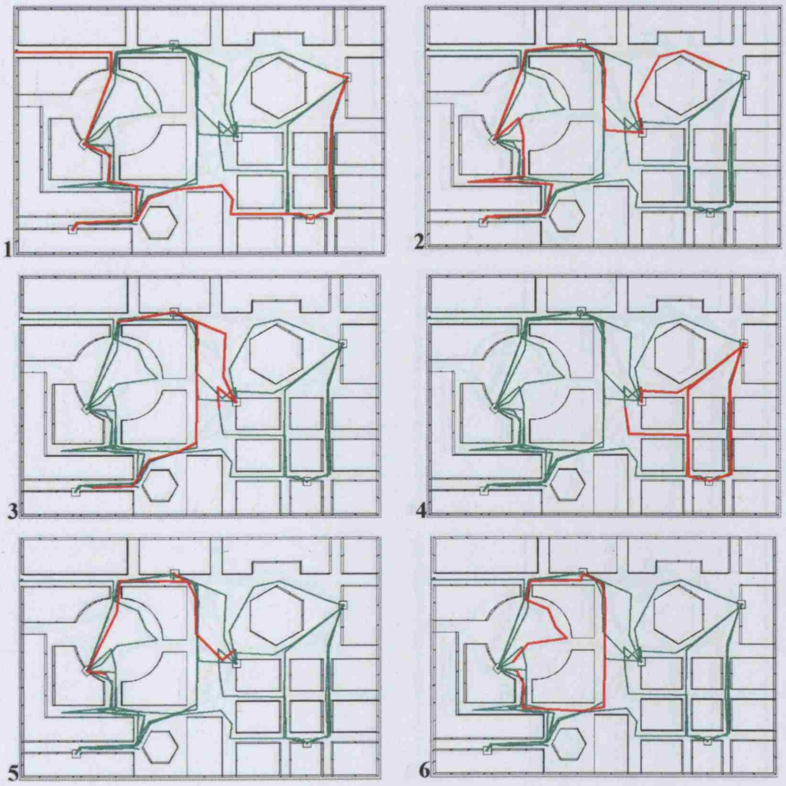


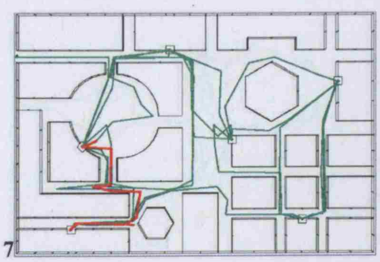


Subject number: 32
Eye condition: -
Group: Sighted
Angle error (rank): 2/32
Distance error (rank): 7/17
Distortion index (rank): 3/33
Sum ranks: 2/23
Exploration time: 2:40 minutes
Length: 155.30 meters
Table hits: 6
Strategies: Cyclic

Figure 11.8 presents the exploratory pattern of a good performer in the MVI group. This subject also belongs to the top 50% and has adopted a variety of strategies to compensate for the partial absence of vision. Looking at the first two intervals, we notice that the subject begins by adopting a perimeter strategy but tends to deviate from the perimeter the moment a table becomes visible, moving directly from table to table. The perimeter strategy however, allowed the subject to gain considerable knowledge regarding the size and shape of the maze. In the remaining intervals the subject changes from the perimeter and cyclic strategies and adopts an object-to-object strategy establishing the relative position of each table.

Figure 11.8 - Exploratory strategies (MVI)

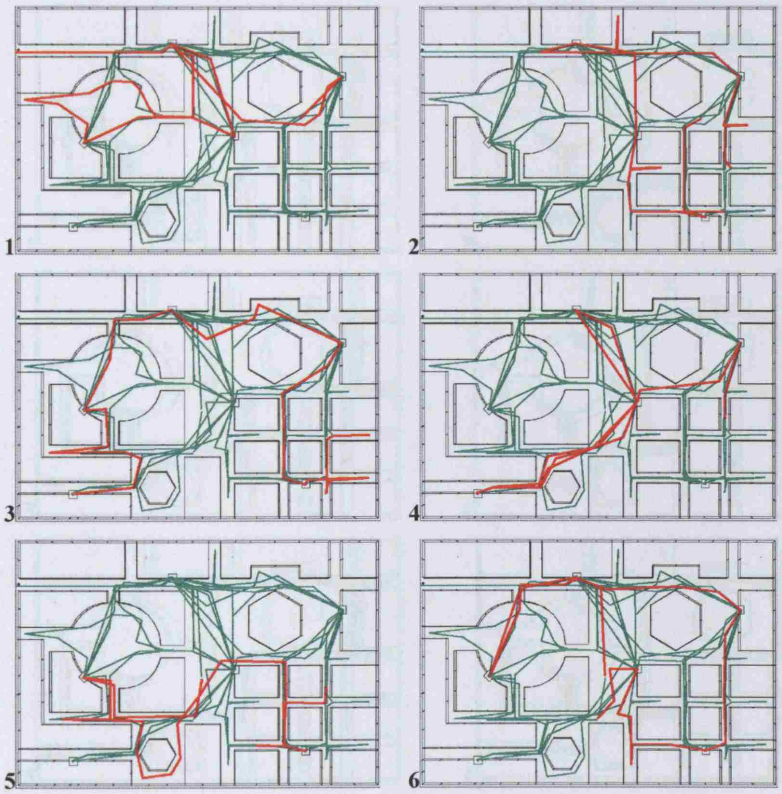


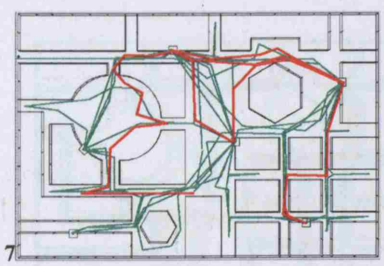


Subject number: 16
Eye condition: Unknown
Group: MVI
Angle error (rank): 12/32
Distance error (rank): 6/17
Distortion index (rank): 9/33
Sum ranks: 8/23
Exploration time: 11:12 minutes
Length: 518.51 meters
Table hits: 18
Strategies: Perimeter, object-to-object and cyclic

Figure 11.9 presents the exploratory pattern of a good performer in the SVI group. This subject also belongs to the top 50% and has ranked lower than the previous MVI subject. During the first two intervals, it seems that the subject was randomly walking across the maze. However it soon becomes apparent that the subject was attempting to employ a gridline strategy. This approach ceases by the end of the second interval where the subject adopts a perimeter-to-object strategy to code the location of the Coffee Shop and the School. By the fourth interval, the subject begins to adopt an object-to-object strategy moving in particular between the Train Station, School and the Bank. In the final interval, the subject implements a cyclic strategy going through all the tables before stopping.

Figure 11.9 - Exploratory strategies (SVI)

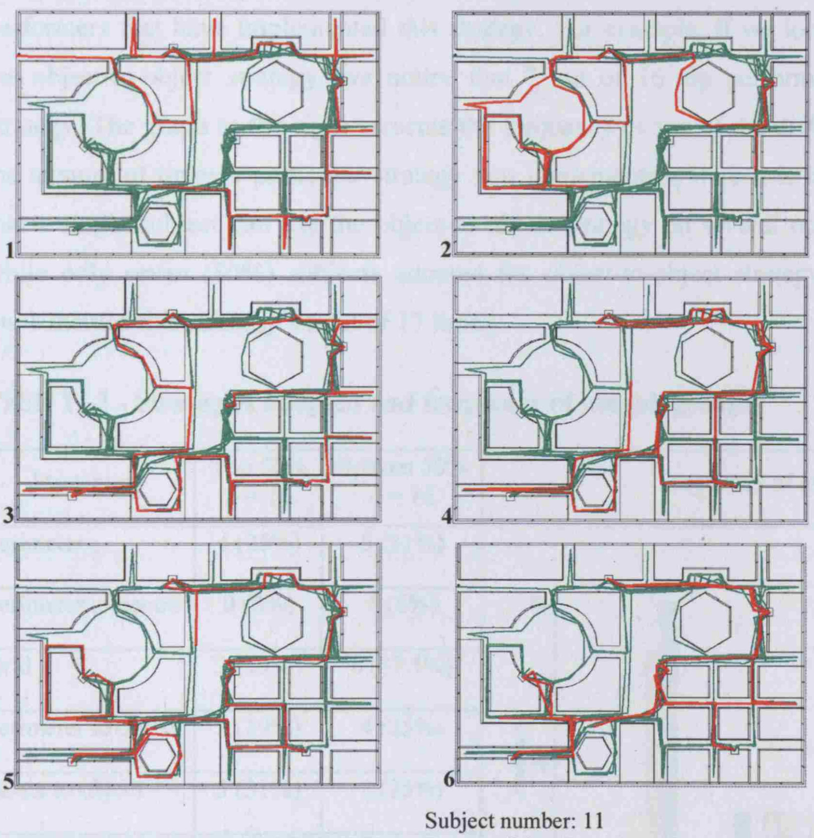




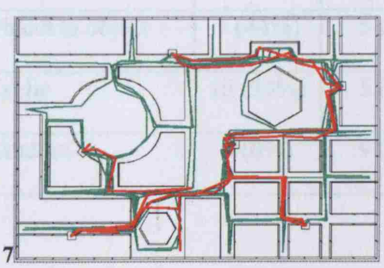
Subject number: 13
Eye condition: Retinal dystrophy
Group: SVI
Angle error (rank): 5/32
Distance error (rank): 7/17
Distortion index (rank): 14/33
Sum ranks:7/23
Exploration time: 17:58 minutes
Length: 951.60 meters
Table hits: 33
Strategies: Grid, cyclic
perimeter-to-object, object-to-object

Figure 11.10 details the exploratory pattern of a good performer in the blind group. Although the rank of this subject is higher (13/23), this subject also belongs to the overall top 50% of performers. During the first two tracks, it becomes clear that this subject thoroughly implemented a perimeter strategy, trailing the wall around the maze and going through all dead-ends encountered on the way. The subject does miss the south-western part of the maze but makes up for it in the third interval once again by implementing a perimeter strategy. With the perimeter strategy, the subject was able to locate all the tables except for the Bakery but this was solved by the fourth interval, when the subject adopts a perimeter-to-centre strategy.

Figure 11.10 - Exploratory strategies (blind)



1 2 3 4 5 6



7

Subject number: 11
Eye condition: Lever's optic neuropathy
Group: Blind
Angle error (rank): 20/32
Distance error (rank): 5/17
Distortion index (rank): 19/33
Sum ranks: 13/23
Exploration time: 32:54 minutes
Length: 1470.56 meters
Table hits: 44
Strategies: Perimeter, perimeter-to-centre, perimeter-to-object, object-to-object, cyclic

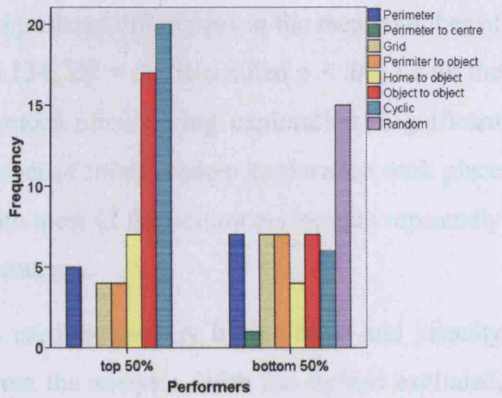
We also note that in the third interval, the subject complements the perimeter strategy with a perimeter to object strategy next to the School and the Train Station. By the fifth interval, this subject is already adopting an object-to-object strategy repeatedly going over all the tables. In the last interval, the subject adopts a cyclic strategy concluding the exploration next to the starting point.

11.2.5.2 Performance, strategy type and frequency of use

What remains to be shown is whether a relationship exists between the strategies adopted, their frequency of use and performance. Table 11.2 presents the strategies adopted by the top and bottom performers during the maze exploration. The left column presents the different strategies and the two columns to the right indicate the number of top or bottom performers that have implemented this strategy. For example, if we look at the row for the object-to-object strategy, we notice that 7 out of 16 top performers adopted this strategy. The graph to the right presents the frequency of use of the different strategies - the amount of times a particular strategy was implemented. Here it is important to note that a single subject can use the object-to-object strategy on several occasions. That is, while only seven (50%) subjects adopted the object-to-object strategy, these subjects implemented this strategy a total of 17 times.

Table 11.2 - Strategies adopted and frequency of use (all groups)

Strategies	Top 50% n = 16	Bottom 50% n = 16	Frequency of use
Perimeter	4 (25%)	5 (31%)	
Perimeter to centre	0 (0%)	1 (6%)	
Grid	3 (19%)	6 (37.5%)	
Perimeter to object	3 (19%)	4 (25%)	
Home to object	5 (31%)	4 (25%)	
Object to object	7 (44%)	5 (31%)	
Cyclic	15 (94%)	5 (31%)	
Random	0 (0%)	9 (56%)	



A series of chi-square tests were performed in order to investigate whether a significant association existed between the type of strategies used and performance. A significant association was found between the use of the cyclic strategy and performance (χ^2 = 13.333, DF = 1, p < .001) with all but one top performer adopting this strategy when exploring the maze. A significant association was also found between random exploration and performance (χ^2 = 12.522, DF = 1, p < .001) with none of the top performers randomly walking around the maze during the exploration period.

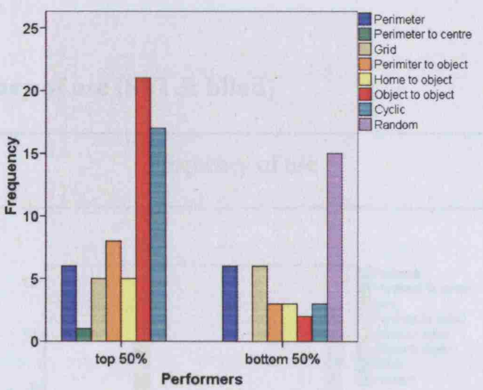
At first these results seem to contradict those found in the past regarding the effectiveness of allocentric strategies in the construction of accurate mental representations. The only strategy found to significantly relate to performance was cyclic, a purely egocentric strategy, at least in terms of movement. However, a quick glance at table B1 in the appendix will reveal that the sighted make up the vast majority of top performers when all groups are included in the analysis. Vision allows for the quick assembly of piecemeal information during navigation. In this manner, while the movement of the sighted may seem egocentric, it is possible that while navigating from one table to the other, they were actually looking back-and-forth and in essence constructing the relationship between the various tables irrespective of their bodies. It seems that at least when vision is available the cyclic strategy is actually an allocentric type of strategy based on the quick visual scanning of the environment and the elements contained within it. The sighted in Gaunet and Thinus-Blanc (1996), the researchers who identified the cyclic strategy, used blindfolds during exploration and consequently could not benefit from the scanning power of vision.

A series of t-tests were conducted in order to investigate whether differences also exist in the number of times the different strategies were adopted by the top and bottom performers. Results from the t-test revealed significant differences in the mean number of times the cyclic strategy was employed (t =4.134, DF = 30, two-tailed p < .001) with the top performers employing these strategies more often during exploration. Significant differences were also found in the mean number of times random exploration took place (t = -3.337, DF = 30, two-tailed p < .001) with most of the bottom performers repeatedly walking around the maze with no particular strategy.

In order to further investigate the strategies used exclusively by the blind and visually impaired, the sighted group was removed from the analysis. With the sighted excluded, the MVI, SVI and blind subjects were ranked again (see table H – 2) and performance was separated between the top and bottom 50%. Table 11.3 presents the strategies adopted and the frequency of use for the MVI, SVI and blind groups.

Results from the chi-square tests indicated a significant association between the use of the object-to-object ($\chi^2 = 7.721$, DF = 1, p = .005) and cyclic ($\chi^2 = 15.476$, DF = 1, p < .001) strategies and performance with 69% of the top performers implementing an object-to-object strategy and 92% implementing a cyclic strategy during exploration. Here again, a significant association was also found between random exploration and performance ($\chi^2 = 13.765$, DF = 1, p < .001) with none of the top performers randomly walking around the maze. Results from the t-tests revealed significant differences in the mean number of times the object-to-object (t = 3.826, DF = 24, two-tailed p = .001) and cyclic (t = 4.465, DF = 24, two-tailed p < .001) strategies were employed with the top performers employing these strategies more often during exploration. Here again, significant differences were also found in the mean number of times random exploration took place (t = -3.638, DF = 30, two-tailed p = .001) with most of the bottom performers repeatedly walking around the maze with no particular strategy. These results are consistent with past research that found that top performers were those that not only adopted an allocentric strategy (object-to-object) but also tended to employ this strategy more frequently during exploration.

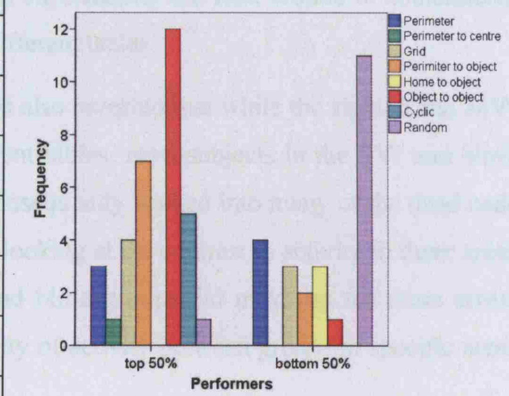
Table 11.3 - Strategies adopted and frequency of use (MVI, SVI & blind)

Strategies	Top 50% n= 13	Bottom 50% n= 13	Frequency of use
Perimeter	5 (39%)	4 (31%)	
Perimeter to centre	1 (8%)	0 (0%)	
Grid	4 (31%)	5 (39%)	
Perimeter to object	5 (39%)	2 (15%)	
Home to object	3 (23%)	3 (23%)	
Object to object	9 (69%)	2 (15%)	
Cyclic	12 (92%)	2 (15%)	
Random	0 (0%)	9 (69%)	

Considering the high number of subjects that have adopted the cyclic strategy (and the corresponding amount of times this strategy was employed), it is still possible that vision continues to guide exploration and influence the strategies that are being selected. In order to check for this effect of vision, both the sighted and the MVI (the two groups that have consistently shown to use vision to guide movement or complete a spatial task) groups were excluded from the analysis. With the sighted and MVI groups removed from the analysis, subjects in the SVI and blind grouped were ranked again (see table B3 in the appendix) and performance was separated between the top and bottom 50%. Table 11.4 presents a summary of the strategies adopted and the frequency of use by the SVI and blind subjects.

Results from the chi-square tests indicated a significant association between the use of the perimeter-to-object ($\chi^2 = 4.381$, DF = 1, p = .036), object-to-object ($\chi^2 = 7.024$, DF = 1, p = .008) and cyclic strategies ($\chi^2 = 10.370$, DF = 1, p = .001) and performance with 67% of the top performers implementing a perimeter-to-object and 83% implementing an object-to-object and cyclic strategy. Once again, a significant association was also found between random exploration and performance ($\chi^2 = 4.667$, DF = 1, p = .031) with only one of the top performers walking around the maze without any particular strategy. Results from the t-tests revealed significant differences in the mean number of times the object-to-object (t = 3.647, DF = 12, two-tailed p = .001) and cyclic (t = 5.855, DF = 12, two-tailed p < .001) strategies were employed with the top performers employing these strategies more often. No significant differences were found in the mean number of times the perimeter-to-object strategy was employed. Significant differences were found in the mean number of times random exploration took place (t = -2.174, DF = 12, two-tailed p = .05) with most of the bottom performers repeatedly walking around the maze with no particular strategy.

Table 11.4 - Strategies adopted and frequency of use (SVI & blind)

Strategies	Top 50% n = 6	Bottom 50% n = 8	Frequency of use
Perimeter	3 (50%)	3 (38%)	
Perimeter to centre	1 (17%)	0 (0%)	
Grid	3 (50%)	3 (38%)	
Perimeter to object	4 (67%)	1 (13%)	
Home to object	0 (0%)	3 (38%)	
Object to object	5 (83%)	1 (13%)	
Cyclic	5 (83%)	0 (0%)	
Random	1 (6%)	6 (75%)	

As in the two previous tables, the top and bottom performers tend to be equally divided regarding the use of the perimeter, grid strategies. These strategies are usually employed during the first intervals of the exploration and prove to be beneficial at least in conveying information about the size and shape of the space. Once this knowledge is acquired, the top performers tend to employ various other strategies most of these allocentric, in an attempt to code the different spatial relationships irrespective of their body. However, what really differentiates between the top and bottom performers is the implementation of the object-to-object and the cyclic strategies. While it was hypothesized that vision favours the use of the cyclic strategy, top performers in both the blind and severely visually impaired groups also employ it during their exploration. For the most part, the cyclic strategy adopted in the last interval as a way to quickly *double check* the position of the different tables.

11.3 Summary and discussion: Exploratory strategies

An analysis of the exploratory pattern of subjects in the different groups revealed that vision played an important role in the manner subjects circulated inside the maze. In general, vision allowed for a quicker exploration where subjects were able to rapidly integrate information into a coherent representation. Sighted subjects spent less time exploring and walked relatively shorter distances inside the maze followed by the MVI, SVI and blind groups. The sighted and the MVI also had the least amount of table hits and this is related to the fact that subjects in these groups could integrate piecemeal information by simply looking at the different locations without having to actually walk towards them. This was confirmed by looking at the individual tracks for subjects in these two groups where it was observed that subjects tended to walk to the middle of the space (most at the time during the last interval of exploration) and look around to authenticate their representation of the position of the different tables.

The activity pattern for the different groups also revealed that while the sighted and MVI tended to walk directly towards the different tables, most subjects in the SVI and blind groups trailed the walls of the maze and consequently walked into many of the dead ends along the perimeter. This was observed by looking at the contrast in activity in these areas between the different groups. The SVI and blind groups did make up for these errors however, and this is evident by the similarity of activity between groups in specific areas of the maze but in particular for areas adjacent to the Train Station, School and Police Station.

Results from the analysis of strategies are consistent with those from past research (Gaunet & Thinus-Blanc, 1996; Hill et al., 1993) that have found a relation between the type and frequency of strategy (or strategies) used to explore space and the accuracy of mental representations. By breaking up the exploratory patterns of the different subjects into separate intervals, a variety of strategies were isolated. These were then related to the ranked performance of subjects in the pointing estimation, distance estimation and the model construction tasks. Results revealed that top performers irrespective of their visual condition used a wider variety of strategies and that the majority of these strategies tended to be object related and allocentric. Results from the chi-square analysis indicated that the top 50% of performers in the blind and visually impaired groups opted for and used more frequently the object-to-object strategy. Top performers in the SVI and blind groups also used the perimeter-to-object strategy when coding the position of locations. In contrast, the bottom performers in all groups did not vary much regarding the type and frequency of strategies used, most of them found to be randomly walking around the maze with no apparent strategy.

Top and bottom performers in all groups also used egocentric strategies (i.e., perimeter and gridline) and these were important in conveying information about the size and shape of the space. What differentiated the top from the bottom performers however, was that once this knowledge was acquired, these subjects went on to employ a variety of object-related strategies where the relative position of the different tables was encoded irrespective of their bodies. Here it was found that sighted subjects and top performers in the MVI and SVI groups used their vision (or what remained of their vision) in the form of a cyclic strategy by moving their bodies and heads in order to code the position of the tables. Although in the past this strategy has been classified as egocentric when adopted by blind subjects, it was argued that when vision is present, eye and body movements allow for different positions to be allocentrically coded. Top performers in the blind groups also adopted this strategy in the final intervals of their exploration as a way of *double-checking* for the accuracy of their mental representations.

Chapter 12
Conclusions and future research

"People do not like to think. If one thinks, one must reach conclusions. Conclusions are not always pleasant. They are a thorn in the spirit. But I consider it a priceless gift and a deep responsibility to think" – Helen Keller (1967)

12.1 The two experiments

This thesis reported on two experiments on the perception and cognition of space conducted with students from Dorton College at the Royal London Blind. The first experiment examined the content and accuracy of mental representations of a well-known environment by asking students to walk a route around the RLSB campus and complete three separate spatial tasks. These tasks were chosen in accordance with past research (Kitchin, 1997) that urged researchers to use multiple converging techniques in the analysis of mental representations as a way to account for the heterogeneity of skills, qualities and conditions between participants. Subjects were asked to make pointing judgements, estimate distances and complete a spatial cued model of the campus. The second experiment considered the wayfinding strategies and spatial coding heuristics used to explore a complex novel environment. A maze was constructed at the site of the RLSB and subjects were given 45 minutes to explore and locate six different tables inside it. Their search patterns were recorded and GIS software was used to extract and code the different strategies used to locate the tables during exploration. Students were tested using the same methods as in the first experiment and their performance was related to the type and frequency of strategies used. Results from both experiments were complemented with a mobility questionnaire, a quality of life questionnaire and intelligence tests as well as ethnographic material collected by the author during the two years spent living and working at the RLSB.

12.2 Visual acuity and the heterogeneity of visual impairment

In the opening chapters of this thesis, special attention was given to the definition and explanation of the concepts of disability, blindness and visual impairment. This emphasis, stemmed from the experiences accumulated by the author during the time spent living and working as a life skills tutor at the RLSB. The blind and visually impaired form part of a population that is extremely heterogeneous. As discussed in chapter 3, impairment can be related to the acuity and the field of vision with visual acuity often chosen as way to group individuals for spatial testing. Although important conclusions have been made based on acuity classifications, researchers should also pay attention to the extent in which the visually impaired make use of their residual vision. Different visual conditions manifest themselves in a variety of ways and can have important implications in psychosocial adjustment and self-esteem. Warren (1984) observed that the field of blindness and visual impairment is plagued by research with contradictory results. He argues, that in many cases these differences can be attributed to the fact that researchers were working with samples that were not equivalent. Finally, this heterogeneity in the population can be particularly problematic if statistical analysis that focuses on group averages is the only method employed in the analysis of data. Results from statistical analysis must be carefully scrutinized; the characteristics of each participant must be described if we are to account for variations in the population.

Results from spatial tasks that focused on the accuracy of mental representations revealed individual differences in performance for all four groups (sighted, MVI, SVI and blind). This variation in performance was particularly high for the two visually impaired groups although both the sighted and blind groups also had very good and very poor performers. In some cases, these variations could be directly attributed to visual acuity (visually impaired groups included individuals with a range of acuities) or whether the impairment was congenital or adventitious.

Individual differences were also considered in relation to the format chosen by subjects to encode and represent distances. In chapter 7, a variety of studies were reviewed where it was argued that the blind and in particular the congenitally blind, are only able to represent the distances between different objects in the environment in functional terms (Carreiras & Codina, 1992; Bigelow, 1991; Veraart & Wanet-Defalque, 1987; Fletcher, 1980; Rieser et al., 1980). That is, the blind think in terms of routes and if not incapable, have considerable problems understanding and representing the straight line or Euclidean relationship among sequentially perceived stimuli. Results from a series of rank order correlations that evaluated the degree of fit between real Euclidean or functional distances and estimated distances, revealed that blind and visually impaired subjects varied regarding to which baseline their estimations adhered more closely to. Although it was found that the estimations of the majority of blind subjects did in fact relate closer to the functional baseline, 50% of subjects in the first experiment and at least one subject in the second experiment estimated closer to the Euclidean baseline. The visually impaired groups were divided between the two baselines although the majority of subjects in both experiments tended to think in Euclidean terms. It seems that vision has a facilitating effect in the formation of Euclidean concepts but this is not exclusive. The blind and visually impaired are also able to understand and manipulate Euclidean concepts derived from the integration of information collected from proprioception, residual vision, and the other sensory modalities – the accuracy of these representations influenced by experience or familiarity with the environment.

12.3 The accuracy of representations

The sighted was the best performing group in all three tasks for both experiments. Vision played an important role in the accuracy of pointing judgments, distance estimation and model construction but this varied between tasks and experiments. Results from the pointing task in the first experiment revealed significant differences between the sighted and the blind and between the MVI and the blind. This was also the case for the second experiment although accuracy improved for all groups. These results are consistent with past research that has shown that the blind and particularly the congenitally blind have difficulties in pointing in both small, medium and large scale environments (Bigelow, 1991; Hollins and Kelley, 1988; Rieser, 1986; 1982; Byrne and Salter, 1983; Herman et al., 1983a; Dodds et al., 1982) although it was emphasized that results from pointing tests have to be carefully analysed as they often put the blind at a disadvantage. Familiarity and experience navigating the environment played a major role in the accuracy of pointing judgements in the RLSB campus. All subjects were significantly better at *pointing to* locations in the *college area* of the campus – the area in which they lived, worked and studied. The effect of familiarity was further illustrated by the higher accuracy when pointing *to* and *from* anchors or landmarks (Student-Centre and Mansion House) around the RLSB campus particularly those that were centrally located (Lloyd, 1989) and in the case of the sighted, structures located on higher ground. In the second experiment, and also consistent with past research (Herman et al., 1983a), accuracy varied as a function of distance from the starting point, number of turns, the complexity of the route and the presence or absence of a reference frame.

Differences in results from the distance estimation task for both experiments are particularly interesting, once again confirming the facilitating effect of vision and the importance of travel and mobility experience in the construction of mental representations. In the first experiment, no differences were found between groups with all subjects being more accurate when estimating distances between locations in the *college area* of the campus. Results from the second experiment revealed that even in novel environments, the blind and visually impaired are able to understand and represent the Euclidean distances between locations although performance did vary as a function of visual acuity. Differences in performance between the two experiments can be attributed to the scale, complexity and familiarity with the two experimental spaces. It was also argued that the size of the experimental space had an important effect on the speed information was integrated into coherent representations. The size of the space also affected accuracy as subjects, especially those in the blind and SVI groups, had more difficulties disentangling differences in distances among objects that were closer to each other, in particularly those around the centre point (The Bakery). Nonetheless, within group differences revealed that despite variations in visual acuity, some of the subjects in the blind and visually impaired groups were able to understand and accurately represent both the Euclidean and functional relationships among the different tables. In general, it can be said that in the case of the blind and SVI groups, proprioception and information collected through the other senses was able to provide these subjects with a functional representation of the distance between elements in space. These representations however, were found to be lacking when compared to those built with help of vision (sighted and MVI) where reference frames were widely available and information was both redundant and convergent (Tufte, 1997; Millar, 1994).

In chapters 7 and 8, it was argued that model tasks could be particularly useful in the analysis of configurational knowledge as they force subjects to represent the allocentric relationships between different elements in the environment. Although it is true that models can be constructed on the basis of sequentially perceived information that is not necessarily compiled into a coherent representation, results from the first and second experiments revealed that when it came to reproduce a complete configuration, the sighted were significantly better than all other groups. Although these results are consistent with some past experiments (Wanet-Defalque et al., 1991; Fletcher, 1980; Casey, 1978) they are directly at odds with more recent research (Jacobson et al., 2001) that has used similar methods (bidimensional regression) in the analysis of models. It should be noted however, that subjects in Jacobson's et al. (2001) study walked the route at least three times. While familiarity surely played a role in the accuracy of models in the first experiment, (subjects were consistently better in their reproduction of the college area) it may be that the participants required more circuits around the RLSB campus before they could integrate and externalize this knowledge into a more accurate model for both areas. That said, models for all groups revealed that subjects did have an accurate knowledge of the topological relationships between the different locations.

12.4 Distortions and the format of representations

The analysis of distortions in mental representations was particularly useful in proving that the blind and visually impaired are able to construct mental representations from proprioception and information collected from other senses. Similarities in constant error in pointing judgements and distance estimation for both experiments, revealed that the representations of the blind and visually impaired share many characteristics in common with those that are built on the basis of vision. These similarities were further confirmed by an in-depth look at the output of multidimensional scaling and bidimensional regression. In the first experiment, results from constant error for locations pointed *to and from* revealed that all groups followed a pattern of clockwise or counter clockwise biases when *pointing to* the different location in the RLSB campus. This was also true for the second experiment where it was found that all groups shared only a clockwise bias when *pointing to* the various tables in the maze.

In relation to the distance estimation task, subjects in the first experiment, irrespective of their vision acuity or condition, tended to overestimate the distance between locations that were closer together and underestimate distances between locations that were further apart. Analysis of the MDS output revealed that for all groups (but particularly for the bottom performers), distortions were the result of the discrepancy between functional and Euclidean distances, the order in which the different locations were visited during the walk and, to a lesser extent, a variation in the orientation of the front door of the building. In the second experiment, results from constant error revealed that all groups had similar patterns of over and underestimation that varied according to the table featured in the triad. Here, an analysis of the multidimensional scaling output aided by a set of rules devised from the design of the maze, revealed that distortions were mainly the result of discrepancies between the Euclidean and functional distances.

In relation to the model task, subjects tended to be more variable regarding the type of distortion committed in the models of the RLSB campus. An anchor magnetism effect was found with all subjects contracting their model toward the Mansion House at the centre of the configuration. Results from the bidimensional regression in the second experiment revealed a similar pattern of distortions among all groups relative to the east/west, north/south translation, angle displacements and scale contractions.

In chapter 6, it was argued that similarities in distortions could be regarded as evidence that individuals are using similar cognitive processes when encoding spatial information. Together the results from the pointing estimation, distance estimation and model tasks indicate that despite differences in the accuracy of mental representations, the mental processes used by the blind and visually impaired in the organization of encoded spatial information, regardless if it is encoded on the basis of visual, proprioceptive or information provided by the other sensory modalities, is similar to those used by the sighted. These results support many of the assumptions put forward by the inefficiency theory regarding the advantages of vision in the formation of accurate mental representation but it also maintains that the blind and visually impaired, congenital or adventitious, are able to use information collected through their different senses in the construction of functional mental representations.

12.5 Intelligence, mobility and quality of life

Blind and visually impaired subjects were asked to complete a mobility and quality of life questionnaire and this data was complemented by intelligence scores derived from literacy and numeracy assessments. This information proved useful in the interpretation of results from the three spatial tasks allowing for important conclusions to be made regarding the importance of mobility training, confidence and intelligence in the construction and manipulation of mental representations. In the first experiment, the relationship between level of independent mobility, quality of life and performance was somewhat blurred and this was attributed to the failure of these questionnaires to account for the level of familiarity and experience of subjects with the RLSB campus. Results from the mobility questionnaire were inconsistent with the author's experience while working as a life-skills tutor. Subjects did vary in relation to their level of mobility and quality of life and it was hard to believe that these factors played such a minor role in the construction and accuracy of mental representations.

Regarding the pointing task, no significant correlations were found between mobility, quality of life and intelligence for the first experiment - visual acuity being the only significant predictor of performance. This was not the case for the second experiment where results from a multiple regression revealed a significant model in which intelligence and visual acuity were found to be significant predictors of performance. It seems that vision is crucial in pointing estimations but that in novel and complex environments the level of intelligence can also assist in the construction of mental representations that serve as a basis for estimations in situations where vision is partially or totally absent.

In relation to the distance estimation task, no significant relationships were found between mobility, quality of life and intelligence. In addition, visual acuity could not predict performance in this task. Given that no significant differences were found between groups, it was argued that all subjects had reached a mobility threshold as a result of their daily interaction with the environment. These results are supported by the fact that in the second experiment, the importance of visual acuity in performance in the distance estimation task was forfeited by the years of mobility training and the level of intelligence. Here it should be noted that more years of mobility training did not necessarily translate into a higher level of independent mobility. This relationship is actually inversely proportional. More years of mobility training can act as an indicator that the subject is still struggling with some skills necessary for independent mobility. In other words, predicted performance in the distance estimation task was the combination of intelligence and advanced mobility skills used by participants during the time spent exploring the maze. Intelligence, possibly reflected by the type and frequency of strategies chosen by the top performers.

The role of mobility and intelligence in the accuracy of representation was further illustrated in the model construction task. In the first experiment, results from the regression revealed that intelligence surpassed visual acuity as a predictor of performance in the accuracy of models built by the blind and visually impaired. Here again, the level of independent mobility was confounded by the questionnaire's inability to account for the subject's level of familiarity with the RLSB campus. A significant relationship between mobility and performance was observed in the second experiment where results from the multiple regression revealed that the level of independent mobility was the only significant predictor of performance. Finally, quality of life also played a significant role in predicting the performance of the MVI and SVI groups for the angle and distance estimation tasks. In the second experiment when only these two groups were considered, quality of life proved to be a stronger predictor of performance than all other variables for all but the model construction task.

12.6 The relation between performance and exploratory strategies

The last section of this thesis examined the relation between performance and the different strategies that can be used to code space in the total and partial absence of vision. The exploratory pattern of the different subjects inside the maze was recorded with a video camera and entered into ArcMap for analysis. As expected, results revealed that vision played an important role in the manner subjects circulated inside the maze. The sighted and the MVI groups spent less time exploring and walked relatively shorter distances compared to the SVI and blind groups. These two groups also had the least amount of table hits, choosing to go to the centre of the space in order to get a good view of the relative position of the different tables. In contrast, subjects in the SVI and blind groups (also some subjects in the MVI group) were forced to move from table to table, encoding and integrating sequentially perceived information in order to generate a coherent representation. Many blind and visually impaired subjects also chose to trail the walls of the maze. This was somewhat of a problematic strategy as these subjects often ran into dead ends and were not able to reach some tables that were not directly situated in the perimeter.

Individual tracks were divided into 7 equal intervals based on the subject's exploration time. Strategies were coded based on a set of rules set-forth by previous research and the author's own observation of exploratory patterns. Results revealed that the blind are not necessarily egocentric and are capable of implementing allocentric strategies when exploring a novel and complex environment. Although there was a general tendency to implement egocentric strategies in the part of the blind and the severely visually impaired, the top performers in each of these groups successfully explored the maze using object related strategies. These results are consistent with those from past research (Gaunet and Thinus-Blanc, 1996; Hill et al., 1993) where it was shown that performance on spatial tasks (or the accuracy of mental representations) is related to the type and frequency of strategies (or strategies) used during spatial exploration.

The importance in teaching the blind and visually impaired to code spatial relationships among objects irrespective of their bodies is highlighted by the impact the use of allocentric strategies had on the accuracy of performance in spatial tasks. The top performers in the blind and visually impaired groups not only employed more object-based strategies (object-to-object and perimeter-to-object), they tended to employ these strategies more frequently combining them with other strategies, many of which egocentric, providing information on the size and shape of the space. In contrast, the bottom performers employed a significantly low number of strategies, (or combination of strategies) most of which were egocentric or tended to randomly walk around the maze with no apparent strategy.

12.7 Contributions to research in geography and psychology

Chapter 2 urged geographers and psychologists to approach disability research from a different stance. Instead of focusing only the differences, it advised researchers to focus and celebrate the abilities of the disabled. The research conducted in this thesis attempted to do just that. It demonstrated, with considerable evidence, that the blind and visually impaired are not only able to construct and manipulate mental representations of space from information assembled from their other senses (and proprioception) but that these representations share many characteristics in common with those constructed with sight. This is a refreshing approach, which in combination with the methods used in the analysis and the wealth and the detail of the data ultimately allowed for important conclusions and contributions to be made in the field of visual impairment and blindness.

12.7.1 Overcoming past challenges

Chapter 7 provided an in depth review of research conducted on the spatial abilities of the blind and visually impaired. Despite important advances, research in this field continues to generate contradictory results. For the most part, the mental representations of the blind and visually impaired are inferior to those constructed with sight but the accuracy and extent of this knowledge varies from experiment to experiment. There are a variety of reasons behind this discrepancy in results and the paragraphs the follow outline how some of these were addressed in the two experiments conducted in this thesis.

12.7.1.1 Moving away from the lab: The RLSB campus and the maze

In chapter 4, it was argued that learning was not something mechanical or individual but a function of the activity and context in which it occurs. The theory of *situated learning* (Lave & Wenger, 1991) argues that learning should take place in situations that reflect real world scenarios. That is, that subjects should be immersed, taught and tested in environments that approximate, as closely as possible, the environment they will actually apply their knowledge. This focus on context translates into a *move away* from the lab, small-scale or simulated environments. The two experiments conducted in this thesis examined the mental representations of the blind and visually impaired in situations specifically chosen to resemble real-world scenarios. This is of paramount importance given that in the total or partial absence of vision, the scale of the environment influences that manner in which information is collected and assembled in the construction of mental representations. Much like the mental representations used for navigation and wayfinding in a city, those constructed while navigating the RLSB campus or exploring the maze depended on the constant (and accurate) updating and integration of displacement information.

Some researchers have in fact *moved away* from the lab and tested subjects in real world environments (Jacobson, 2001; Wanet-Defalque, 2001; Espinosa, 1998; Rieser, 1982; Byrne & Salter, 1983; Hollyfield and Fouke, 1983; Casey, 1978). These experiments have generated important results particularly regarding the advantages of vision in the formation of mental representations. The accuracy of the mental representation formed by the blind and visually impaired subjects often regarded as *functional* but lacking in comparison to those of the sighted. What these experiments lacked however, was an in depth look at the reasons behind this underperformance and exactly what was similar or different in the representations constructed with sight and those constructed in the total or partial absence of vision.

The maze was specifically designed to address some of these issues and particular care was given to the construction of the different areas and the positioning of the elements inside it. This careful manipulation of stimuli proved to be beneficial in the analysis of distortions, exploratory and wayfinding strategies allowing for stronger inferences to be made regarding the differences/similarity in the representations constructed by the blind, the visually impaired and the sighted. Although still not representative of a real-world scenario, the maze, unlike past experiments that have tested subjects in open spaces, allowed for analysis of movements in an area bounded by corridors and dead-ends where spatial coding depended on the integration of movement information from a combination of egocentric and allocentric exploratory strategies.

12.7.1.2 Variety of methods

In chapter 8, it was argued that researchers should use multiple converging techniques in order to address some of the shortcomings of visual impairment research. Mutually supportive methods used in the collection and the analysis of cognitive data, are necessary in order to account for the heterogeneity of characteristics and skills between participants. Only by testing subjects in a variety of spatial tasks and analysing their performance through a combination of quantitative and qualitative methods, can we distinguish between potential (the biological and genetic structure of an individual) and present competence. In many cases, the underperformance of the blind and visually impaired can be more the result of a testing artefact (lack of redundancy and convergence of information) rather than their actually ability to form and manipulate mental representations.

Subjects were put through three specific tests in the two experiments conducted for this thesis. They were asked to make pointing judgements, estimate distances and build cued models of the testing environment. Data from these tasks was then analysed with the help of a variety of statistical techniques (analysis of variance, regression, bidimensional regression, multidimensional scaling) and complemented by detailed data on the characteristics of each subject which included information on their visual condition, level of independent mobility, quality of life and intelligence. This attention to detail was crucial in the development of models regarding differences in the accuracy of representations by the sighted and those constructed in the total or partial absence of vision. This is an important improvement from past research where the abilities of the blind and visually impaired were often generalized from their performance in one specific task and where no links were established in relation to the characteristics of the subjects, albeit their visual acuity.

In addition, the use of multiple converging techniques made evident some of the weaknesses associated with some methods, in particular pointing judgements. Pointing is not an action common to the blind as it relies to a great extent on vision often putting the blind at disproportionate disadvantage in relation to the sighted and visually impaired. This was the case for the experiment in the RLSB campus and the maze. In both cases, the discrepancy in error from pointing tasks was larger than those from the distance estimation and model construction. Although, different tasks were chosen to measure different aspects of knowledge, a certain amount of care must be exercised when deriving conclusions from a particular task. It is one thing to say that the blind are inferior to the sighted and visually impaired regarding their ability to make pointing judgements; it is another thing to say that they are unable to construct functional mental representations of a previously learned of explored environment. This is evident from the fact that no differences were found in the ability to estimate distances between location in the RLSB campus and that some blind subjects were to produce very accurate models of the RLSB campus and the maze.

12.7.1.3 Focusing on the individual

In the first chapter, particular care was taken to describe the position of the author as a life-skills tutor at the RLSB. The experience of living and working among the subjects, not very common for a researcher in geography and experimental psychology, allowed for the collection of detailed and ethnographic data that was used to complement and make sense of results from statistical analysis. In fact, it was this insight into the real world of blindness and visual impairment that allowed the researcher to overcome some of the limitations inherent in the classification of individuals strictly based on their visual acuity. Although subjects were classified according to their visual acuity, care was taken to explain individual differences in performance in relation to their level of independent mobility, quality of life and intelligence. In some cases, group comparisons were forfeited to the analysis of the relationship between "raw" visual acuity (LogMAR) and the factors influencing performance. This is common practice in the field of ophthalmology but something that has not yet been entirely adopted in research on blindness and visual impairment in the disciplines of geography and psychology.

12.7.1.4 GIS and the analysis of exploratory strategies

As discussed in chapters 10 and 11, the maze experiment was an attempt to build on past research (Gaunet & Thinus-Blanc, 1996; Hill et al., 1993) that examined the relationship between performance in spatial tasks and the strategies used to explore and code the position of different elements in space. There are at least three direct contributions of the maze experiment to general research on curiosity, exploration and the formation of mental representations. First, the size and design of the maze allowed for important conclusions to be made regarding the use of egocentric and allocentric strategies in the coding of elements in a space that is both large and complex. As mentioned above, this is a welcome change from research conducted inside the lab or gym where the experimental space is often small, open and undifferentiated. The second contribution is the incorporation of GIS as a tool in the analysis of movement patterns. Whereas past research relied on the analysis on direct video data for the classification and analysis of exploratory strategies, GIS allowed for the construction of a database on the movement of each subject, which along with the *Tracking Analyst* extension simplified the process of extracting egocentric and allocentric strategies from the overall movement pattern. It allowed for greater control of dynamic information, where movement inside the maze could be individually represented or aggregated in relation to differences in visual acuity. GIS also allowed for the video data to be viewed from a perspective that was different from the one captured in the video. The coding of movement as polylines on a two-dimensional plan of the maze allowed for a global view (bird's eye view) of movement, which proved to be particularly useful when coding strategies along the different corridors of the maze. Finally, the maze experiment was able to build on past research that focused exclusively on the exploratory strategies used by the blind. The strategies used by the blind, visually impaired and sighted subjects were investigated, and important conclusions were made regarding the role of vision in the choice and frequency of strategies used. The selection and use of exploratory strategies by the blind and visually impaired can be of significant use in the development of future orientation and mobility programs and the design and use of electronic travel aids. These findings and particularly those relating to the use of a variety of exploratory strategies can have important implications for the updating of the orientation and mobility curriculum that in the past has focused almost exclusively in teaching the perimeter, gridline and object-to-object strategies.

12.8 Exploratory strategies and the future of orientation and mobility

In the introduction to their book Imagining the possibilities: Creative approaches to orientation and mobility instruction for persons who are visually impaired, Fazzi and Petersmeyer (2001) argue that only orientation and mobility specialists who "can develop a repertoire of creative teaching approaches" will be effective in delivering instruction that is both meaningful, easy to adopt and functional. Despite several notable efforts (Blasch, Wiener & Welsh, 1997; Gaunet & Thinus-Blanc, 1996; Hill et al., 1993; Hill & Ponder, 1976; Tellevik, 1992) there seems to be a reluctance to move away from theoretical approaches and actually assess the use and possible applications of some elements in the orientation and mobility curriculum (for more information see Blasch, Wiener & Welsh, 1997). This is particularly true as it applies to exploratory strategies where there seems to be a lack of empirical evidence regarding their role in the formation of accurate mental representations of space. In this section, we discuss some of the possible applications that these strategies can have and argue based on the results from the second experiment that there is a pressing need to update certain aspects of the orientation and mobility curriculum to include (a) a broader set of functional and efficient exploratory strategies that are both egocentric and allocentric and (b) more creativity in the teaching methods to include environments, both real or specifically designed, that force the individual to adopt a variety of strategies and helps them learn how to translate these strategies to situations in the real world.

12.8.1 Beyond the perimeter and gridline

Open any manual on orientation and mobility, flip to the index and you will probably find a link to a section on the perimeter and the gridline strategies. What you will probably not find is a direct link to empirical evidence that supports the significance of teaching these strategies or a discussion of how useful these strategies really are or how easy is it to apply them to real world scenarios. Results from the second experiment open an inspiring avenue to study the relationship between these strategies and the development of accurate mental representations. Apart from replicating important results on the role of the perimeter, gridline and object-to-object strategies in the formation of accurate representations, the second experiment demonstrated that these strategies could be applied to large and complex environments that resemble the streets of many urban settings. The experimental space was indeed a controlled environment but navigating and wayfinding within it required the constant updating of movement and recourse to mental representations that had to be accurate enough to indicate not only the relative position between the different tables but the specific manoeuvres necessary to reach them.

There are several strategies that can be adopted by the individual when learning a new environment. The choice of strategy, or more important the combination of strategies, will depend not only on the individual but the actual setting. It is for this reason that orientation and mobility instructors should teach and make sure students develop a large repertoire of strategies and an understanding when and where a particular strategy or set of strategies should be implemented. In relation to the maze experiment, it became evident that the top performers were those that began their search with a perimeter strategy but once they had coded the size and shape of the space, went on to adopt other strategies. The perimeter strategy was a valuable strategy but the development of accurate representations of all tables in the maze required subjects to use strategies that would allow for an exploration of the centre of the maze. The gridline and the perimeter to centre strategies allowed for a more in-depth exploration of the space. However, success in the implementation of both these strategies depended on the subject's ability to adapt and circumvent situations where both the gridline and the perimeter to centre were obstructed by the design (dead-ends) and corridors in the maze. It seems that orientation and mobility instructors should not only teach exploratory strategies but also teach how to overcome situations when the application of these strategies is interrupted or impossible.

The maze experiment also demonstrated the importance of teaching exploratory strategies that allow for the formation of representations irrespective of body orientation and position. In fact, this is perhaps the most valuable lesson to be gained from the second experiment. What essentially differentiated top and bottom performers in the blind and visually impaired groups, irrespective of their visual acuity, was the implementation of allocentric strategies during the exploration of the maze. For the orientation and mobility instructor this is an invaluable lesson relating to teaching of object-to-object strategies when an individual is faced with a novel and complex environment. In their famous work on exploratory strategies, Hill et al., (1994) had already shown the importance of these strategies for the accurate encoding of novel environments. What the maze experiment did was to show that there are a variety of object related strategies that can be implemented, that these strategies can be implemented in environments with varying degrees of complexity and that individuals vary in the frequency and choice of strategies they use. Apart from direct movement from one table to another, a large percentage of top performers utilized perimeter-to-object and home-to-object strategies. Although these strategies were perhaps not ideal for the maze environment they should still be part of a "strategy repertoire" as there is as much to be learned about an environment when a particular strategy works or when its application is impeded by the actual design and constraints of the space. It is now up for academics and orientation and mobility instructors to further validate these techniques and for this type of work to be mainstreamed and incorporated in a new more progressive and creative orientation and mobility curriculum.

12.8.2 From teaching to real-world application

Perhaps one of the main advantages of maze experiment was that it was conducted in a somewhat complex environment where exploration was constrained to the actual shape and design of the maze. This forced the individual to form mental representations of space that not only included information on the relative position of the different objects but also on the different ways they could navigate back and forth to these objects. This is a welcome change to past experiments conducted in open environments as it allows for a more ecologically valid discussion of how these strategies could be implemented in real-world city scenarios. The question remains as to whether this knowledge can be translated to real-world situations. The answer to this question will depend on the creativity of teaching methods and practice.

The maze was specifically designed to resemble a city and was made up of grid patterns, open areas and dead-ends. Although the primary intention of this research was not to teach the subject strategies that could be applied to the real world, it could be easily understood how such an environment lends itself to the teaching of orientation and mobility. The detail put in the construction of such environments could be used by orientation and mobility instructors when teaching and practicing a variety of mobility techniques (and in particular) strategies for the exploration of novel environments. Here it can be conceived that teaching an individual how to switch between the perimeter strategy to adopt an object-to-object strategy in order to get to a location in the centre of the maze can also be applied inside a shopping centre, park or even an urban street when the subject is moving from a particular shop/tree to a bench located at the distance from the perimeter or boundary of the space. Orientation and mobility professionals do strive to work in environments that approximate as closely as possible real world scenarios. At the Royal London Society for the blind for example, students are often taken to the town centre in order to experience what it is to navigate independently in a city. However, environments such as the maze offer these professionals the opportunity to practice with their students in environments that are specifically designed and easily manageable/adaptable to tackle the instruction and implementation of specific strategies. The maze is only one potential environment others will depend on the needs and the creative power of professionals.

12.9 The future of visual impairment research

There are still a number of questions that need to be addressed in research in this area. Many of these stem from limitations in past research, some of which could not be fully addressed in the present study. The sections that follow present some of these limitations as well as some suggestion as to how they can be addressed.

12.9.1 Sample size and the classification of subjects

The issue of small sample sizes is something that has always plagued researchers in this field. While efforts have been to increase the number of participants, securing an adequate sample of blind and visually impaired subjects can be difficult, not to mention time consuming and expensive. Working with organisations, such as the RLSB, that cater specifically to the needs of the blind and visually impaired and taking advantage of the ready availability of subjects is s step in the right direction. Even in these situations however, selecting an appropriate sample can be a challenging feat. This is because blindness and visual impairment in the western world is often the result of another disability. In 2006 it was estimated that in England alone, 41000 (29%) of those registered as blind and 39000 (27%) of those registered as visually impaired had an additional disability (NHS, 2006). Of these individuals, over 60% reported having a physical disability and around 20% reported having a hearing impairment. Surely, selecting the appropriate sample will vary according to the purpose of the research. Nonetheless, a certain amount of care must be exercised when generalising results if we are to account for the heterogeneity of this population. [84]

Future research should also pay closer attention to other characteristics of participants in the classification of subjects. As it has been demonstrated in both experiments conducted in this thesis, classifications based on visual acuity alone can be dangerously simplistic. Although information on visual field is not always readily available, peripheral-field testing can be easily conducted by the researcher, with the *confrontation method*, prior to the testing phase. Relating performance in spatial tasks to differences in peripheral vision can be of particular assistance in explaining individual differences in performance and an important complement to results based on visual acuity scores alone. Apart from information on the vision characteristics of the participants, researchers should also try to gather information on other factors that have been shown to affect spatial ability such as the level of independent mobility, quality of life and intelligence.

12.9.2 Innovative techniques

In chapter 11, GIS was presented as a useful tool in the analysis of movement patterns and the coding of exploratory strategies. This method however, has yet to become common practice in research with the blind and visually impaired, particularly in the discipline of psychology. Although a certain a amount of bias will always remain as the researcher is the person who ultimately isolates and codes the different strategies, the use of GIS allows for a clearer and more controlled management of dynamic information. In addition to being time efficient, it allows for data to be easily shared among researchers working in a similar project of field. This has direct implications for the isolation and coding of exploratory strategies and the agreement among researcher as to what constitutes a particular strategy.

There are also other methods for the collection and analysis cognitive data that have not been used as much as they should in research dealing with the spatial abilities of the blind and visually impaired. Projective convergence (Kitchin, 1996; Siegel, 1981) allows for

[84] Here it should also be noted that the statistics relating to blind and visually impaired individuals with an additional disability is likely to understate the real numbers. This is due to the fact that many blind and visually impaired subjects are either not registered or gain any additional benefit for claiming another disability (NHS, 2006).

the calculation of *locational accuracy* through the extension and intersection of different direction vectors. If a location is estimated from three different points, a triangulation method can be used to generate a hypothetical triangle of error. Locational accuracy is defined as the distance between the centre of the triangle and the real target (Golledge, 1992). The intersections of the three vectors make up a triangle where the position of the target is thought to be (the mean centre taken as the cognitive location of the place). *Locational accuracy* is determined by calculating the distance between the centre of the estimated triangle and the target. A variation of this method exists where participants estimate distance and direction between different elements in the environment. This method has been used with considerable success with sighted subjects (Hardwick, et al., 1976) but is yet to be included in research with the blind and visually impaired.

Kitchin and Jacobson (1997) argue that route-choice studies can be hard to incorporate in research with the blind and visually impaired given that this population's route choice is often constrained to known paths. This is not always the case in studies on the construction of mental representations through active exploration such as the experiment conducted in the maze. In such situations, the utility of mental representations can be assessed by comparing the ideal path (shortest distance) to a set of pre-selected locations and the actual route taken by the individuals. Similar to the maze experiment, participants are either guided or asked to explore a specific area to locate and learn the position of different elements in the environment. The researcher then selects some of these locations and asks the subjects to sequentially visit them in a specific order. The navigated paths are recorded and error is calculated by comparing the length of the route travelled by the participant to the ideal (shortest-route) length.

Route-choice studies provide an important complement to the other data gathering techniques that focus on the content and accuracy of mental representations. It is reasonable to assume that the greater the accuracy of a mental representation, the greater is its utility. However, the concepts of utility and accuracy should not be confused. There is a very important difference between *knowing the path* and actually *walking the path*. Departing from a structural functional approach, the ability to successfully navigate between two locations is far more relevant (and useful for daily living) than the actual accuracy or correspondence between the physical world and a mental construct. Blades (1997) elegantly sums up this point when he notes that focusing "on accuracy should not ignore the fact that environmental representations do not necessarily need to include information about metric distances and directions" (p. 117). He argues that this is particularly relevant to any discussion on wayfinding where it is possible for a person to navigate through an environment without an exact knowledge of the distances between points.

12.10 An amodal interpretation: Is vision really necessary?

In the beginning of chapter 7, three theories were presented in an attempt to explain the spatial abilities of the blind and visually impaired. The deficiency theory stated that vision was essential for the formation of mental representations. The inefficiency theory argued that other sensory modalities are inferior to vision, and although the blind and visually impaired are capable of understanding and manipulating spatial concepts their representations based on auditory, kinaesthetic and haptic cues are substandard when compared to those formed with the aid of vision. The difference theory stated that the blind and visually impaired have the same abilities as the sighted to process and understand spatial concepts but that these may be developed more slowly and by different means. Differences in performance can usually be explained by intervening variables such as stress, familiarity, access to information and the characteristics of the tasks.

Results from the two experiments conducted for this dissertation show considerable support for the difference theory. Although vision proved to be an important factor in the development of accurate mental representations (performance of the sighted was always higher when compared to the visually impaired and blind groups), it was not a necessary precondition for their formation and manipulation. Some individuals in the visually impaired and blind groups were able to build functionally equivalent representations as evidenced by the accuracy of their performance in the distance estimation and model construction tasks.

The difference theory can also account for the variation between and within groups in the different spatial tasks. In relation to the angle estimation task, the lower performance of some subjects in the blind group was not evidence that these individuals cannot orient themselves in space but related to the fact that pointing is not an action usually undertaken by the blind. Their sub-performance the result of a testing artefact – the extraction of their representation in a format they are not familiar with. Adopting an amodal interpretation to the development and accuracy of mental representations allows for a better understanding of the variability of performance while crediting the ability of the other senses (and proprioception) to encode spatial information. Differences in performance can be attributed to the lack of present, convergent and redundant information during the learning and testing phase (for both experiments). These differences (between and within groups) were shown to be related to the level of independent mobility, intelligence, quality of life and the exploratory strategies used by these individuals – variables that in themselves provide the necessary convergence and redundancy and are capable of helping the individual capture the information necessary for the formation of accurate mental representations.

12.10.1 A fresh take on cognitive mapping theory

Montello's continuous framework (1998) challenged the classic notion that spatial knowledge develops through a series of invariant and qualitatively different stages. Throughout the years, considerable evidence has been brought forward regarding the large individual differences in spatial abilities of children and adults. Evidence that contradicts many of the assumptions regarding the strict developmental progression from egocentric to allocentric spatial coding first put forward by Piaget (Piaget & Inhelder, 1956) and later incorporated into other theories such as those by Hart and Moore (1973) and Siegel and White (1975) regarding the shift from route knowledge to configurational knowledge. It seems that adults and children are able to understand and represent Euclidean and metric properties in a short period of time, with relatively little experience and without necessarily going through or following a set of predetermined and invariable stages. For research in blindness and visual impairment, this break from the classical approach has allowed for a fresh look at the cognitive mapping abilities of this population. This new attitude towards the abilities of the blind and visually impaired also takes into consideration a variety of factors (personal and environmental) other than vision that are involved in the formation of accurate mental representations.

The two experiments conducted in this thesis have shown that the blind are not necessarily egocentric. That they are able to form mental representations from information collected from their other sensory modalities and proprioception, and that these representations share many characteristics in common (analysis of distortions) and can be as coherent and accurate as those developed with the help of vision. Following Susanna Millar's (1994) CAPIN model where she notes that the absence of a sensory modality creates an imbalance between inputs that normally converge, it has been argued that the formation of accurate mental representations by the blind and visually impaired depends on convergent information from various channels. The higher performance of the sighted in the three spatial tasks does not necessarily translate into an inability by the blind and visually impaired to accurately represent space. Differences in performance (between and within groups) can be understood as the result of reduced contact between the individual and the environment (reduced mobility being one of the most debilitating aspects of blindness and visual impairment) and the consequent lack of redundancy of information arriving through the different sensory channels. The re-weighting theory (Newcombe and Huttenlocher, 2000) fits well with the many of the assumptions in the CAPIN model. The idea of conflicting systems (cue learning, place learning, response learning and dead reckoning) of spatial coding is well in tune with Millar's (1994) notion that that self-referent coding will predominate as long as external cues fail to be capture (or elicit attention) either because they are too far away or visually exclusive. Coding systems in this manner are related to the detection and use of extra (sensorial salient) information (Millar, 1988).

In tactile or proprioceptive "sterile" conditions, where there is no salient referent information to guide the other senses, blind and severely visually impaired individuals tend to code space in terms of their body, their resulting mental representation limited by the type, frequency and intensity of their interaction with the environment. Here it should be noted that the organization of information in terms of allocentric frames of reference in the absence of vision depends on the transformation of egocentric like information provided by proprioception and kinaesthetic inputs. Information on displacement provided by the movement of the body and the limbs is crucial for the development of the various relationships between the objects in the environment. This is consistent with the view that certain individuals adopt different strategies, some more efficient that others, while learning a space and when externalizing this knowledge. Repetition and practice will allow for individuals to test and select which strategies are appropriate for both the coding and the eventual externalization of the spatial knowledge. It is now up to future research to make evident the spatial abilities of the blind and visually impaired. To expose and celebrate the fact that humans were brought into this world equipped with senses other than vision and a brain with an enormous capacity to adapt.

Chapter 2 made evident that the future of research in disability and geography relied in the understanding of disability in a relational manner - as the interplay between the individual and a wide variety of contextual factors. Together the two experiments conducted in this thesis follow a more progressive movement in geography of disability, which seeks a broader understanding of the different dimensions of impairment, and disablement in society. Performance in the various spatial tasks did indeed vary as a result of impairment but that was only part of the answer. Although the thesis did concentrate on the impact of other individual factors it also accounted for different contextual factors and aspects of the psychosocial adjustment of individuals with impairment. Shakespeare (2006) acknowledges that impairment can be restrictive, limiting the choices of disabled people in an environment that is far from being barrier free. What this thesis showed, is that in relation to the formation of mental representations necessary for navigation and wayfinding, blind and visually impaired individuals are able to overcome many of these limitations.

Bibliography

Accuracy. (2007). *Dictionary.com.* Retrieved April 17, 2007 from http://dictionary.reference.com/browse/accuracy

Acredolo, L., P. (1977). Developmental changes in the ability to coordinate perspectives of a large-scale space. *Developmental Psychology, 13*(1-8).

Acredolo, L., P. (1981). Small and large-scale spatial concepts in infancy and childhood. In L. Liben, A. Patterson & N. Newcombe (Eds.), *Spatial representations and behaviour across the lifespan* (pp. 63-81). New York: Academic Press.

Acredolo, L., P., & Evans, D. (1980). Developmental changes in the effect of landmarks on infant spatial behaviour. *Developmental Psychology, 16*, 312-318.

Allen, G. L. (1981). A developmental perspective on the effect of "subdividing" macrospatial experience. *Journal of Experimental Psychology, 7*, 120-132.

Allen, G. L., Kirasic, K. C., Siegel, A. W., & Herman, J. F. (1979). Developmental issues in cognitive mapping: The selection and utilization of environmental landmarks. *Child Development, 50*, 1062-1070.

Anselin, L. (1988). *Spatial econometrics: Methods and models.* Dordrecht: Martinus Nijhoff.

Arditi, A., Holmes, E., Reedijk, P., & Whitehouse, R. (1999). Interactive tactile maps, visual disability and accessibility of building interiors. *Visual Impairment Research, 1*, 11-21.

Armstrong, D. M. (1960). *Berkeley's theory of vision: A critical examination of bishop Berkeley's essay towards a new theory of vision.* Melbourne: Melbourne University Press.

Ashcroft, S. C. (1959). The blind and partially seeing. *Review of Educational Research: The Education of Exceptional Children, 29*, 519-528.

Ashcroft, S. C. (1966). The visually handicapped. *Review of Educational Research: The Education of Exceptional Children, 36*, 75-92.

Ashmead, D. H., Hill, E. W., & Talor, C. R. (1989). Obstacle perception by congenitally blind children. *Perception and Psychophysics, 46*, 425-433.

Ashmead, D. H., Wall, R. S., Ebinger, K. A., Eaton, S., B., Snook-Hill, M. M., & Yang, X. (1998). Spatial hearing in children with visual disabilities. *Perception, 27*, 105-122.

Bach-y-Rita, P. (1967). Sensory plasticity. Applications to a vision substitution system. *Acta Neurolica Scandinavica, 43*, 417-426.

Bach-y-Rita, P. (1972). *Brain mechanisms in sensory substitution.* New York: Academic Press.

Barasch, M. (2001). *Blindness: A history of mental image in western thought.* New York: Routledge.

Barber, O. P., & Lederman, J. S. (1988). Encoding direction in manipulatory space and the role of visual experience. *Journal of Visual Impairment and Blindness, 82,* 99-106.

Barnes, C., & Mercer, G. (Eds.). (1997). *Doing disability research.* Leeds: Disability Press.

Barnes, C., Mercer, G., & Shakspeare, T. (1999). *Exploring disability: A sociological introduction.* Cambridge: Polity Press.

Bateman, B. (1962). Sighted children's perception of blind children's abilities. *Exceptional Children, 29,* 42-46.

Bauman, M. K. (1964). Group differences disclosed by inventory items. *International Journal for the Education of the Blind, 13,* 101-106.

Berlyne, D. E. (1960). *Conflict, arousal, and curiosity.* New York: McGraw-Hill.

Berlyne, D. E. (1966). Curiosity and exploration. *Science, 153,* 25-33.

Bickenbach, J., Chatterji, S., Badley, E., & Ustun, T. (1999). Models of disablement universalism and the international classification of impairments, disabilities and handicaps. *Social Science and Medicine, 48,* 1173-1187.

Bigelow, E. A. (1991). Spatial mapping of familiar locations in blind children. *Journal of Visual Impairment and Blindness, 85,* 113-117.

Bigelow, E. A. (1992). Locomotion and search behaviour in blind infants. *Infant Behavior and Development, 15,* 179-189.

Bigelow, E. A. (1996). Blind and sighted children's spatial knowledge of their home environments. *International Journal of Behavioral Development, 19,* 797-816.

Birns, S. L. (1986). Age at onset blindness and development of space concepts: From topological to projective space. *Journal of Visual Impairment and Blindness, 80,* 577-582.

Bishop, V. E. (1986). Selected anomalies and diseases of the eye. Retrieved December 17, 2007, from www.tsbvi.edu/Education/anomalies/eye.doc

Blades, M. (1991). Wayfinding theory and research; the need for a new approach. In D. M. Mark & A. U. Frank (Eds.), *Cognitive and linguistic aspects of geographic space* (pp. 137-165). Netherlands: Kluwer Academic Publishers.

Blades, M., Lippa, Y., Golledge, G. R., Jacobson, D., & Kitchin, R. M. (2002). The effect of spatial tasks on visually impaired peoples' wayfinding abilities. *Journal of Visual Impairment and Blindness, 96,* 407-419.

Blanco, F., & Travieso, D. (2003). Haptic exploration and mental estimation of distances in a fictitious island: From mind's eye to mind's hand. *Journal of Visual Impairment and Blindness, 97*, 298-300.

Blaut, J. M., McCleary, C. F., & Blaut, A. S. (1970). Environmental mapping in young children. *Environment and Behaviour, 2*, 335-349.

Boehm, R. (1986). The use of echolocation as a mobility aid for blind persons. *Journal of Visual Impairment and Blindness, 80*(9), 953-954.

Borgatti, S., P. (1996). *Anthropac 4.0 methods guide*. Nattick, MA: Analytic Technologies.

Brambring, M. (1976). The structure of haptic space in the blind and sighted. *Psychological Research, 38*, 283-302.

Brambring, M. (2006). Divergent development of gross motor skills in children who are blind and sighted. *Journal of Visual Impairment and Blindness, 100*, 620-634.

Bremner, J. G., & Bryant, P. E. (1977). Place versus responses as the basis of spatial errors made by young infants. *Journal of Experimental Child Psychology, 23*, 162-171.

Brown, G., & Desforges, C. (1979). *Piaget's theory: A psychological critique*. London; Boston: Routledge & K. Paul.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated learning and the culture of learning. *Educational Researcher, 18*, 32-42.

Bruce, I., McKennell, A., & Walker, E. (1991). *Blind and partially sighted adults in Britain: The RNIB survey*. London: RNIB.

Bryant, P. E. (1972). The understanding of invariance in very young children. *Canadian Journal of Psychology, 26*, 78-96.

Burton, M., L., & Nerlove, S., B. (1976). Balanced designs for triads tests: Two experiments from English. *Social Science Research, 5*, 247-267.

Butler, R. (1994). Geography and vision-impaired and blind populations. *Transactions of the Institute of British Geographers, 19*, 366-368.

Buttenfield, B. P. (1986). Comparing distortion on sketch maps and MDS configurations. *Professional Geographer, 38*, 238-246.

Butterworth, G. (1981). *Infancy and epistemology: An evaluation of Piaget's theory*. Brighton, Sussex: Harvester Press.

Byrne, R. W. (1979). Memory for urban geography. *Quarterly Journal of Experimental Psychology, 31*, 147-154.

Byrne, R. W., & Salter, E. (1983). Distances and directions in the cognitive maps of the blind. *Canadian Journal of Psychology, 37*, 293-299.

Carpenter, P., & Eisenberg, P. (1978). Mental rotation and the frame of reference in blind and sighted individuals. *Perception & Psychophysics, 23*, 117-124.

Carreiras, M., & Codina, B. (1992). Spatial cognition of the blind and sighted: Visual and amodal hypothesis. *Cahiers de Psychologie Cognitive, 12*, 51-78.

Caruso, D. A. (1993). Dimensions of quality in infants exploratory behavior: Relationships to problem solving ability. *Infant Behavior and Development, 16*, 441-454.

Casey, S. M. (1978). Cognitive mapping by the blind. *Journal of Visual Impairment and Blindness, 72*, 297-301.

Catherwood, D., Drew, L., Hein, B., & Grainger, H. (1998). Haptic recognition in two infants with low vision assessed by a familiarization procedure. *Journal of Visual Impairment and Blindness, 92*, 212-215.

Chebat, D. R. (2006). *Aspects theoriques de la substitution sensorielle.* Montreal: Universite de Montreal - Ecole d'optometrie.

Chess, S., & Gordon, S. G. (1984). Psychosocial development and human variance. *Review of Research in Education, 11*, 3-62.

Cleaves, W. T., & Royal, R. W. (1979). Spatial memory for configurations by congenitally blind, late blind and sighted adults. *Journal of Visual Impairment and Blindness, 73*, 13-19.

Coe, R. (2000). What is an 'effect size'? Retrieved March 5, 2006, from http://www.cemcentre.org/ebeuk/research/effectsize/ESguide.htm

Cohen, J. (1990). Things I have learned (so far). *American Psychologist, 45*, 1304-1312.

Cohen, J. (1994). The earth is round (p <.05). *American Psychologist, 49*, 997-1003.

Cohen, R., & Schuepfer, T. (1980). The representation of landmarks and routes. *Child Development, 51*, 1065-1071.

Cohen, S. L., & Cohen, R. (1985). The role of activity in spatial cognition. In R. Cohen (Ed.), *The development of spatial cognition* (pp. 199-221). Hillsdale, New Jersey: Lawrence Earlbaum Associates.

Colenbrander, A. (2002). Measuring vision and vision loss. In W. Tasman & E. Jaeger (Eds.), *Duane's clinical ophthalmology.* Philadelphia, PA: Lippincott Williams & Wilkins.

Collis, M. G., & Lewis, V. (1997). Reflections on blind children and developmental psychology. In V. Lewis & M. G. Collis (Eds.), *Blindness and psychological development in young children* (pp. 130-136). Leicester: The British Psychological Society.

Corn, A. L., & Koenig, A. J. (1996a). *Foundations of low vision: Clinical and functional perspectives.* New York: AFB Press.

Corn, A. L., & Koenig, A. J. (1996b). Perspectives on low vision. In A. L. Corn & A. J. Koenig (Eds.), *Foundations of low vision: Clinical and functional perspectives* (pp. 3-25). New York: AFB Press.

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

Cowen, E. L., Underberg, R. P., Verillo, R. T., & Benham, F. G. (1961). *Adjustment to visual disability in adolescents*. New York: AFB Press.

D'Angiuilli, A., Kennedy, J. M., & Heller, M. A. (1998). Blind children recognizing tactile pictures respond like sighted children given guidance in exploration. *Scandinavian Journal of Psychology, 39*, 187-190.

Davis, K. (1990). A social barriers model of disability: Theory into practice - the emergence of the "seven needs", *Derbyshire Coalition of Disabled People*. Derbyshire.

Descartes, R. (1965). *Discourse of method, optics, geometry and meteorology* (P. J. Olscamp, Trans.). Indianapolis: Bobbs-Merrill.

Diderot, D. (1973). *Diderot's early philosophical works*. New York: AMS Press.

Disability Discrimination Act, 1995. (1995). *Office of Public Sector Information*. Retrieved November 20, 2007 from http://www.dwp.gov.uk/aboutus/business.asp

Disability Discrimination Act, 2005. (2005). *Office of Public Sector Information*. Retrieved November 20, 2007 from http://www.dwp.gov.uk/aboutus/business.asp

Dodds, A. G. (1983). Mental rotation and visual imagery. *Journal of Visual Impairment and Blindness, 77*, 16-18.

Dodds, A. G. (1988). *Mobility training for visually handicapped people: A person-centred approach*. London: Croom Helm.

Dodds, A. G., Howarth, C. I., & Carter, D. C. (1982). The mental maps of the blind: The role of previous visual experience. *Journal of Visual Impairment and Blindness, 76*, 5-12.

Dodds, A. G., Howarth, C. I., & Carter, D. C. (1983). Memory for movement in blind children: The role of previous visual experience. *Journal of Motor Behavior, 15*, 343-352.

Doherty, S., Gale, N., Pellegrino, J. W., & Golledge, G. R. (1989). Children's versus adults' knowledge of places and distances in a familiar neighborhood environment. *Children's Environment Quarterly, 6*, 65-71.

Donaldson, M. C. (1978). *Children's minds*. London: Croom Helm.

Downs, M. R. (1981). Maps and mapping as metaphors for spatial representations. In L. Liben, A. Patterson & N. Newcombe (Eds.), *Spatial representation and behavior across the life span: Theory and application* (pp. 143-166). New York: Academic Press.

Downs, M. R., & Stea, D. (Eds.). (1973). *Image and environment: Cognitive mapping and spatial behaviour*. Chicago: Aldine Publishing Company.

DPI. (1982). *Proceedings of the first world congress*. Singapore: Disabled People's International.

Dulin, D., & Hatwell, Y. (2006). The effects of visual experience and training in raised-line material on the mental spatial imagery of blind persons. *Journal of Visual Impairment and Blindness, 100*, 414-424.

Durkheim, E., & Mauss, M. (1963). *Primitive classification*. Chicago: University of Chicago Press.

Easton, R. D., & Bentzen, B. L. (1987). Memory for verbally presented routes: A comparison of strategies used by blind and sighted people. *Journal of Visual Impairment and Blindness, 81*, 100-105.

Ekstrom, K. (2006). How many blind and partially sighted people are there. *NB, August 2006*, 23-28.

Espinosa, A., M., Ungar, S., Ochaita, E., Blades, M., & Spencer, C. (1998). Comparing methods for introducing blind and visually impaired people to unfamiliar urban environments. *Journal of Environmental Psychology, 18*, 277-287.

Evans, G., & Pezdek, K. (1980). Cognitive mapping: Knowledge of real world distance and location information. *Journal of Experimental Psychology: Human Learning and Memory, 6*, 13-24.

Eysenck, M. W., & Keane, M. T. (1990). *Cognitive psychology: A student's handbook*. Hove: Erlbaum.

Eysenck, M. W., & Keane, M. T. (2005). *Cognitive psychology: A student's handbook*. Hove, East Sussex; New York: Psychology Press.

Faye, E. E. (1984). *Clinical low vision*. Boston: Little, Brown.

Fazzi, D. L., & Petersmeyer, B. A. (2001). *Imagining the possibilities: Creative approaches to orientation and mobility instruction for persons who are visually impaired*. New York: AFB Press.

Feinman, S. (1978). The blind as ordinary people. *Journal of Visual Impairment and Blindness, 72*, 231-238.

Ferell, A., K. (1986). Infancy and early childhood development. In G. T. Scholl (Ed.), *Foundations of education for blind and visually handicapped children and youth: Theory and practice* (pp. 119-144). New York: American Foundation for the Blind.

Ferell, A., K. (1998). Project prism: A longitudinal study of developmental patterns of children who are visually impaired. Retrieved June 23, 2007, from http://vision.unco.edu/Faculty7Ferrell/PRISM/default.html

Ferell, A., K. (2003). Growth and development of young children. In C. Holbrook, M. & A. Koenig, J. (Eds.), *Foundations of education: History and theory of teaching children and youths with visual impairments* (Vol. 1, pp. 135-160). New York: AFB Press.

Flavell, J. H. (1971). Stage related properties of cognitive development. *Cognitive Psychology*, 421-453.

Fletcher, F. J. (1980). Spatial representation in blind children. 1: Development compared to sighted children. *Journal of Visual Impairment and Blindness, 74*, 381-385.

Fletcher, F. J. (1981a). Spatial representation in blind children. 2: Effect of task variation. *Journal of Visual Impairment and Blindness, 75*, 1-3.

Fletcher, F. J. (1981b). Spatial representation in blind children. 3: Effects of individual differences. *Journal of Visual Impairment and Blindness, 75*, 46-49.

Forrester, J. V. (2002). *The eye: Basic sciences in practice*. Edinburgh; New York: W.B. Saunders.

Foulke, E., & Hatlen, P. (1992). A collaboration of two technologies: Part 2: Perceptual and cognitive training: Its nature and importance. *British Journal of Visual Impairment, 10*, 47-49.

Foulke, E. (1983). Spatial ability and the limitations of perceptual systems. In H. L. Pick & L. Acredolo, P. (Eds.), *Spatial orientation: Theory, research and application* (pp. 125-141). New York: Plenum Press.

Fraiberg, S., & Fraiberg, L. (1977). *Insights from the blind: Comparative studies of blind and sighted infants*. New York: Basic Books.

Freeman, R. D., Goetz, E., Richards, D. P., & Groenveld, M. (1991). Defiers of negative prediction: A 14-year follow up study of legally blind children. *Journal of Visual Impairment and Blindness, 85*, 365-370.

French, S. (1993). Disability, impairment or something in between? In J. Swain, S. Finkelstein, S. French & M. Oliver (Eds.), *Disabling barriers - enabling environments* (pp. 17-25). London: Sage Publications.

Friedman, A., & Kohler, B. (2003). Bidimensional regression: Assessing the configural similarity and accuracy of cognitive maps and other two-dimensional data sets. *Psychological Methods, 8*, 468-491.

Friedman, J., & Pasnak, R. (1973). Attainment of classification and seriation concepts by blind and sighted children. *Education of the Visually Handicapped, 5*, 55-62.

Gale, N., Pellegrino, J. W., & Doherty, S. (1990). The acquisition and integration of route knowledge in an unfamiliar neighborhood. *Journal of Environmental Psychology, 5*, 125-152.

Gardner, H. (1983). *Frames of mind: The theory of multiple intelligences*. New York: Basic Books.

Gaulejac, F., & Gallo, A. (1996). L'animal et la nouveaute: Representation ou acto-spatialite? *Intellectica, 22*, 169-184.

Gaunet, F., Martinez, J.-L., & Thinus-Blanc, C. (1997). Early-blind subjects' spatial representation of manipulatory space: Exploratory strategies and reaction to change. *Perception, 26*, 345-366.

Gaunet, F., & Thinus-Blanc, C. (1996). Early-blind subjects' spatial abilities in the locomotor space: Exploratory strategies and reaction-to-change performance. *Perception, 25*, 967-981.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin.

Gibson, J. J. (1986). *The ecological approach to visual perception*. Hillsdale, New Jersey: Lawrence Erlbaum Associates, Publishers.

Gleeson, B. (1996). A geography for disabled people? *Transactions of the Institute of British Geographers, 21*, 387-396.

Glotzbach, P. A., & Heft, H. (1982). Ecological and phenomenological contributions to the psychology of perception. *Nous, 16*(1), 108-121.

Goldin, S. E., & Thorndyke, P. W. (1982). Simulating navigation for spatial knowledge acquisition. *Human Factors, 24*, 457-471.

Goldstein, E. B. (1981). The ecology of J.J. Gibson's perception. *Leonardo, 14*, 191-195.

Golledge, G. R. (1978). Representing, interpreting and using cognized environments. *Papers and Proceedings, Regional Science Association, 41*, 169-204.

Golledge, G. R. (1990a). The conceptual and empirical basis of a general theory of spatial knowledge. In M. M. Fischer, P. Nijkamp & Y. Y. Papageorgiou (Eds.), *Spatial choices and processes* (pp. 147-168). North Holland: Elsevier Science Publishers B.V.

Golledge, G. R. (1992). Place recognition and wayfinding: Making sense of space. *Geoforum, 23*, 199-214.

Golledge, G. R. (1993). Geography and the disabled: A survey with special reference to vision impaired and blind populations. *Transactions of the Institute of British Geographers, 18*, 63-85.

Golledge, G. R. (1994). A response to Ruth Butler. *Transactions of the Institute of British Geographers, 19*, 369-372.

Golledge, G. R. (1996). A response to Gleeson and Imrie. *Transactions of the Institute of British Geographers, 21*, 404-411.

Golledge, G. R. (1998). "You don't have to have sight to have vision". Department of Geography and Research Unit on Spatial Cognition and Choice - University of California (Ed.). Santa Barbara, California: UCSB Press.

Golledge, G. R., Loomis, J. M., Klatzky, L. R., Pellegrino, J. W., Doherty, S., & Cicinelli, J. G. (1988). *Environmental cognition and assessment: Spatial cognition of the blind and visually impaired.* Paper presented at the Environmental Cognition and Assessment, Umea, Sweden.

Golledge, G. R., Loomis, J. M., Klatzky, L. R., & Yang, X. L. (1991b). Designing a personal system to aid navigation without sight: Progress with the GIS component. *International Journal of Geographical Information Science, 5.* 373-396.

Golledge, G. R., Rivizzigno, V., & Spector, A. (1976). Learning about a city: Analysis by multidimensional scaling. In G. R. Golledge & G. Rushton (Eds.), *Spatial choice and spatial behaviour: Geographic essays in the analysis of preferences and perceptions* (pp. 95-118). Columbus: Ohio State University Press.

Golledge, G. R., Ruggles, A. J., Pellegrino, J. W., & Gale, N. (1993). Integrating route knowledge in an unfamiliar neighborhood: Along and across route experiments. *Journal of Environmental Psychology, 13*, 293-307.

Golledge, R. (Ed.). (1999). *Wayfinding behaviour: Cognitive mapping and other spatial processes*. Baltimore: The Johns Hopkins University Press.

Golledge, R., Klatzky, R., & Loomis, J. (1996). Cognitive mapping and wayfinding by adults without vision. In J. Portugali (Ed.), *The construction of cognitive maps* (pp. 215-246). Dordrecht: Kluwer Academic Publishers.

Gottesmann, M. (1976). Stage development of blind children: A Piagetian view. *New Outlook for the Blind, 70*, 94-100.

Gould, P. (1976). Cultivating the garden: A commentary and critique on some multidimensional speculation. In G. R. Golledge & G. Rushton (Eds.), *Spatial choice and spatial behaviour: Geographic essays on the analysis of preferences and perceptions* (pp. 83-91). Columbus: Ohio State University Press.

Gouteux, S., Vauclair, J., & Thinus-Blanc, C. (2001). Reorientation in a small-scale environment by 3-, 4- and 5-year-ol children. *Cognitive Development, 16*, 853-869.

Gregory, R. (2004). The blind leading the sighted: An eye-opening experience of the wonders of perception. *Nature, 430*, 1.

Gregory, R., & Wallace, J. (1963). Recovery from early blindness: A case study. *Experimental Psychology Society Monograph, 2*, 1-44.

Griffin-Shirley, N., & Nes, S. L. (2005). Self-esteem and empathy in sighted and visually impaired preadolescents. *Journal of Visual Impairment and Blindness, 99*, 276-285.

Guth, D. A., Hill, E. W., & Rieser, J. J. (1989). Tests of blind pedestrians' use of traffic sounds for street-crossing alignment. *Journal of Visual Impairment and Blindness, 83*, 461-468.

Gärling, T., Böök, A., Lindberg, E., & Arce, C. (1991). Evidence of a response bias explanation of non-Euclidean cognitive maps. *Professional Geographer, 42*, 143-149.

Gärling, T. (1999). Human information processing in sequential spatial choice. In G. R. Golledge (Ed.), *Wayfinding behaviour: Cognitive mapping and other spatial processes* (pp. 89-98). Baltimore: The John Hopkins University Press.

Haber, L., Haber, R. N., Pennigroth, S., Novak, K., & Radgowski, H. (1993a). Comparison of nine methods of indicating the direction of objects: Data from blind subjects. *Perception, 22*, 35-47.

Haber, R. N., Haber, L. R., Levin, C. A., & Hollyfield, R. M. (1993b). Properties of spatial representations: Data from sighted and blind subjects. *Perception and Psychophysics, 54*, 1-13.

Hardwick, D. A., McIntyre, C. W., & Pick, H. L. (1976). The content and manipulation of cognitive maps in children and adults. *Monographs of the Society for Research in Child Development, 41*, 1-55.

Harman, J. E., & Betak, F. J. (1976). Behavioral geography, multidimensional scaling, and the mind. In G. R. Golledge & G. Rushton (Eds.), *Spatial choice and spatial behavior: Geographic essays on the analysis of preferences and perceptions* (pp. 3-20). Columbus: Ohio State University Press.

Hart, R. A., & Moore, G. T. (1973). The development of spatial cognition: A review. In M. R. Downs & D. Stea (Eds.), *Image and environment* (pp. 246-288). Chicago: Aldine.

Harrington, R. G., & McDermott, D. (1993). A model for the interpretation of personality assessments of individuals with visual impairments. *Journal of Rehabilitation, 59*, 24-29.

Hatlen, P. (2000). Historical perspectives. In C. Holbrook, M. & A. J. Koenig (Eds.), *Foundations of education: History and theory of teaching children and youths with visual impairments* (Vol. 1, pp. 1-54). New York: AFB Press.

Hatton, D. D., Bailey, D. B., Burchinal, M. R., & Ferrell, K. A. (1997). Developmental growth curves of preschool children with vision impairments. *Child Development, 68*, 788-806.

Hatwell, Y. (1966). *Privation sensorielle et intelligence, effets de la câecitâe prâecoce sur la genâese des structures logiques de l'intelligence.* Paris: Presses Iniversitaires de France.

Hatwell, Y. (2003). *Psychologie cognitive de la cecite precoce.* Paris: Dunod Editeur.

Hatwell, Y., & Stephens, B. (1985). *Piagetian reasoning and the blind.* New York, N.Y.: American Foundation for the Blind.

Heft, H. (1983). Wayfinding as the perception of information over time. *Population and Environment: Behavioral and Social Issues, 6*, 133-150.

Heft, H. (1996). The ecological approach to navigation: A Gibsonian perspective. In J. Portugali (Ed.), *The construction of cognitive maps* (pp. 105-132). Dordrecht: Kluwer Academic Publishers.

Heft, H. (1997). The relevance of Gibson's approach to perception for environment-behaviour studies. In G. T. Moore & R. W. Marans (Eds.), *Advances in environment, behaviour, and design: Toward the integration of theory, methods, research and utilization* (pp. 71-108). New York: Plenum Press.

Hegarty, M., Richardson, A. E., Montello, R. D., Lovelace, K., & Subbiah, I. (2002). Development of a self-report measure of environmental spatial ability. *Intelligence, 30,* 425-447.

Heller, M. A. (2000). *Touch, representation, and blindness.* Oxford; New York: Oxford University Press.

Heller, M. A., & Kennedy, J. M. (1990). Perspective taking, pictures and the blind. *Perception and Psychophysics, 45,* 459-466.

Herman, J. E., Herman, T. G., & Chatman, S. P. (1983a). Constructing cognitive maps from partial information: A demonstration study with congenitally blind subjects. *Journal of Visual Impairment and Blindness, 77,* 195-198.

Herman, J. F., Chatman, S. P., & Roth, S., F. (1983b). Cognitive mapping in blind people: Acquisition of spatial relationships in a large-scale environment. *Journal of Visual Impairment and Blindness, 77,* 161-166.

Herman, J. F., & Siegel, A. W. (1978). The development of cognitive mapping of the large-scale environment. *Journal of Experimental Child Psychology, 26,* 389-406.

Hermelin, B., & O'Connor, N. (1975). Location and distance estimates by blind and sighted children. *Quarterly Journal of Experimental Psychology, 27,* 295-301.

Hill, E., & Ponder, P. (1976). *Orientation and mobility techniques: A guide for the practitioner.* New York: American Foundation for the Blind.

Hill, E. W., & Hill, M.-M. (1980). Revision and validation of a test for assessing the spatial conceptual abilities of visually impaired children. *Journal of Visual Impairment and Blindness, 74,* 373-380.

Hill, E. W., Rieser, J. J., Hill, M. M., Hill, M., Halpin, J., & Halpin, R. (1993). How persons with visual impairments explore novel spaces: Strategies of good and poor performers. *Journal of Visual Impairment and Blindness,* 87, 295-301.

Hirtle, S., & Hudson, J. (1992). Acquisition of spatial knowledge for routes. *Journal of Environmental Psychology, 11,* 335-347.

Hirtle, S., & Mascolo, M. F. (1986). Effect of semantic clustering on the memory of spatial locations. *Journal of Experimental Psychology: Learning, Memory and Cognition, 12,* 182-189.

Holbrook, C., M., Mamer, L., MacCuspie, A., & McConnell, D. (2000). *The impact of vision loss on the development of children from birth to 12 years: A literature review.*

Hollins, M., & Kelley, E. K. (1988). Spatial updating in blind and sighted people. *Perception and Psychophysics, 43*, 380-388.

Hollyfield, R. M., & Foulke, E. (1983). The spatial cognition of blind pedestrians. *Journal of Visual Impairment and Blindness, 77*, 204-210.

Hoy, A. W. (1987). *Educational psychology*. Englewood Cliffs, N.J.: Prentice-Hall.

Huebner, K. M. (2000). Visual impairment. In C. Holbrook, M. & A. J. Koenig (Eds.), *Foundations of education: History and theory of teaching children and youths with visual impairments* (Vol. 1, pp. 55-76) . New York: AFB Press.

Huertas, J. A., & Ochaíta, E. (1992). The externalization of spatial representation by blind performers. *Journal of Visual Impairment and Blindness*, 86, 398-402.

Huggett, N. (Ed.). (1999). *Space from Zeno to Einstein*. Massachusetts: MIT Press.

Hugo, V., & Denny, N. (1982). *Les Miserables*. London: Penguin Books.

Hunt, P. (1972, Wednesday September 20). *The Guardian.*

Hutchinson, J. O., Atkinson, K., & Orpwood, J. (1998). *Breaking down barriers*. Cheltenham: Stanley Thornes.

Huttenlocher, J., Newcombe, N., & Sandberg, E. H. (1994). The coding of spatial location in young children. *Cognitive Psychology, 27*, 115-147.

Huurre, T. M., Komulainen, E. J., & Aro, H. M. (1999). Social support and self-esteem among adolescents with visual impairments. *Journal of Visual Impairment and Blindness, 93*, 26-37.

ICOPH. (2006). International council of ophthalmology: Visual standards - Aspects and ranges of vision loss. Retrieved November 22, 2006, from http://www.icoph.org/standards/visionres.html

Imrie, R. (1996). Ableist geographies, disablist spaces: Towards a reconstruction of Golledge's geography and the disabled. *Transactions of the Institute of British Geographers, 21*, 397-403.

Imrie, R. (2000). Disabling environments and the geography of access policies and practices. *Disability & Society, 15*, 5-24.

Imrie, R. (2004). Demystifying disability: A review of the international classification of functioning, disability and health. *Sociology of health and illness, 26*(3), 1-19.

Imrie, R., & Hall, P. (2001). *Inclusive design: Designing and developing accessible environments*. London: Spon Press.

Imrie, R., & Edwards, C. (2007). The geographies of disability: Reflections on the development of a sub-discipline. *Geography Compass, 1*(3), 623-640.

Ishikawa, T., & Montello, R. D. (2006). Spatial knowledge acquisition from direct experience in the environment: Individual differences in the development of metric knowledge and the integration of separately learned places. *Cognitive Psychology, 52*, 93-129.

Israel, I., Chapuis, N., Glasauer, S., Charade, O., & Berthoz, A. (1993). Estimation of passive horizontal linear whole-body displacement in humans. *Journal of Neuralphysiology, 70,* 1270-1273.

Ittelson, W. H. (1973). Environment perception and contemporary perceptual theory. In W. H. Ittelson (Ed.), *Environment & cognition.* New York: Seminar Press.

Jacobson, D. (1999). *Exploring geographies of blindness: Learning, reading and communicating geographic space.* Queens University, Ireland.

Jacobson, D., Lippa, Y., Golledge, G. R., Kitchin, R. M., & Blades, M. (2001). Rapid development of cognitive maps in people with visual impairments when exploring novel geographic spaces. *IAPS Bulletin of People-Environment Studies (Special issue on Environmental Cognition),* 18, 3-6.

Jacobson, R. D. (1998). Cognitive mapping without sight: Four preliminary studies of spatial learning. *Journal of Environmental Psychology, 18*, 289-305.

Jacobson, R. D., & Kitchin, R. M. (1995). Assessing the configurational knowledge of people with visual impairment or blindness. *Swansea Geographer, 32*, 14-24.

Johnson-Laird, P. N. (1983). *Mental models: Towards a cognitive science of language, inference and consciousness*. Cambridge [Cambridgeshire]; New York: Cambridge University Press.

Johnson-Laird, P. N. (1988). *The computer and the mind: An introduction to cognitive science*. Cambridge, Mass.: Harvard University Press.

Jones, B. (1975). Spatial perception in the blind. *British Journal of Psychology, 66*, 461-472.

Jose, R. T. (1983). *Understanding low vision.* New York: American Foundation for the Blind.

Juurmaa, J. (1973). Transposition in mental spatial manipulation: A theoretical analysis. *American Foundation for the Blind Research Bulletin, 26*, 87-134.

Juurmaa, J., & Lehtinen-Railo, S. (1994). Visual experience and access to spatial knowledge. *Journal of Visual Impairment and Blindness, 88*, 157-170.

Juurmaa, J., & Suonio, K. (1975). The role of audition and motion in the spatial orientation of the blind and sighted. *Scandinavian Journal of Psychology, 16*, 209-216.

Kahl, H. B., Herman, J. F., & Klein, C. A. (1984). Distance distortion in children's cognitive maps: An examination of the information storage model. *Journal of experimental Psychology, 38*, 134-146.

Kanski, J., Menon, J., & Bolton, A. (2003). *Clinical ophthalmology: A systematic approach*. London: Butterworth-Heinemann.

Kant, I., & Pluhar, W. S. (1999). *Critique of pure reason (abridged)*. Indianapolis, Ind.: Hackett Pub.

Kay, L. (1973). Sonic glasses for the blind: A progress report. *American Foundation for the Blind Research Bulletin, 25*, 25-58.

Kef, S. (2002). Psychosocial adjustment and the meaning of social support for visually impaired adolescents. *Journal of Visual Impairment and Blindness, 96*, 22-37.

Keller, H. (1920). *Out of the dark*. New York: Doubleday, Page & Company.

Keller, H., & Foner, P. S. (1967). *Helen Keller, her socialist years; writings and speeches*. New York: International Publishers.

Kephart, J. G., Kephart, C. P., & Schwarz, G. C. (1974). A journey into the world of the blind child. *Exceptional Children, 40*, 421-427.

Kerr, H. N. (1983). The role of "visual imagery" experiments: Evidence from the congenitally blind. *Journal of Environmental Psychology, 112*, 265-277.

Kirasic, K. C., Allen, G. L., & Siegel, A. W. (1984). Expression of configurational knowledge of large-scale environments: Students' performance of cognitive tasks. *Environment and Behaviour, 16*, 667-712.

Kirtley, D. D. (1975). *The psychology of blindness*. Chicago: Nelson-Hall.

Kish, D. B., Hannah. (2006). Echolocation: What it is, and how it can be taught and learned. Retrieved November 22, 2006, from http://worldaccessfortheblind.org/echolocation.rtf

Kitchin, R. M. (1993). Using bidimensional regression to analyze cognitive maps. *Swansea Geographer, 30*, 33-50.

Kitchin, R. M. (1996). Methodological convergence in cognitive mapping research: Investigating configurational knowledge. *Journal of Environmental Psychology, 16*, 163-185.

Kitchin, R. M. (2000). The researched opinions on research: Disabled people and disability research. *Disability & Society, 15*, 25-47.

Kitchin, R. M., & Blades, M. (2002). *The cognition of geographic space*. New York: I.B. Tauris & Co Ltd.

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.

Kitchin, R. M., & Jacobson, D. (1997). Techniques to collect and analyze the cognitive map knowledge of persons with visual impairment or blindness: Issues of validity. *Journal of Visual Impairment and Blindness, 91, 360-376.*

Klatzky, L. R., Golledge, G. R., Loomis, J. M., Cicinelli, J. G., & Pellegrino, J. W. (1995). Performance of blind and sighted persons on spatial tasks. *Journal of Visual Impairment and Blindness, 89*, 70-82.

Klatzky, L. R., Loomis, J. M., Beall, A. C., Chance, S., & Golledge, G. R. (1998). Updating an egocentric spatial representation during real, imagined and virtual locomotion. *Psychological Science, 9*, 293-298.

Klatzky, L. R., Loomis, J. M., & Golledge, G. R. (1997). Encoding spatial representations through nonvisual guided locomotion: Tests of human path integration. In D. Medin (Ed.), *The psychology of learning and motivation.* (pp. 41-84). San Diego: Academic Press.

Klatzky, L. R., Loomis, J. M., & Golledge, G. R. (2002). Nonvisual navigation based on information about self-motion. In L. Backman & C. von Hofsten (Eds.), *Psychology at the turn of the millennium, volume 1: Cognitive, biological and health perspectives* (pp. 245-260). New York: Taylor & Francis, Inc.

Klatzky, L. R., Loomis, J. M., Golledge, G. R., Cicinelli, J. G., Doherty, S., & Pellegrino, J. W. (1990). Acquisition of route and survey knowledge in the absence of vision. *Journal of Motor Behavior, 22*, 19-43.

Klatzky, R. L. (1999). Path completion after haptic exploration without vision: Implications for haptic spatial representations. *Perception and Psychophysics, 61*, 220-235.

Kline, R. B. (2004). *Beyond significance testing: Reforming data analysis methods in behavioral research.* Washington, DC: American Psychological Association.

Klippel, A., Knuff, L., Hommel, B., & Freksa, C. (2004). *Perceptually induced distortions in cognitive maps.* Paper presented at the Spatial cognition conference.

Koffka, K. (1935). *Principles of gestalt psychology.* New York: Harcourt, Brace and Company.

Köhler, W. (1940). *Dynamics in psychology.* New York: Liveright Publishing Corporation.

Kuipers, B. J. (1977). *Representing knowledge of large-scale space.* Massachusetts Institute of Technology, Massachusetts.

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

Landau, B. (1986). Early map use as an unlearned ability. *Cognition, 22*, 201-223.

Landau, B. (1991). Spatial representation of objects in the young blind child. *Cognition, 38*, 145-178.

Landau, B., Gleitman, H., & Spelke, E. (1981). Spatial knowledge and geometric representation in a child blind from birth. *Science, 213*, 1275-1278.

Landau, B., Spelke, E., & Gleitman, H. (1984). Spatial knowledge in a young blind child. *Cognition, 16*, 225-260.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* Cambridge: Cambridge University Press.

Lechelt, C., Eugene, & Hall, L., David. (2000). *The impact of vision loss on the development of children from birth to 12 years: A literature review*: CNIB.

Lederman, J. S., & Klatzky, L. R. (1987). Hand movements: A window into haptic object recognition. *Cognitive Psychology, 19*, 342-368.

Lederman, S. J., Klatzky, R. L., & Barber, P. O. (1985). Spatial and movement-based heuristics for encoding pattern information through touch. *Journal of Experimental Psychology: General, 114*, 33-49.

Levack, N. (1991). *Low vision: A resource guide with adaptations for students with visual impairments.* Austin: Texas School for the Blind and Visually Impaired.

Levine, M., Jankovic, I., & Palij, M. (1982). Principles of spatial problem solving. *Journal of Experimental Psychology: General, 111*, 157-175.

Lewis, V., & Collis, M. G. (1997). Methodological and theoretical issues associated with the study of children with visual impairment. In V. Lewis & M. G. Collis (Eds.), *Blindness and psychological development in young children* (pp. 1-8). Leicester: The British Psychological Society.

Lewis, V., & Lewis, V. (2003). *Development and disability.* Malden, MA: Blackwell Pub.

Liben, L. (1981). Spatial representation and behavior: Multiple perspectives. In L. Liben, A. Patterson & N. Newcombe (Eds.), *Spatial representation and behavior across the life span* (pp. 3-36). New York: Academic Press.

Liben, L. (1982). Children's large-scale spatial cognition: Is the measure the message? In R. Cohen (Ed.), *New directions for child development: Children's conceptions of spatial relationships* (51-64). San Francisco, CA: Jossey-Bass.

Liben, L. (1988). Conceptual issues in the development of spatial cognition. In J. Stiles-Davis, M. Krtichersky & U. Bellugi (Eds.), *Spatial cognition: Brain bases and development* (pp. 167-194). Hillsdale, New Jersey: Earlbaum.

Lloyd, R. (1989). Cognitive maps: Encoding and decoding information. *Annals, Association of American Geographers, 79*, 101-124.

Lloyd, R. (1997). *Spatial cognition: Geographic environments.* London: Kluwer Academic Press.

Lloyd, R., & Heivly, C. (1987). Systematic distortions in urban cognitive mapping. *Annals of the Association of American Geographers, 77*, 191-207.

Locke, J., & George Fabyan Collection (Library of Congress). (1689). *An essay concerning humane understanding: In four books*. London: Printed by Eliz. Holt for Thomas Bassett.

Lockman, J. J., Rieser, J. J., & Pick, H. L. (1981). Assessing blind traveler's knowledge of spatial layout. *Journal of Visual Impairment and Blindness, 75*, 321-326.

Long, R. G., & Hill, E. W. (1997). Establishing and maintaining orientation for mobility. In B. B. Blasch, W. R. Wiener & R. L. Welsh (Eds.), *Foundations of orientation and mobility* (pp. 39-59). New York: AFB Press.

Long, R. G., Rieser, J. J., & Hill, E. W. (1990). Mobility in individuals with moderate visual impairments. *Journal of Visual Impairment and Blindness, 84*, 111-118.

Loomis, J. M., Klatzky, R. L., Golledge, R. G., Cicinelli, J. G., Pellegrino, J. W., & Fry, P. A. (1993). Nonvisual navigation by blind and sighted: Assessment of path integration ability. *Journal of Experimental Psychology: General, 122*, 73-91.

Lopez-Justicia, M. D., & Cordoba, I. N. (2006). The self-concept of Spanish young adults with retinitis pigmentosa. *Journal of Visual Impairment and Blindness, 100*, 366-370.

Lopez-Justicia, M. D., Pichardo, M. C., Amezcua, J. A., & Fernandez, E. (2001). The self-concepts of Spanish children and adolescents with low vision and their sighted peers. *Journal of Visual Impairment and Blindness, 95*, 7-16.

Low vision. National institute of aging. (2007). Retrieved April 17, 2007, from http://www.niapublications.org/agepages/eyes.asp

Low-vision. (2007). Recommended standards for low vision services. *NHS Eyecare Services Programme* Retrieved February 11, 2007, from www.rnib.org.uk/xpedio/groups/public/documents/publicwebsite/public_dvstandards.doc

Lowenfeld, B. (1963). The visually handicap. *Review of Educational Research: The Education of Exceptional Children, 33*, 38-47.

Lowenfeld, B. (1981). *Berthold Lowenfeld on blindness and blind people: Selected papers*. New York: American Foundation for the Blind.

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

Mace, W. M. (2005). James J. Gibson ecological approach: Perceiving what exists. *Ethics & The Environment, 10*, 195-216.

Mackintosh, N. J. (2002). Do not ask whether they have a cognitive map, but how they find their way about. *Psicologica, 23*, 165-185.

Maki, R. H. (1981). Categorization and distance effects with spatial linear orders. *Journal of Experimental Psychology: Human Learning and Memory, 7*, 15-32.

Marmor, G. S., & Zaback, L. A. (1976). Mental rotation by the blind: Does mental rotation depend on visual imagery? *Journal of Experimental Psychology: Human Perception and Performance, 2*, 515-521.

Marron, J. A., & Bailey, I. L. (1982). Visual factors and orientation-mobility performance. *American Journal of Optometry and Physiological Optics, 59*, 413-426.

Massof, R. W., & Rubin, G. S. (2001). Visual function assessment questionnaires. *Survey of Ophthalmology, 45*(6), 531-548.

Maxfield, K., & Buchholz, S. (1957). *A social maturity scale for blind preschool children: A guide to its use*. New York: American Foundation for the Blind.

Maxfield, K., Erroll, F., & Harriett, A. (1942). The social maturity of the visually handicapped preschool child. *Child Development, 13*, 1-27.

McNamara, T. P. (1986). Mental representations of spatial relations. *Cognitive Psychology, 18*, 87-121.

McNamara, T. P. (1992). Spatial representation. *Geoforum, 23*, 139-150.

McNamara, T. P., & Diwadkar, V. (1997). Symmetry and asymmetry in human spatial memory. *Cognitive Psychology, 34*, 160-190.

McNamara, T. P. R., R.□McKoon, G. (1984). The mental representation of knowledge acquired from maps. *Journal of Experimental Psychology: Human Learning and Memory, 10*, 723-732.

Meighan, T. (1971). *An investigation of the self-concept of blind and visually handicapped adolescents*. New York: American Foundation for the Blind.

Middlebrooks, J. C., & Green, D. M. (1991). Sound localization by human listeners. *Annual Review of Psychology, 42*, 135-159.

Millar, S. (1976). Spatial representation by blind and sighted children. *Journal of Experimental Child Psychology, 21*, 460-479.

Millar, S. (1979). Utilization of shape and movement cues in simple spatial tasks by blind and sighted children. *Perception, 8*, 11-20.

Millar, S. (1982). The problem of imagery and spatial development in the blind. In B. d. Gelder (Ed.), *Knowledge and representation* (pp. 111-120). London: Routledge & Kegan Paul.

Millar, S. (1988). Models of sensory deprivation: The nature / nurture dichotomy and spatial representation in the blind. *International Journal of Behavioral Development, 11*, 69-87.

Millar, S. (1994). *Understanding and representing space: Theory and evidence from studies with blind and sighted children.* Oxford: Oxford University Press.

Millar, S. (1997). Theory, experiment and practical application in research on visual impairment. *European Journal of Psychology of Education, 12*, 415-430.

Millar, S. (2000). Modality and mind: Convergent active processing in interrelated networks as a model of development and perception. In M. A. Heller (Ed.), *Touch, representation, and blindness* (pp. 99-141). Oxford; New York: Oxford University Press.

Miller, L. (1992). Diderot reconsidered: Visual impairment and auditory compensation. *Journal of Visual Impairment and Blindness, 85*, 206-210.

Moar, I., & Bower, G. (1983). Inconsistency in spatial knowledge. *Memory and Cognition, 11*, 107-113.

Moar, I., & Carleton, L. R. (1982). Memory for routes. *Quarterly Journal of Experimental Psychology, 34*, 381-394.

Molyneux's problem. (2007). Retrieved June 14, 2007, from http://plato.stanford.edu/entries/molyneux-problem/

Montello, R. D. (1991). The measurement of cognitive distance: Methods and construct validity. *Journal of Environmental Psychology, 11*, 101-122.

Montello, R. D. (1992). The geometry of environmental knowledge. In A. U. Frank, I. Campari & U. Formentini (Eds.), *Theories and methods of spatio-temporal reasoning in geographic space* (pp. 136-152). Berlin: Springer-Verlag.

Montello, R. D. (1998). A new framework for understanding the acquisition of spatial knowledge in large-scale environments. In J. M. Egenhofer & G. R. Golledge (Eds.), *Spatial and temporal reasoning in geographic information systems* (pp. 143-154). New York: Oxford University Press.

Montello, R. D., & Golledge, G. R. (1999). *Scale and detail in the cognition of geographic information: Report of specialist meeting of project Varenius*: University of California at Santa Barbara.

Moore, J. E., Graves, W. H., & Patterson, J. B. (1997). *Foundations of rehabilitation counselling with persons who are blind or visually impaired.* New York: AFB Press.

Morgan, M. J. (1977). *Molyneux's question: Vision, touch, and the philosophy of perception.* Cambridge; New York: Cambridge University Press.

Morris, J. (1991). *Pride against prejudice: A personal politics of disability.* London: Women's Press.

Morrongiello, B. A., Humphrey, K., Timney, B., Choi, J., & Rocca, P. T. (1994). Tactual object exploration and recognition in blind and sighted children. *Perception, 23*, 833-848.

Morrongiello, B. A., Timney, B., Humphrey, K., Anderson, S., & Skory, C. (1995). Spatial knowledge in blind and sighted children. *Journal of Experimental Child Psychology, 59*, 211-233.

Morse, J. L. (1983). Psychosocial aspects of low vision. In R. T. Jose (Ed.), *Understanding low vision* (pp. 43-54). New York: AFB Press.

Nagy, S. (1991). Disability concepts revisited: Implications for prevention. In A. Pope & A. Tarlov (Eds.), *Disability in America: Towards a national agenda for prevention.* Washington, DC: National Açademic Press.

Newcombe, N., & Huttenlocher, J. (2000). *Making space: The development of spatial representation and reasoning.* Cambridge, Mass.: MIT Press.

Newton, I., Cohen, I. B., & Whitman, A. M. (1999). *The principia: Mathematical principles of natural philosophy.* Berkeley: University of California Press.

NHS. (2006). Registered blind and partially sighted people year ending 31 march 2006. Retrieved December 21, 2007, from http://www.ic.nhs.uk/statistics-and-data-collections/social-care/adult-social-care-information/people-registered-as-blind-and-partially-sighted-triennial-2006-england

Nielsen, L. (1991). Spatial relations in congenitally blind infants: A study. *Journal of Visual Impairment and Blindness, 85*, 11-16.

Norris, M., Spaulding, P. J., & Brodie, F. H. (1957). *Blindness in children.* Chicago: University of Chicago Press.

O'Donnell, L. M., & Livingston, R. L. (1991). Active exploration of the environment by young children with low vision: A review of literature. *Journal of Visual Impairment and Blindness, 85*, 287-291.

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

Ochaíta, E. (1982). *El conocimiento del espacio en los ninos ciegos.* Facultad Autonoma de Madrid, Madrid.

Ochaíta, E. (1984). Una applicacion de la teoria piagetiana al estudio del conocimiento espacial. *Infancia y Aprendizaje, 25*, 81-104.

Oliver, M. (1983). *Social work with disabled people.* Basingstoke: MacMillan.

Oliver, M. (1990). *The politics of disablement.* London: Macmillan.

Oliver, M. (1992). Changing the social relations of research production. *Disability, Handicap and Society, 7*, 101-114.

Oliver, M. (1996a). Defining impairment and disability: Issues at stake. In C. Barnes & G. Mercer (Eds.), *Exploring the divide.* Leeds: The Disability Press.

Oliver, M. (1996b). *Understanding disability: From theory to practice.* Basingstoke: Macmillan.

Olson, M. (1981). Enhancing the exploratory behavior of visually impaired preschoolers. *Journal of Visual Impairment and Blindness, 75*, 375-377.

Paivio, A. (1971). *Imagery and verbal processes.* New York: Holt: Rinehart & Winston.

Pascual-Leone, J. (1976). Metasubjective problems of constructive cognition: Forms of knowing and their psychological mechanisms. *Canadian Psychological Review, 81*, 497-510.

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

Passini, R., Delisle, J., Langlois, C., & Proulx, G. (1988). Wayfinding information for congenitally blind individuals. *Journal of Visual Impairment and Blindness, 92*, 425-429.

Passini, R., Dupre, A., & Langlois, C. (1985). *Étude descriptive de la mobilité et de l'orientation spatiales chez des handicapes visuels en milieu urbain*. Montreal: Université de Montréal: Faculté de l'aménagement.

Passini, R., Dupre, A., & Langlois, C. (1986). Spatial mobility of the visually handicapped active person: A descriptive study. *Journal of Visual Impairment and Blindness, 80*, 904-907.

Passini, R., & Proulx, G. (1988). Wayfinding without vision: An experiment with congenitally, totally blind people. *Environment and Behaviour, 20*, 227-252.

Passini, R., Proulx, G., & Rainville, C. (1990). The spatio-cognitive abilities of the visually impaired population. *Environment and Behaviour, 22*, 91-116.

Passini, R., Rainville, C., & Habib, M. (2000). Spatio-cognitive deficits in right parietal lesion and its impact on wayfinding: A case study. *Neurocase, 6*, 245-257.

Paterson, M. (2006). Seeing with the hands': Blindness, touch and the enlightenment spatial imaginary. *British Journal of Visual Impairment, 24*, 52-59.

Peadboy, R. L., & Birch, J. W. (1967). Education implications of partial-vision-new findings from the national study. *Sight Saving Review, 77*, 92-96.

Peuquet, D. (1998). *Geographic knowledge as a multi-representational and dynamic system*. Pittsburgh: Varenius Workshop Report.

Peuquet, D. J. (2002). *Representations of space and time*. New York: Guilford Press.

Piaget, J. (1954). *The construction of reality in the child*. New York: Basic Books.

Piaget, J., & Inhelder, B. (1956). *The child's conception of space*. London: Routledge and Kegan Paul.

Piaget, J., Inhelder, B., & Szeminska, A. (1960). *The child's conception of geometry*. London: Routledge & Kegan Paul.

Pollok, B., Schnitzler, I., Stoerig, P., Mierdorf, T., & Schnitzler, A. (2005). Image-to-sound conversion: Experience-induced plasticity in auditory cortex of blindfolded adults. *Experimental Brain Research, 167*, 287-291.

Portugali, J. (Ed.). (1996). *The construction of cognitive maps*. Dordrecht: Kluwer Academic Publishers.

Power, D. A. (1969). *British masters of medicine*. Freeport, N.Y.: Books for Libraries Press.

Presson, C. C., & Hazelrigg, D. M. (1984). Building spatial representations through primary and secondary learning. *Journal of Experimental Psychology: Learning, Memory and Cognition, 10*, 716-722.

Presson, C. C., & Montello, R. D. (1988). Points of reference in spatial cognition: Stalking the elusive landmark. *British Journal of Developmental Psychology, 6*, 378-381.

Presson, C. C., & Montello, R. D. (1994). Updating after rotational and translational body movements: Coordinate structure of perspective space. *Perception*, 1447-1455.

Ptito, M., & Kupers, R. (2005). Cross-modal plasticity in early blindness. *Journal of Integrative Neuroscience, 4*, 479-488.

Ptito, M., Moesgaard, S. M., Gjedde, A., & Kupers, R. (2005). Cross-modal plasticity revealed by electrotactile stimulation of the tongue in the congenitally blind. *Brain, 128*, 606-614.

Revesz, G. (1950). *Psychology and the art of the blind* (H. A. Wolff, Trans.). London: Longmans Green.

Reynell, J. (1978). Developmental patterns of visually handicapped children. *Child: Care, Health and Development, 4*, 291-303.

Rieser, J. J., Guth, D. A., & Hill, E. W. (1982). Mental processes mediating independent travel: Implications for orientation and mobility. *Journal of Visual Impairment and Blindness, 76*, 213-218.

Rieser, J. J., Guth, D. A., & Hill, E. W. (1986). Sensitivity to perspective structure while walking without vision. *Perception, 15*, 173-188.

Rieser, J. J., Hill, E. W., Talor, C. R., Bradfield, A., & Rosen, S. (1992). Visual experience, visual field size, and the development of nonvisual sensitivity to the spatial structure of outdoor neighborhoods explored by walking. *Journal of Experimental Psychology: General, 121*, 210-221.

Rieser, J. J., Lockman, J. J., & Pick, L. H. (1980). The role of visual experience in knowledge of spatial layout. *Perception & Psychophysics, 28*, 185-190.

Rieser, J. J., & Rider, E. A. (1991). Young children's spatial orientation with respect to multiple targets when walking without vision. *Developmental Psychology, 27*, 97-107.

RLSB. (2004). *Diseases syndromes and eye conditions*. Sevenoaks: Royal London Society for the Blind.

RNIB. (2007). Statistics - numbers of people with sight problems in the UK. Retrieved May 2, 2007, from http://www.rnib.org.uk/xpedio/groups/public/documents/PublicWebsite/public_researchstats.hcsp

Rosa, A. (1993). Caracterizacion de la ceguera y las deficiencias visuales. In A. Rosa & E. Ochaita (Eds.), *Psicologia de la ceguera* (pp. 19-49). Madrid: Alianza Editorial.

Rosa, A., & Ochaíta, E. (1993). *Psicologia de la ceguera.* Madrid: Alianza Editorial.

Rosenblum, P., L. (2000). Perceptions of the impact of visual impairment on the lives of adolescents. *Journal of Visual Impairment and Blindness, 94*, 434-445.

Russell, B. (1927). *An outline of philosophy.* London: G. Allen & Unwin.

Sacks, O. (1995). *An anthropologist on mars: Seven paradoxical tales.* London: Picador.

Sacks, S. Z. (1996). Psychological and social implications of low vision. In A. L. Corn & A. J. Koenig (Eds.), *Foundations of low vision: Clinical and functional perspectives* (pp. 26-42). New York: AFB Press.

Saddala, E., Burroughs, W., & Staplin, L. (1980). Reference points in spatial cognition. *Journal of Experimental Psychology: Human Learning and Memory, 5*, 516-528.

Saddala, E., & Magel, S. (1980). The perception of traversed distance. *Environment and Behaviour, 12*, 65-79.

Sampaio, E. (1994). Le development precoce des enfants aveugles: Les travaux pionniers de selma Fraiberg. *Psychiatrie de l'enfant, 37*, 29-47.

Schellingerhout, R., Smitsman, A. W., & Van Galen, G. P. (1998). Haptic object exploration in congenitally blind infants. *Journal of Visual Impairment and Blindness, 92*, 674-678.

Schinazi, V. (2005). Spatial representation and low vision: Two studies on the content, accuracy and utility of mental representations, *International Congress Series*: Elsevier.

Schlaegel, T. F. (1953). The dominant method of imagery in blind compared to sighted adolescents. *Journal of Genetic Psychology, 83*, 265-277.

Senden, M. v. (1932). *Raum- und gestaltauffassung bei operierten blindgeborenen vor und nach der operation.* Leipzig: J. A. Barth.

Senden, M. v. (1960). *Space and sight; the perception of space and shape in the congenitally blind before and after operation.* Glencoe, Ill.: Free Press.

Saint Euxpéry, A. d., & Woods, K. (1943). *The little prince.* New York: Reynal & Hitchcock.

Shakespeare, T. (2006). *Disability rights and wrongs.* New York: Routledge.

Shakspeare, T. (2006). Looking back, moving forward. *Ouch!* Retrieved April 24, 2006, from http://www.bbc.co.uk/ouch/columnists/tom/250906_index.shtml

Shapiro, D. R., Moffett, A., Lieberman, L., & Dummer, G. M. (2005). Perceived competence of children with visual impairments. *Journal of Visual Impairment and Blindness, 99*, 15-25.

Sholl, J. M. (1987). Cognitive maps as orienting schemata. *Journal of Experimental Psychology: Learning, Memory and Cognition, 13*, 615-628.

Siegel, A. W. (1981). The externalization of cognitive maps by children and adults: In search of ways to ask better questions. In L. Liben, A. Patterson & N. Newcombe (Eds.), *Spatial representation and behaviour across the life span: Theory and application* (pp. 167-194): Academic Press, Inc.

Siegel, A. W., & Cousins, J. (1985). The symbolizing and symbolized child in the enterprise of cognitive mapping. In R. Cohen (Ed.), *The development of spatial cognition* (pp. 347-368). London: Lawrence Erlbaum.

Siegel, A. W., Herman, J. F., Allen, G. L., & Kirasic, K. C. (1979). The development of cognitive maps of large- and small-scale spaces. *Child Development, 50*, 582-585.

Siegel, A. W., & White, S. H. (1975). The development of spatial representations of large-scale environments. *Advances Child Development and Behavior, 10*, 9-55.

Smothergill, D. W., Hughes, F. P., Timmons, S. A., & Hutko, P. (1975). Spatial visualizing in children. *Developmental Psychology, 11*, 4-13.

Smythe, M. M., & Kennedy, J. E. (1982). Orientation in spatial representations within multiple frames of reference. *British Journal of Psychology, 73*, 527-535.

Sorrows, M., & Hirtle, S. (1999). *The nature of landmarks for real and electronic spaces.* Paper presented at the Lecture Notes in Computer Science #1661, Spatial information theory: Cognitive and Computational Foundations of Geographic Information Science (COSIT '99), Berlin.

Spencer, C., Blades, M., & Morsley, K. (1989). *The child in the physical environment: The development of spatial knowledge and cognition.* Chichester, New York: Wiley.

Spencer, C., & Weetman, M. (1980). The microgenesis of cognitive maps: A longitudinal study of new residents of an urban area. *Transactions of the Institute of British Geographers, 6*, 375-384.

Spray, J. A. (1986). Absolute error revisited: An accuracy indicator in disguise. *Journal of Motor Behavior, 18*, 225-238.

Stark, M., Coslett, B. H., & Saffran, E. M. (1996). Impairment of an egocentric map of locations: Implications for perception and action. *Cognitive Neuropsychology, 13*, 481-523.

Stephens, A., & Coupe, E. P. (1978). Distortions in judged spatial relations. *Cognitive Psychology, 10*, 422-437.

Stephens, B., & Grube, C. (1982). Development of Piagetian reasoning in congenitally blind children. *Journal of Visual Impairment and Blindness, 76*, 133-143.

Sternberg, R. J. (1977). *Intelligence, information processing, and analogical reasoning: The componential analysis of human abilities.* New York: Lawrence Erlbaum Associates.

Strelow, E. (1985). What is needed for a theory of mobility: Direct perception and cognitive maps - lessons from the blind. *Psychological Review, 92*, 226-248.

Sutherland, P. (1992). *Cognitive development today: Piaget and his critics*. London: P. Chapman Pub.

Swain, J., French, S., & Cameron, C. (2003). *Controversial issues in a disabling society*. Buckingham: OU Press.

Telford, L., Howard, I. P., & Ohmi, M. (1995). Heading judgments during active and passive self-motion. *Experimental Brain Research, 104*, 502-510.

Tellevik, J. M. (1992). Influence of spatial exploration patterns on cognitive mapping by blindfolded sighted persons. *Journal of Visual Impairment and Blindness, 86*, 221-224.

Thinus-Blanc, C., Bouzouba, K., Chaix, N., Chapuis, N., Durup, M., & B., P. (1987). A study of spatial parameters encoded during exploration in hamsters. *Journal of experimental psychology: Animal behaviour processes, 13*, 418-427.

Thinus-Blanc, C., & Gaunet, F. (1997). Representation of space in blind persons: Vision as a spatial sense? *Psychological Bulletin, 121*, 20-42.

Thinus-Blanc, C., & Gaunet, F. (1999). Spatial processing in animals and humans: The organizing function of representations for information gathering. In R. Golledge (Ed.), *Wayfinding behavior: Cognitive mapping and other spatial processes* (Vol. 1, pp. 427). Baltimore: The Johns Hopkins University Press.

Thorndyke, P., & Hayes-Roth, B. (1982). Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology, 14*, 560-581.

Tobin, M., J. (1972). Conservation of substance in the blind and partially sighted. *British Journal of Educational Psychology, 42*(2), 192-197.

Tobin, M., J. (1998). Is blindness a handicap. *British Journal of Special Education, 25*, 107-113.

Tobin, M., J., Bozic, N., Douglas, G., Greaney, J., & Ross, S. (1997). Visually impaired children: Development and implications for education. *European Journal of Psychology of Education, 12*, 431-447.

Tobler, W. R. (1976). The geometry of mental maps. In G. R. Golledge (Ed.), *Spatial choice and spatial behaviour* (pp. 69-81). Columbus Ohio: Ohio State University Press.

Tobler, W. R. (1994). Bidimensional regression. *Geographical Analysis, 26*, 187-212.

Tolman, E. C. (1948). Cognitive maps in rats and men. *The Psychological Review, 5*, 189-208.

Tresniowski, A., & Arias, R. (2006, July). The boy who sees with sound. *People Magazine*.

Trowbridge, C. C. (1913). On fundamental methods of orientation and "imaginary maps". *Science, 38*, 888-897.

Turano, K., & Schuchard, R. (1991). Space perception in observers with visual field loss. *Clinical Vision Science, 6*, 289-299.

Turano, K., Geruschat, D. R., Stahl, J. W., & Massof, R. W. (1999). Perceived visual ability for independent mobility in persons with retinitis pigmentosa. *Investigative Ophthalmology & Visual Science, 40*, 2803-2809.

Tuttle, D. W. (1987). The role of special education. *Journal of Visual Impairment and Blindness, 81*, 156-161.

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

Tversky, B. (1992). Distortions in cognitive maps. *Geoforum, 23*, 131-138.

Tversky, B. (1993). Cognitive maps, cognitive collages, and spatial mental models. In A. U. Frank & I. Campari (Eds.), *Spatial information theory: A theoretical basis for GIS* (pp. 14-24). Berlin: Springer-Verlag.

Tversky, B. (2005). Functional significance of visuospatial representations. In P. Shah & A. Miyake (Eds.), *The Cambridge handbook of visuospatial thinking* (pp. 1-34). New York: Cambridge University Press.

Ungar, S. Cognitive mapping without visual experience. (2000). In R. Kitchin & S. Freundschuh (Eds.), *Cognitive mapping: Past, present and future* (221-248). London: Routledge.

Ungar, S. (1994a). *The ability of young visually impaired children to use tactile maps.* University of Sheffield, Sheffield.

Ungar, S. (1994b). Can the visually impaired children use tactile maps to estimate directions? *Journal of Visual Impairment and Blindness, 88*, 221-228.

Ungar, S. (1996). The ability of visually impaired children to locate themselves on a tactile map. *Journal of Visual Impairment and Blindness, 90*, 526-531.

Ungar, S., & Blades, M. (1997). Teaching visually impaired children to make distance judgments from a tactile map. *Journal of Visual Impairment and Blindness, 91*, 163-177.

Ungar, S., Blades, M., & Spencer, C. (1996). The construction of cognitive maps by children with visual impairments. In J. Portugali (Ed.), *The construction of cognitive maps* (pp. 247-273). Dordrecht: Kluwer Academic Publishers.

UPIAS. (1976). *Fundamental principles of disability.* London.

Van der Kolk, C. J. (1977). Intelligence testing for visually impaired persons. *Journal of Visual Impairment and Blindness, 71*, 158-163.

Veraart, C., & Wanet-Defalque, M. C. (1987). Representation of locomotor space by the blind. *Perception & Psychophysics, 42*, 132-139.

Vygotsky, L. S. (1978). *Mind in society*. Cambridge, MA: Harvard University Press.

Waller, D., Loomis, J. M., & Haun, D. B. M. (2004). Body-based senses enhance knowledge of directions in large-scale environments. *Psychonomic Bulletin & Review, 11*, 157-163.

Waller, D., Loomis, J. M., & Steck, S. D. (2003). Inertial cues do not enhance knowledge of environmental layout. *Psychonomic Bulletin & Review, 10*, 987-993.

Wanet-Defalque, M. C., Vanlierde, A., & Michaux, G. (2001). Mental representation of spaces and objects in a historic site: Influence of visual impairment. *Journal of Visual Impairment and Blindness, 95*, 172-175.

Warren, D. H. (1978). Childhood visual impairment: Perspectives on research design and methodology. *Journal of Visual Impairment and Blindness, 72*, 404-411.

Warren, D. H. (1984). *Blindness and early childhood development*. New York, NY: American Foundation for the Blind.

Warren, D. H. (1994). *Blindness and children: An individual differences approach*. Cambridge; New York: Cambridge University Press.

Warren, D. H., & Rossano, M. J. (1991). Intermodality relations: Vision and touch. In M. A. Heller & W. Schiff (Eds.), *The psychology of touch* (pp. 119-137). London: Lawrence Erlbaum Associates.

Waterman, S., & Gordon, D. (1984). A quantitative-comparative approach to analysis of distortion in mental maps (Israel). *Professional Geographer, 36*, 326-337.

WHO. (2002). *Towards a common language for functioning, disability and health*. Geneva.

Williamsonn, M. (1992). *A return to love: Reflections on the principles of a course in miracles*. New York: Harper Collins.

Wolffsohn, J. S., & Cochrane, A. L. (2000). Design of the low vision quality-of-life questionnaire (LVQOL) and measuring the outcome of low-vision rehabilitation. *American Journal Of Ophthalmology, 130*, 793.

Wood, D., & Beck, R. (1976). Talking with environmental a: An experimental mapping language. In G. T. Moore & G. R. Golledge (Eds.), *Environmental knowing: Theories, research and methods* (pp. 351-161). Dowden: Hutchinson and Ross.

Wood, P. (1980). *International classification of impairments, disabilities and handicaps*. Geneva: The World Health Organization.

Worchel, P. (1951). Space perception and orientation in the blind. *Psychological Monographs, 65*, 1-28.

Wright, J. C., & Vliestra, A. G. (1975). The development of selective attention: From perceptual exploration to logical search. In H. W. Reese (Ed.), *Advances in child development and behaviour* (Vol. 10, pp. 195-239). New York: Academic Press.

Zacharias, J. (2000). Shopping behavior at the Alexis-Nihon plaza in Montreal. *Journal of Shopping Centre Research, 7*, 67-79.

Zacharias, J., & Schinazi, V. (2003). The impact of an entertainment retrofit on the performance of a shopping centre. *Journal of Shopping Centre Research, 10*, 29-44.

Zeevi, Y. Y., & Kronauer, R. E. (1975). Signal processing in visual systems and its relevance to pattern recognition. In G. F. Ibar (Ed.), *Signal analysis and pattern recognition in biomedical engineering*. New York: John Wiley & Sons.

Appendix A
Tables

This appendix includes tables from the two experiments conducted with students at the RLSB.

Appendix A 1

Characteristics of the participants in the RLSB campus experiment

Subject	Age	Sex	Group	Visual acuity	Visual field	Near vision	Colour vision	Visual condition	Age of onset	Additional condition	Mobility (years)	Intelligence
1	18	F	MVI	R 1/6 L 1/6 both 1/6	Constricted all round both eyes	N18	Normal w/ Ishihara test	Retinitis pigmentosa	Birth	None	1	Lit. 66/72 Num. 38/50
2	21	F	SVI	R 1/15 L 1/20 both 1/10	Constricted all round both eyes	N18	Normal w/ Ishihara test	RP, Myopia & Astigmatism	Birth	None	2	FSA. 27/45
3	24	M	SVI	R 1/30 L 1/30 both 1/30	Highly constricted (5°)	N24	Failed Ishihara test	Retinitis pigmentosa	Birth	Lawrence Moon Biedl Syndrome	8	Lit. 66/72 Num. 42/50
4	20	M	SVI	R 1/60 L 1/15 both 1/12	Poor central / peripheral vision	?	Bright colours only	Retinitis pigmentosa	Birth	Dyspraxia (motor skill difficulty)	3	FSA 19/45
5	19	M	SVI	R 1/10	?	?	Problems w/ some colours	Microphthalmos, cataracts, nystagmus	Birth	None (suspect learning difficulty)	7	FSA 26/45
6	20	M	MVI	R 1/3 L 1/2 both 1/2	Constricted field	N14	Able to detect all colours	Not assigned	Birth	Epilepsy	6	FSA 20/45

Subject	Age	Sex	Group	Visual acuity	Visual field	Near vision	Colour vision	Visual condition	Age of onset	Additional condition	Mobility (years)	Lit. Num. & FSA
7	21	M	SVI	R 1/12 L no LP	peripheral restriction	N 14	Perfect Ishihara test	Myopia	3	Learning difficulty	6	FSA 24/45
8	19	M	Blind	Light perception	-	-	-	Retinopathy of prematurity	Birth	Epilepsy diabetes	13	Lit. 31/72 Num. 43/50
9	19	M	Blind	No light perception	-	-	-	Retinopathy of prematurity	Birth	None	12	FSA 35/45
10	18	M	SVI	R 1/60 L (LP) both 1/60	Constricted field	N 60	Failed Ishihara	Congenital glaucoma	Birth	None	12	Lit. 43/72 Num. 43/50
11	18	M	SVI	R 1/60 L no vision	Restricted all around	N24	Failed Ishihara. Can recognize gross colours and pastel shades	Pete's anomaly (never proven) Microphthalmus Glaucoma	Birth	None	12	Lit. 72/72 Num. 42/50
12	19	M	Blind	Light perception	-	-	-	Leber's optic neuropathy (first blurry now no vision)	17	None	1	Lit. 56/72 Num. 46/50
13	22	M	MVI	R 1/6 L 1/60 both 1/6	Highly constricted (severe tunnel vision)	N 24	Problems differentiating colours	Retinitis pigmentosa (deteriorating rapidly)	Birth	Lawrence Moon Biedl Syndrome	1	FSA 13/45
14	19	M	MVI	R 1/ 60 L 1/6 both 1/6	Right eye somewhat constricted. Vision blurred in periphery	?	Failed Ishihara. Can recognise gross colours (red, blue, green, yellow)	Brain tumour. Left with no vision on L eye and partial on R eye. Vision started to improve after the operation.	16	Aspergers (very mild) Tuberous sclerosis	1	Lit. 58/72 Num. 46/50

Subject	Age	Sex	Group	Visual acuity	Visual field	Near vision	Colour vision	Visual condition	Age of onset	Additional condition	Mobility (years)	Lit. Num. & FSA
15	21	M	MVI	R 1/15 L 1/10 both 1/6	Constricted all around	N12	Difficulty with colours especially pastel and dark shades	Visual impairment due to congenital hydrocephalus Premature birth with associated optic nerve damage	Birth	Hemipares affecting left side. Suspected learning difficulties	2	FSA 14/45
16	18	M	MVI	R 1/6 L 2/3 both 2/33	Field very restricted	N5	15/17 on Ishihara Able to identify most colours and shades	Retinitis pigmentosa (affecting periphery) very weak night vision	Birth	Muscle Hypotonia (decreased muscle tone)	3	Lit. 49/52 Num. 14/50
17	19	F	MVI	R 1/3 L 1/4 both 1/3	-	N10	-	Congenital cataracts	Birth	None	4	FSA 32/50
18	20	M	Blind	-	-	-	-	Optic atrophy (meningitis)	Before 2 years	None	16	FSA 14/50
19	19	F	MVI	R 1/3 L 1/6 both 1/3	Upper field constricted	-	Passed Ishihara	Bilateral congenital cataracts, nystagmus on both eyes. Operation when 11 years old not very successful has problems focusing with left eye.	Birth	None	3	FSA 30/50
20	18	F	Blind	-	-	-	-	Retinopathy of prematurity (LP)	Birth	None	5	Lit. 61/72 Num. 38/50

Subject	Age	Sex	Group	Visual acuity	Visual field	Near vision	Colour vision	Visual condition	Age of onset impairment	Additional condition	Mobility (years)	Lit. Num. & FSA
21	17	F	Blind	-	-	-	-	Retinopathy of prematurity	Birth	None	11	Lit. 70/72 Num. 45/50
22	22	M	SVI	R 1/15 L 1/15 both 1/12	Constricted	N18	Failed Ishihara. Only gross colours	Stargardt's macular dystrophy (periphery OK, not deteriorating)	10	None	1	-
23	21	M	MVI	R 2/3 L 2/3 both 2/3	Some of the periphery constricted	-	Passed Ishihara No problems differentiating colours	Divergent squint Nystagmus	Birth	Short-term memory weak (never diagnosed)	4	FSA 30/50
24	19	F	Blind	-	-	-	-	Cause unknown (LP)	Birth	-	7	FSA 25/50

Appendix A 2

Rank order correlations for estimated distances in RLSB campus

Group (subject #)	Euclidean	Functional
Sighted (25)	(rho = .808, N = 45 , p = .000)*	(rho = .703, N = 45 , p = .000)
Sighted (26)	(rho = .920, N = 45 , p = .000)*	(rho = .905, N = 45 , p = .000)
Sighted (27)	(rho = .929, N = 45 , p = .000)*	(rho = .913, N = 45 , p = .000)
Sighted (29)	(rho = .918, N = 45 , p = .000)*	(rho = .828, N = 45 , p = .000)
MVI (1)	(rho = .853, N = 45 , p = .000)	(rho = .890, N = 45 , p = .000)*
MVI (6)	(rho = .883, N = 45 , p = .000)*	(rho = .819, N = 45 , p = .000)
MVI (13)	(rho = .785, N = 45 , p = .000)*	(rho = .736, N = 45 , p = .000)
MVI (14)	(rho = .937, N = 45 , p = .000)*	(rho = .855, N = 45 , p = .000)
MVI (15)	(rho = .826, N = 45 , p = .000)*	(rho = .751, N = 45 , p = .000)
MVI (16)	(rho = .922, N = 45 , p = .000)*	(rho = .842, N = 45 , p = .000)
MVI (17)	(rho = .886, N = 45 , p = .000)*	(rho = .832, N = 45 , p = .000)
MVI (19)	(rho = .903, N = 45 , p = .000)*	(rho = .854, N = 45 , p = .000)
MVI (23)	(rho = .702, N = 45 , p = .000)	(rho = .736, N = 45 , p = .000)*
SVI (2)	(rho = .808, N = 45 , p = .000)	(rho = .843, N = 45 , p = .000)*
SVI (3)	(rho = .825, N = 45 , p = .000)	(rho = .842, N = 45 , p = .000)*
SVI (4)	(rho = .858, N = 45 , p = .000)*	(rho = .839, N = 45 , p = .000)
SVI (5)	(rho = .837, N = 45 , p = .000)*	(rho = .804, N = 45 , p = .000)
SVI (7)	(rho = .860, N = 45 , p = .000)*	(rho = .834, N = 45 , p = .000)
SVI (10)	(rho = .916, N = 45 , p = .000)*	(rho = .784, N = 45 , p = .000)
SVI (11)	(rho = .829, N = 45 , p = .000)*	(rho = .794, N = 45 , p = .000)
SVI (22)	(rho = .911, N = 45 , p = .000)*	(rho = .845, N = 45 , p = .000)
Blind (8)	(rho = .790, N = 45 , p = .000)	(rho = .838, N = 45 , p = .000)*
Blind (9)	(rho = .904, N = 45 , p = .000)*	(rho = .820, N = 45 , p = .000)
Blind (12)	(rho = .940, N = 45 , p = .000)*	(rho = .891, N = 45 , p = .000)
Blind (18)	(rho = .803, N = 45 , p = .000)	(rho = .834, N = 45 , p = .000)*
Blind (20)	(rho = .823, N = 45 , p = .000)*	(rho = .823, N = 45 , p = .000)*
Blind (21)	(rho = .829, N = 45 , p = .000)	(rho = .865, N = 45 , p = .000)*
Blind (24)	(rho = .817, N = 45 , p = .000)	(rho = .834, N = 45 , p = .000)*

Appendix A 3

Characteristics of participants in the maze experiment

Subject	Age	Sex	Group	Visual acuity	Visual field	Near vision	Colour vision	Visual condition	Age of onset	Additional condition	Mobility (years)	Intelligence
1	22	M	MVI	R 1/3 L 1/6 Both 1/3	Restricted central and peripheral	N24	-	Ocular Toxoplasmosis (macular scarring) Short sighted, sensitive to bright lights and sunlight	Birth (before 3)	None	7	FSA 24/45
2	21	F	SVI	R1/15 L 1/20 Both 1/10	Constricted all round both eyes	N18	Normal w/ Ishihara test	RP, Myopia & Astigmatism	Birth	None	2	FSA 27/45
3	18	M	MVI	R 1/6 L 1/60 Both 1/6	Restricted: 40 degrees all around	N 18	Failed Ishihara. Can recognise gross colours (red, blue, green, yellow)	Unknown	Birth	Left side weakness (left hand) and limp	2	Lit. 51/72 Num. 25/50
4	19	M	Blind	LP	-	-	-	Retinopathy of prematurity	Birth	Epilepsy diabetes	13	Lit. 31/72 Num. 43/50
5	19	M	Blind	NLP	-	-	-	Microphthalmos (uses bilateral false eyes)	Birth	None	7	Lit. 54/72 Num. 30/50
6	18	F	Blind	NLP	-	-	-	Retinopathy of prematurity (LP)	Birth	None	5	Lit. 61/72 Num. 38/50

Subject	Age	Sex	Group	Visual acuity	Visual field	Near vision	Colour vision	Visual condition	Age of onset	Additional condition	Mobility (years)	Intelligence
7	18	F	MVI	R 1/6 L 1/6 Both 1/6	Constricted all round both eyes	N18	Normal w/ Ishihara test	Retinitis pigmentosa	Birth	None	1	Lit. 66/72 Num. 38/50
8	18	M	SVI	RE 6/60 LE (hand movement) Both 6/60	Restricted all around / mainly left side	N48	Normal w/ Ishihara test	Stickler's syndrome: connective tissue in bones, joints, heart and ears affected. Suffered retinal detachment but corrected after surgery in 2003	Birth	None	7	Lit. 45/72 Num. 23/50
9	20	M	MVI	RE 6/9 LE 6/9 Both 6/9	Restricted all around but mainly on top	N5	Normal w/ Ishihara test	Diagnosed with Retinitis Pigmentosa	Birth	Congenital Adrenal Hypoplasia:	1	Lit. 66/72 Num 45/50
10	18	M	SVI	R 1/60 L no vision	Restricted all around	N24	Failed Ishihara. Can recognize gross colours and pastel shades	Pete's anomaly (never proven) Micropthalmic eye Glaucoma	Birth	None	12	Lit. 72/72 Num. 42/50
11	19	M	Blind	LP	-	-	-	Leber's optic neuropathy (first blurry now no vision)	17	None	1	Lit. 56/72 Num. 46/50

Subject	Age	Sex	Group	Visual acuity	Visual field	Near vision	Colour vision	Visual condition	Age of onset	Additional condition	Mobility (years)	Intelligence
12	19	M	MVI	R 1/ 60 L 1/6 Both 1/6	Right eye somewhat constricted. Vision blurred in periphery	?	Failed Ishihara. Can recognise gross colours (red, blue, green, yellow)	Brain tumour. No vision on L eye & partial on R eye. Vision started to improve after operation	16	Aspergers (very mild) Tuberous sclerosis	1	Lit. 58/72 Num. 46/50
13	18	M	SVI	R 1/60 L 1/60 Both 1/60	Normal	-	Failed Ishihara	Congenital retinal dystrophy, nystagmus and photophobia	Birth	None	1	Lit. 59/72 Num. 33/50
14	20	M	MVI	R 1/3 L 1/2 Both 1/2	Constricted field	N14	Able to detect all colours	Not assigned	Birth	Epilepsy	6	FSA 20/45
15	18	M	SVI	R 1/60 L (LP) Both 1/60	Constricted field	N 60	Failed Ishihara	Congenital glaucoma	Birth	None	12	Lit. 43/72 Num. 43/ 50
16	18	M	MVI	R 3/60 L 6/60 Both 6/36	Restricted only above	N10	Normal	Unknown	Birth	None	4	Lit. 39/72 Num. 40/50
17	19	F	MVI	R 1/3 L 1/4 Both 1/3	-	N10	-	Congenital cataracts	Birth	Nome	4	FSA 32/50
18	25	M	SVI	R 4/40 L 4/60 Both 6/60	Constricted all around. Upper field restricted to midline	N19	Failed Ishihara (identified gross colours)	Rod / Cone Dystrophy. Severe problems in low light	Birth	None	1	-

Subject	Age	Sex	Group	Visual acuity	Visual field	Near vision	Colour vision	Visual condition	Age of onset	Additional condition	Mobility (years)	Intelligence
19	18	M	MVI	R 1/6 L 2/3 Both 2/33	Field very restricted	N5	15/17 on Ishihara Identified most colours & shades	Retinitis pigmentosa very weak night vision	Birth	Muscle Hypotonia (decreased muscle tone)	3	Lit. 49/52 Num. 14/50
20	19	F	MVI	R 1/3 L 1/6 Both 1/3	Upper field constricted	-	Passed Ishihara	Bilateral congenital cataracts, nystagmus on both eyes. Operation when 11 years old not very successful: Problems focusing with left eye	Birth	None	3	FSA 30/50
21	24	M	SVI	R 1/30 L 1/30 Both 1/30	Highly constricted (5°)	N24	Failed Ishihara	Retinitis pigmentosa	Birth	Lawrence Moon Biedl Syndrome	8	Lit. 66/72 Num. 42/50
22	17	M	MVI	R 6/36 L 6/18 Both 6/18	Normal	N5	Normal	Horizontal nystagmus, right convergent squint	Birth	Possible Aspergers, weakness on right side	1	Lit. 61/72 Num. 40/50
23	19	M	SVI	R 1/10	?	?	Problems w/ some colours	Microphthalmos, cataracts, nystagmus	Birth	None (suspect learning difficulty)	7	FSA 26/45

Subject	Age	Sex	Group	Visual acuity	Visual field	Near vision	Colour vision	Visual condition	Age of onset	Additional condition	Mobility (years)	Intelligence
24	17	M	Blind	R NLP L LP	-	-	-	Retinopathy of prematurity	Birth	Some problems with gait and balance makes him prone to falling	10	Lit. 55/72 Num. 20/50
25	22	M	Blind	NLP	-	-	-	Anophthalmia	Birth	None	11	Lit. 67/72 Num. 42/50
27	22	M	MVI	R 1/6 L 1/60 both 1/6	Highly constricted (severe tunnel vision)	N 24	Problems differentiating colours	Retinitis pigmentosa (deteriorating rapidly)	Birth	Lawrence Moon Biedl Syndrome	1	FSA 13/45

Appendix A 4

Rank order correlations for estimated distances in maze

Group (subject #)	Euclidean	Functional
Sighted (26)	(rho = .890, N = 15 , p < .000)*	(rho = .886, N = 15 , p < .000)
Sighted (28)	(rho = .924, N = 15 , p < .000)*	(rho = .755, N = 15 , p < .001)
Sighted (29)	(rho = .898, N = 15 , p < .000)	(rho = .923, N = 15 , p < .000)*
Sighted (30)	**(rho = .445, N = 15 , p = .097)**	**(rho = .324, N = 15 , p = .239)**
Sighted (31)	(rho = .797, N = 15 , p < .000)*	(rho = .766, N = 15 , p = .001)
Sighted (32)	(rho = .746, N = 15 , p = .001)*	(rho = .710, N = 15 , p = .003)
Sighted (33)	(rho = .942, N = 15 , p < .000)*	(rho = .897, N = 15 , p < .000)
MVI (1)	(rho = .876, N = 15 , p = .000)*	(rho = .829, N = 15 , p = .000)
MVI (3)	**(rho = .474, N = 15 , p = .074)**	**(rho = .200, N = 15 , p = .475)**
MVI (7)	(rho = .946, N = 15 , p < .000)*	(rho = .841, N = 15 , p < .000)
MVI (9)	(rho = .921, N = 15 , p < .000)*	(rho = .881, N = 15 , p < .000)
MVI (12)	(rho = .890, N = 15 , p < .000)*	(rho = .8564, N = 15 , p < .000)
MVI (14)	**(rho = .468, N = 15 , p = .078)**	**(rho = .461, N = 15 , p = .084)**
MVI (16)	(rho = .801, N = 15 , p < .000)	(rho = .819, N = 15 , p < .000)*
MVI (17)	(rho = .829, N = 15 , p < .000)	(rho = .857, N = 15 , p < .000)*
MVI (19)	(rho = .507, N = 15 , p = .054)	(rho = .604, N = 15 , p = .017)*
MVI (20)	(rho = .829, N = 15 , p < .000)*	(rho = .729, N = 15 , p < .002)
MVI (22)	(rho = .867, N = 15 , p < .000)*	(rho = .807, N = 15 , p < .000)
MVI (27)	**(rho = .090, N = 15 , p = .749)**	**(rho = .165, N = 15 , p = .558)**
SVI (2)	**(rho = .084, N = 15 , p = .767)**	**(rho = .225, N = 15 , p = .419)**
SVI (8)	**(rho = -.083, N = 15 , p = .769)**	**(rho = -.311, N = 15 , p = .259)**
SVI (10)	(rho = .636, N = 15 , p = .011)*	(rho = .541, N = 15 , p = .037)
SVI (13)	(rho = .791, N = 15 , p < .000)	(rho = .864, N = 15 , p < .000)*
SVI (15)	(rho = .707, N = 15 , p = .003)*	(rho = .620, N = 15 , p = .014)
SVI (18)	(rho = .897, N = 15 , p < .000)*	(rho = .840, N = 15 , p < .000)*
SVI (21)	**(rho = .405, N = 15 , p = .134)**	**(rho = .478, N = 15 , p = .071)**
SVI (23)	(rho = .618, N = 15 , p = .014)	(rho = .680, N = 15 , p = .005)*
Blind (4)	**(rho = .209, N = 15 , p = .455)**	**(rho = .169, N = 15 , p = .548)**
Blind (5)	**(rho = .092, N = 15 , p = .744)**	**(rho = .102, N = 15 , p = .717)**
Blind (6)	**(rho = .130, N = 15 , p = .644)**	**(rho = .187, N = 15 , p = .505)**
Blind (11)	(rho = .862, N = 15 , p < .000)*	(rho = .813, N = 15 , p < .000)
Blind (24)	**(rho = .308, N = 15 , p = .264)**	**(rho = 223, N = 15 , p = .425)**
Blind (25)	(rho = .423, N = 15 , p = .117)	(rho = .573, N = 15 , p = .026)*

***Red marking – not significant in relation either Euclidean or functional baselines**

Appendix B
Subject ranking and tracking

The first part of this appendix presents the ranking transformations for all subjects based on the scores for the three tasks. Ranking is presented alongside the score for each task and an overall ranking score is given based on the sum of performance in the three tasks. The second part of the appendix presents the ArcMap files containing the tracking information for all subjects when exploring the maze (experiment II). Exploration is divided into 7 tracks (i.e., if the subject explored the maze for a total of 21 minutes then each section in the tracking page is equivalent to a three minute block). The red line indicates the current movement while the green line indicate previous and future movement. The last cell in the table includes additional information on the subject (subject number, eye condition, group, task performance, rank for the three tasks, exploration time, length of exploration, table hits and strategies used).

Appendix B 1

Subject ranking all groups

Subject	Group	Angle error (°)	Rank	Performance	Euclidean error	Rank	Performance	Model error (DI)	Rank	Performance	Overall rank	Overall performance
1	MVI	11.13	8	top 50%	0.93	4	top 50%	17.8825	18	bottom 50%	10	top 50%
2	SVI	13.30	11	top 50%	2.93	17	bottom 50%	36.1535	25	bottom 50%	16	bottom 50%
3	MVI	27.53	23	bottom 50%	1.87	10	bottom 50%	16.174	13	top 50%	14	bottom 50%
4	Blind	65.07	32	bottom 50%	2.27	13	bottom 50%	74.4963	30	bottom 50%	22	bottom 50%
5	Blind	49.47	26	bottom 50%	2.80	16	bottom 50%	20.5912	21	bottom 50%	18	bottom 50%
6	Blind	52.33	27	bottom 50%	2.40	14	bottom 50%	59.4119	28	bottom 50%	20	bottom 50%
7	MVI	8.87	4	top 50%	0.67	2	top 50%	13.7215	10	top 50%	3	top 50%
8	SVI	58.20	29	bottom 50%	2.80	16	bottom 50%	99.6619	33	bottom 50%	23	bottom 50%
9	MVI	16.63	16	bottom 50%	0.53	1	top 50%	11.3342	8	top 50%	6	top 50%
10	SVI	23.90	22	bottom 50%	1.73	9	bottom 50%	34.0222	24	bottom 50%	17	bottom 50%
11	Blind	19.90	20	bottom 50%	1.07	5	top 50%	17.9024	19	bottom 50%	13	bottom 50%
12	MVI	14.77	13	top 50%	0.80	3	top 50%	19.4197	20	bottom 50%	11	top 50%
13	SVI	9.03	5	top 50%	1.47	7	top 50%	16.3481	14	top 50%	7	top 50%
14	MVI	16.13	15	top 50%	1.87	10	bottom 50%	49.1631	26	bottom 50%	15	bottom 50%
15	SVI	17.50	18	bottom 50%	1.60	8	bottom 50%	9.2996	4	top 50%	10	top 50%
16	MVI	14.27	12	top 50%	1.20	6	top 50%	11.6468	9	top 50%	8	top 50%
17	MVI	5.70	1	top 50%	1.07	5	top 50%	10.0946	6	top 50%	2	top 50%
18	SVI	17.77	19	bottom 50%	0.80	3	top 50%	9.3761	5	top 50%	8	top 50%
19	MVI	20.53	21	bottom 50%	1.87	10	bottom 50%	21.3917	22	bottom 50%	16	bottom 50%
20	MVI	11.17	9	top 50%	1.20	6	top 50%	13.7801	11	top 50%	7	top 50%
21	SVI	40.70	25	bottom 50%	2.00	11	bottom 50%	54.4972	27	bottom 50%	18	bottom 50%
22	MVI	11.47	10	top 50%	0.80	3	top 50%	17.3141	16	top 50%	9	top 50%
23	SVI	29.90	24	bottom 50%	1.87	10	bottom 50%	65.1763	29	bottom 50%	18	bottom 50%
24	Blind	64.23	31	bottom 50%	2.53	15	bottom 50%	78.557	32	bottom 50%	23	bottom 50%
25	Blind	62.93	30	bottom 50%	2.13	12	bottom 50%	27.1077	23	bottom 50%	19	bottom 50%
26	Sighted	8.70	3	top 50%	0.80	3	top 50%	8.7485	2	top 50%	1	top 50%
27	MVI	55.37	28	bottom 50%	2.40	14	bottom 50%	76.2439	31	bottom 50%	21	bottom 50%

Subject	Group	Angle error (°)	Rank	Performance	Euclidean error	Rank	Performance	Model error (DI)	Rank	Performance	Overall rank	Overall performance
28	Sighted	14.80	14	top 50%	0.67	2	top 50%	8.6452	1	top 50%	4	top 50%
29	Sighted	.	.	.	0.93	4	top 50%	16.573	15	top 50%	.	.
30	Sighted	17.27	17	bottom 50%	2.40	14	bottom 50%	10.4707	7	top 50%	12	bottom 50%
31	Sighted	9.20	6	top 50%	0.93	4	top 50%	15.9755	12	top 50%	5	top 50%
32	Sighted	7.60	2	top 50%	1.47	7	top 50%	9.2552	3	top 50%	2	top 50%
33	Sighted	9.30	7	top 50%	0.67	2	top 50%	17.4197	17	bottom 50%	7	top 50%

Appendix B 2

Subject ranking (MVI, SVI & blind)

Subject	Group	Angle error (°)	Rank	Performance	Euclidean error	Rank	Performance	Model error (DI)	Rank	Performance	Overall rank	Overall performance
1	MVI	11.13	4	top 50%	0.93	4	top 50%	17.88	11	top 50%	5	top 50%
2	SVI	13.30	7	top 50%	2.93	17	bottom 50%	36.15	18	bottom 50%	12	bottom 50%
3	MVI	27.53	17	bottom 50%	1.87	10	bottom 50%	16.17	8	top 50%	9	top 50%
4	Blind	65.07	26	bottom 50%	2.27	13	bottom 50%	74.50	23	bottom 50%	17	bottom 50%
5	Blind	49.47	20	bottom 50%	2.80	16	bottom 50%	20.59	14	bottom 50%	13	bottom 50%
6	Blind	52.33	21	bottom 50%	2.40	14	bottom 50%	59.41	21	bottom 50%	15	bottom 50%
7	MVI	8.87	2	top 50%	0.67	2	top 50%	13.72	6	top 50%	2	top 50%
8	SVI	58.20	23	bottom 50%	2.80	16	bottom 50%	99.66	26	bottom 50%	18	bottom 50%
9	MVI	16.63	11	top 50%	0.53	1	top 50%	11.33	4	top 50%	3	top 50%
10	SVI	23.90	16	bottom 50%	1.73	9	bottom 50%	34.02	17	bottom 50%	12	bottom 50%
11	Blind	19.90	14	bottom 50%	1.07	5	top 50%	17.90	12	top 50%	8	top 50%
12	MVI	14.77	9	top 50%	0.80	3	top 50%	19.42	13	top 50%	7	top 50%
13	SVI	9.03	3	top 50%	1.47	7	top 50%	16.35	9	top 50%	5	top 50%
14	MVI	16.13	10	top 50%	1.87	10	bottom 50%	49.16	19	bottom 50%	10	bottom 50%
15	SVI	17.50	12	top 50%	1.60	8	bottom 50%	9.30	1	top 50%	6	top 50%
16	MVI	14.27	8	top 50%	1.20	6	top 50%	11.65	5	top 50%	5	top 50%
17	MVI	5.70	1	top 50%	1.07	5	top 50%	10.09	3	top 50%	1	top 50%
18	SVI	17.77	13	bottom 50%	0.80	3	top 50%	9.38	2	top 50%	4	top 50%

Subject	Group	Angle error (°)	Rank	Performance	Euclidean error	Rank	Performance	Model error (DI)	Rank	Performance	Overall rank	Overall performance
19	MVI	20.53	15	bottom 50%	1.87	10	bottom 50%	21.39	15	bottom 50%	11	bottom 50%
20	MVI	11.17	5	top 50%	1.20	6	top 50%	13.78	7	top 50%	4	top 50%
21	SVI	40.70	19	bottom 50%	2.00	11	bottom 50%	54.50	20	bottom 50%	13	bottom 50%
22	MVI	11.47	6	top 50%	0.80	3	top 50%	17.31	10	top 50%	5	top 50%
23	SVI	29.90	18	bottom 50%	1.87	10	bottom 50%	65.18	22	bottom 50%	13	bottom 50%
24	Blind	64.23	25	bottom 50%	2.53	15	bottom 50%	78.56	25	bottom 50%	18	bottom 50%
25	Blind	62.93	24	bottom 50%	2.13	12	bottom 50%	27.11	16	bottom 50%	14	bottom 50%
27	MVI	55.37	22	bottom 50%	2.40	14	bottom 50%	76.24	24	bottom 50%	16	bottom 50%

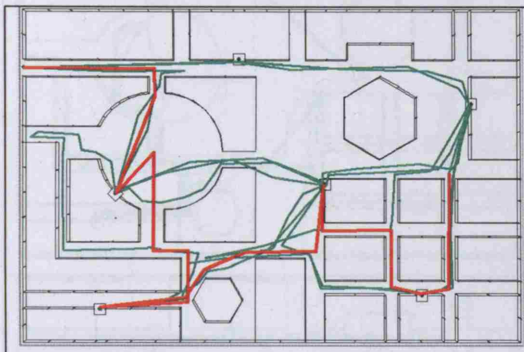
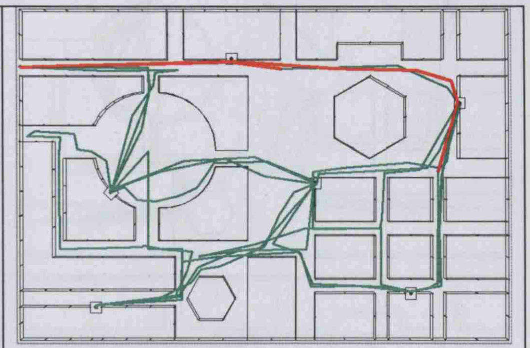
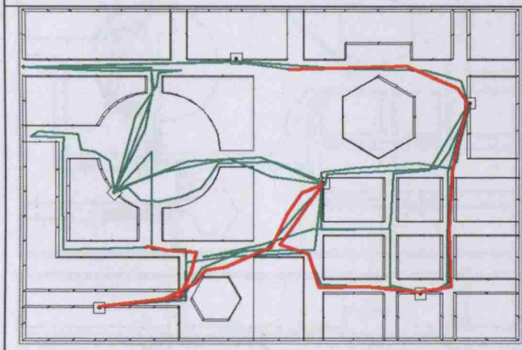
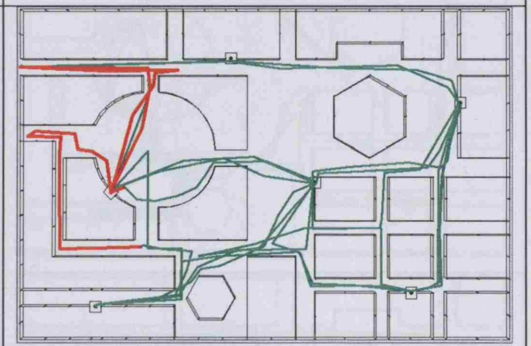
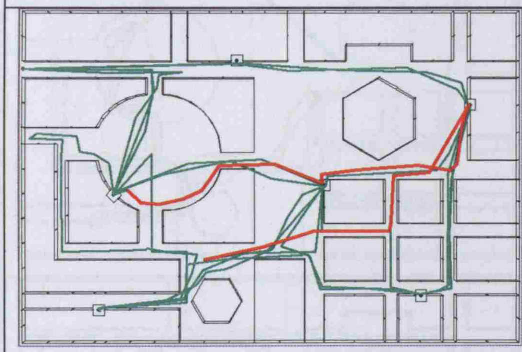
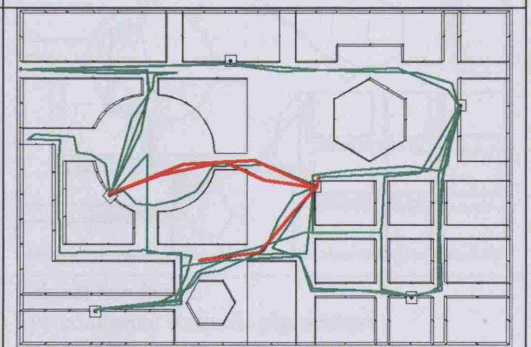
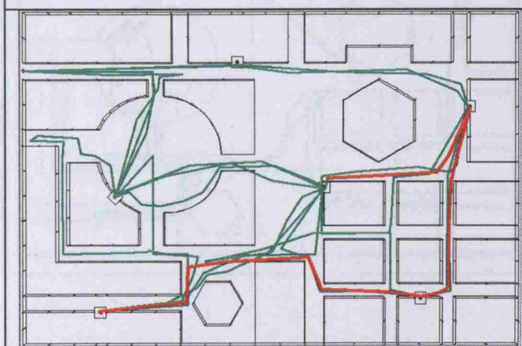
Appendix B 3

Subject ranking (SVI & blind)

Subject	Group	Angle error (°)	Rank	Performance	Euclidean error	Rank	Performance	Model error (DI)	Rank	Performance	Overall rank	Overall performance
2	SVI	13.30	2	top 50%	2.93	13	bottom 50%	36.15	8	bottom 50%	5	top 50%
4	Blind	65.07	14	bottom 50%	2.27	9	bottom 50%	74.50	12	bottom 50%	9	bottom 50%
5	Blind	49.47	9	bottom 50%	2.80	12	bottom 50%	20.59	5	top 50%	7	bottom 50%
6	Blind	52.33	10	bottom 50%	2.40	10	bottom 50%	59.41	10	bottom 50%	8	bottom 50%
8	SVI	58.20	11	bottom 50%	2.80	12	bottom 50%	99.66	14	bottom 50%	10	bottom 50%
10	SVI	23.90	6	top 50%	1.73	5	top 50%	34.02	7	top 50%	4	top 50%
11	Blind	19.90	5	top 50%	1.07	2	top 50%	17.90	4	top 50%	3	top 50%
13	SVI	9.03	1	top 50%	1.47	3	top 50%	16.35	3	top 50%	1	top 50%
15	SVI	17.50	3	top 50%	1.60	4	top 50%	9.30	1	top 50%	2	top 50%
18	SVI	17.77	4	top 50%	0.80	1	top 50%	9.38	2	top 50%	1	top 50%
21	SVI	40.70	8	bottom 50%	2.00	7	bottom 50%	54.50	9	bottom 50%	6	bottom 50%
23	SVI	29.90	7	top 50%	1.87	6	top 50%	65.18	11	bottom 50%	6	bottom 50%
24	Blind	64.23	13	bottom 50%	2.53	11	bottom 50%	78.56	13	bottom 50%	10	bottom 50%
25	Blind	62.93	12	bottom 50%	2.13	8	bottom 50%	27.11	6	top 50%	7	bottom 50%

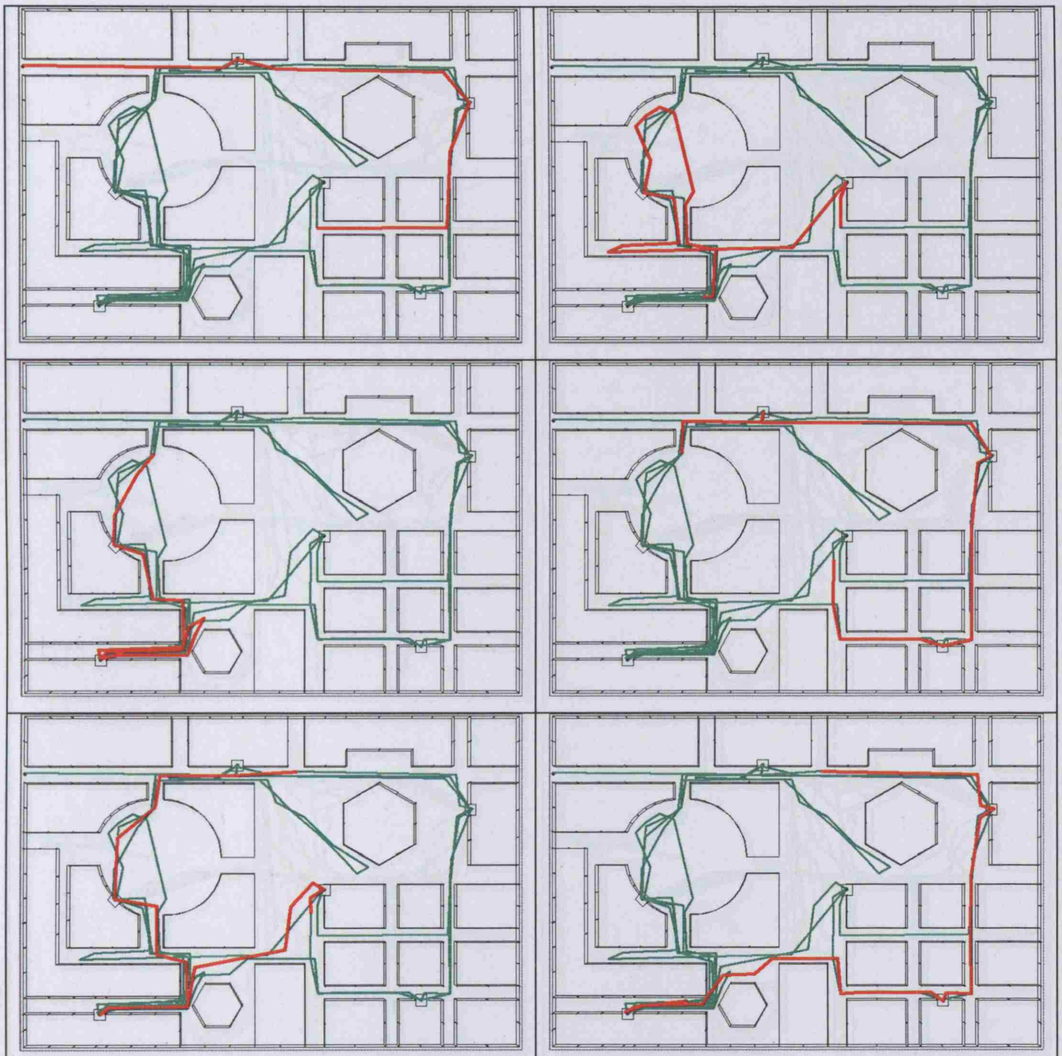
Subject tracks

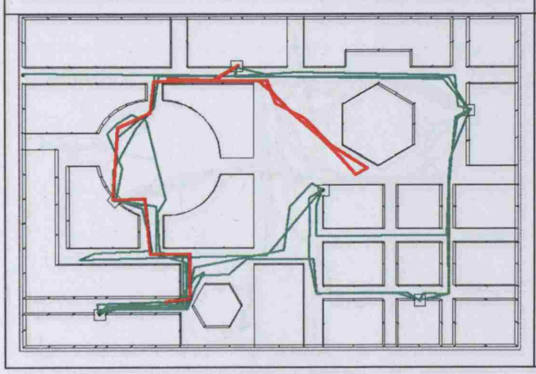
Subject 1

Subject number: 1
Eye condition: Ocular Toxoplasmosis
Group: MVI
Angle error (rank): 8/32
Distance error (rank): 4/17
Distortion index (rank): 18/33
Sum ranks: 10/23
Exploration time: 13:46 minutes
Length: 573.04 meters
Table hits: 22
Strategies: Perimeter, home to object, object-to-object and cyclic

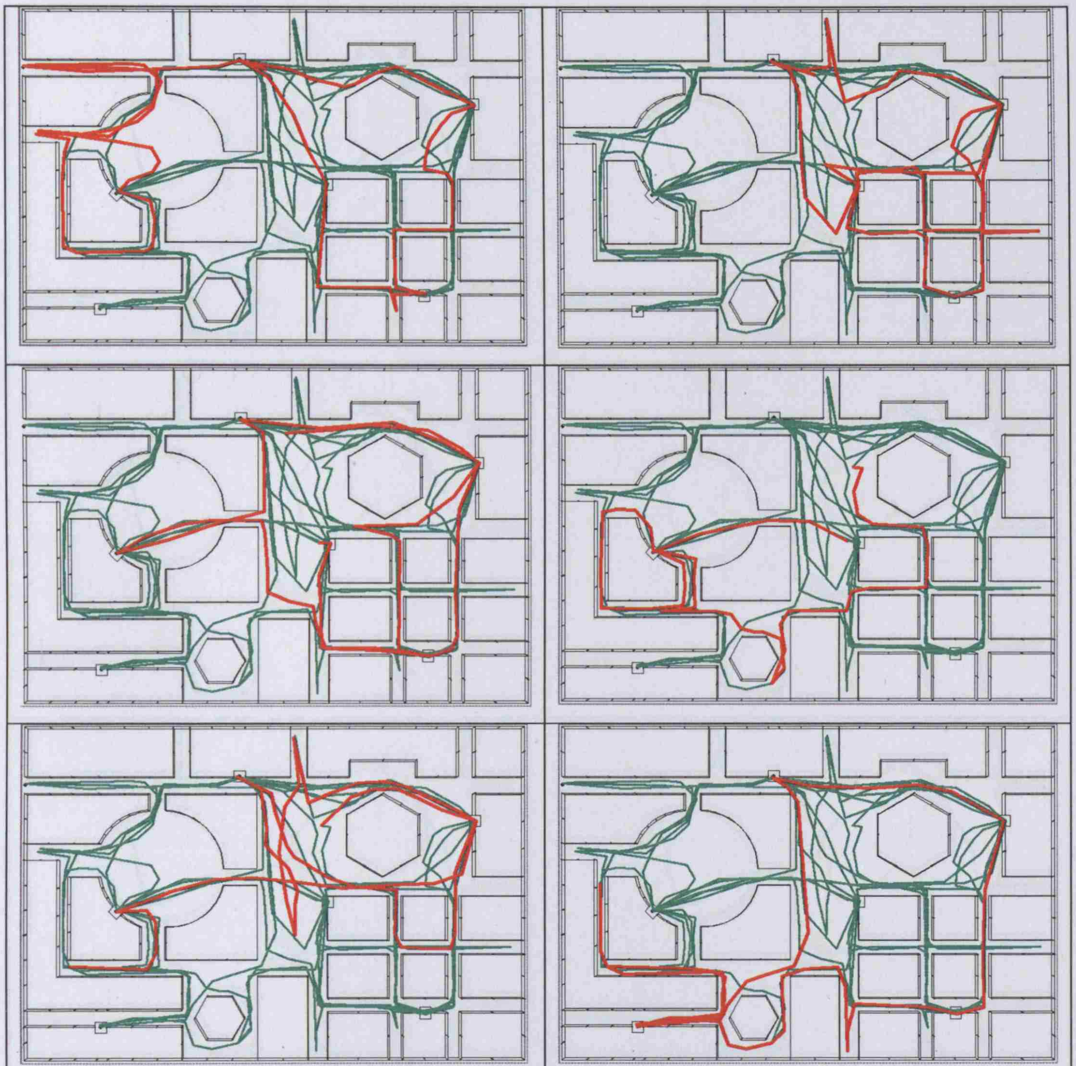
Subject 2

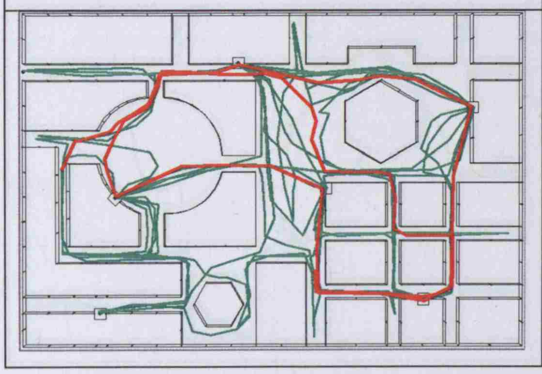




Subject number: 2
Eye condition: Retinitis pigmentosa
Group: SVI
Angle error (rank): 11/32
Distance error (rank): 17/17
Distortion index (rank): 25/33
Sum ranks: 16/23
Exploration time: 8:28 minutes
Length: 516.23 meters
Table hits: 19
Strategies: Object-to-object and cyclic

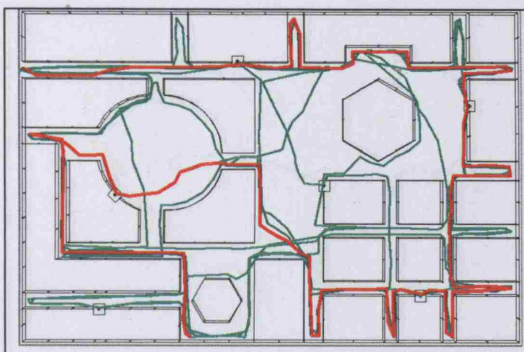
Subject 3

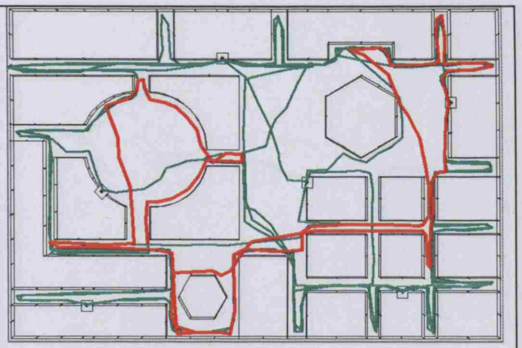


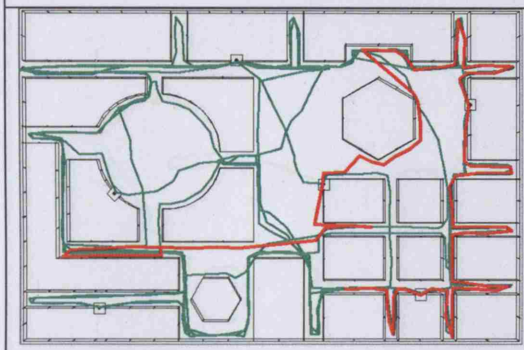


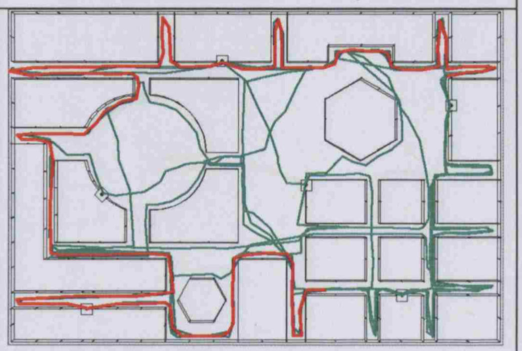
Subject number: 3
Eye condition: Unknown
Group: MVI
Angle error (rank): 23/32
Distance error (rank): 10/17
Distortion index (rank): 13/33
Sum ranks: 14/23
Exploration time: 30:00 minutes
Length: 1179.25 meters
Table hits: 37
Strategies: Grid, perimeter-to-centre, object-to-object and cyclic

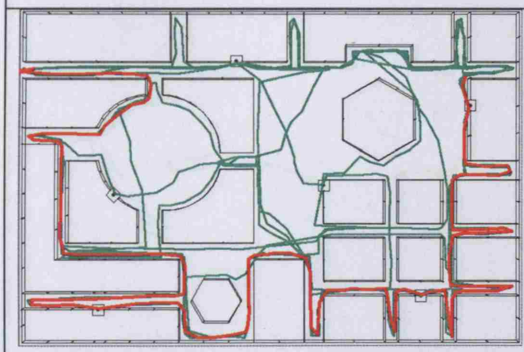
Subject 4

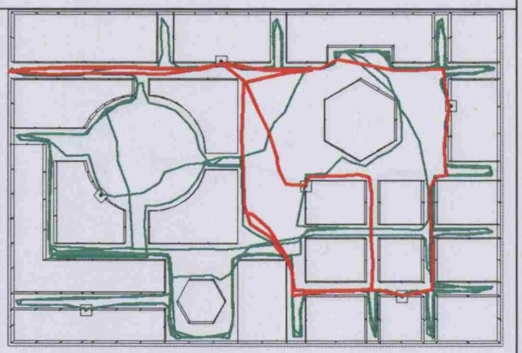


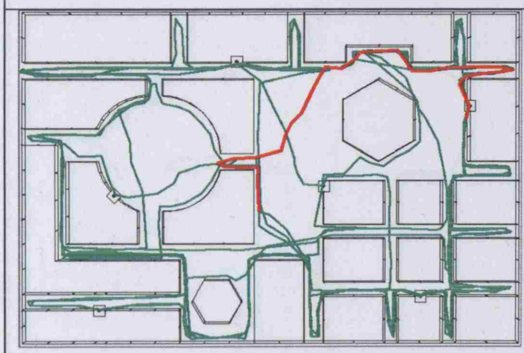






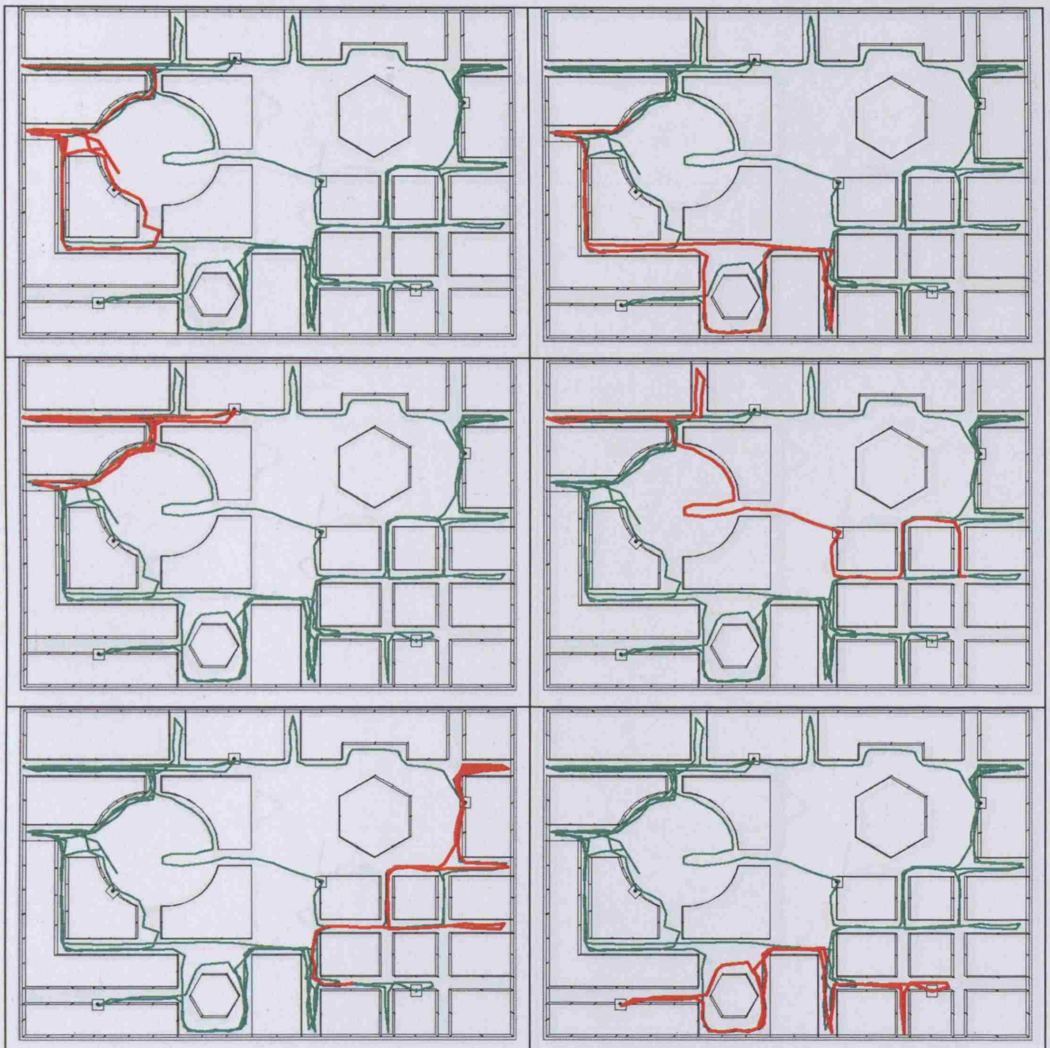


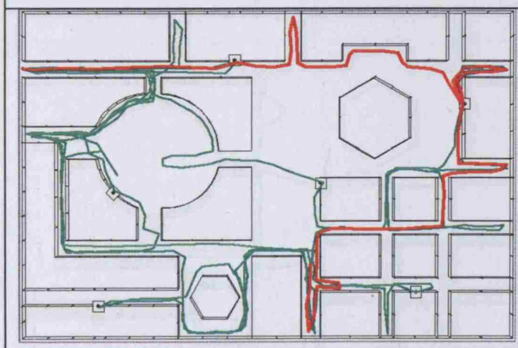




Subject number: 4
Eye condition: Retinopathy of prematurity
Group: Blind
Angle error (rank): 32/32
Distance error (rank): 13/17
Distortion index (rank): 30/33
Sum ranks: 22/23
Exploration time: 45:00 minutes
Length: 1225.58 meters
Table hits: 22
Strategies: Perimeter

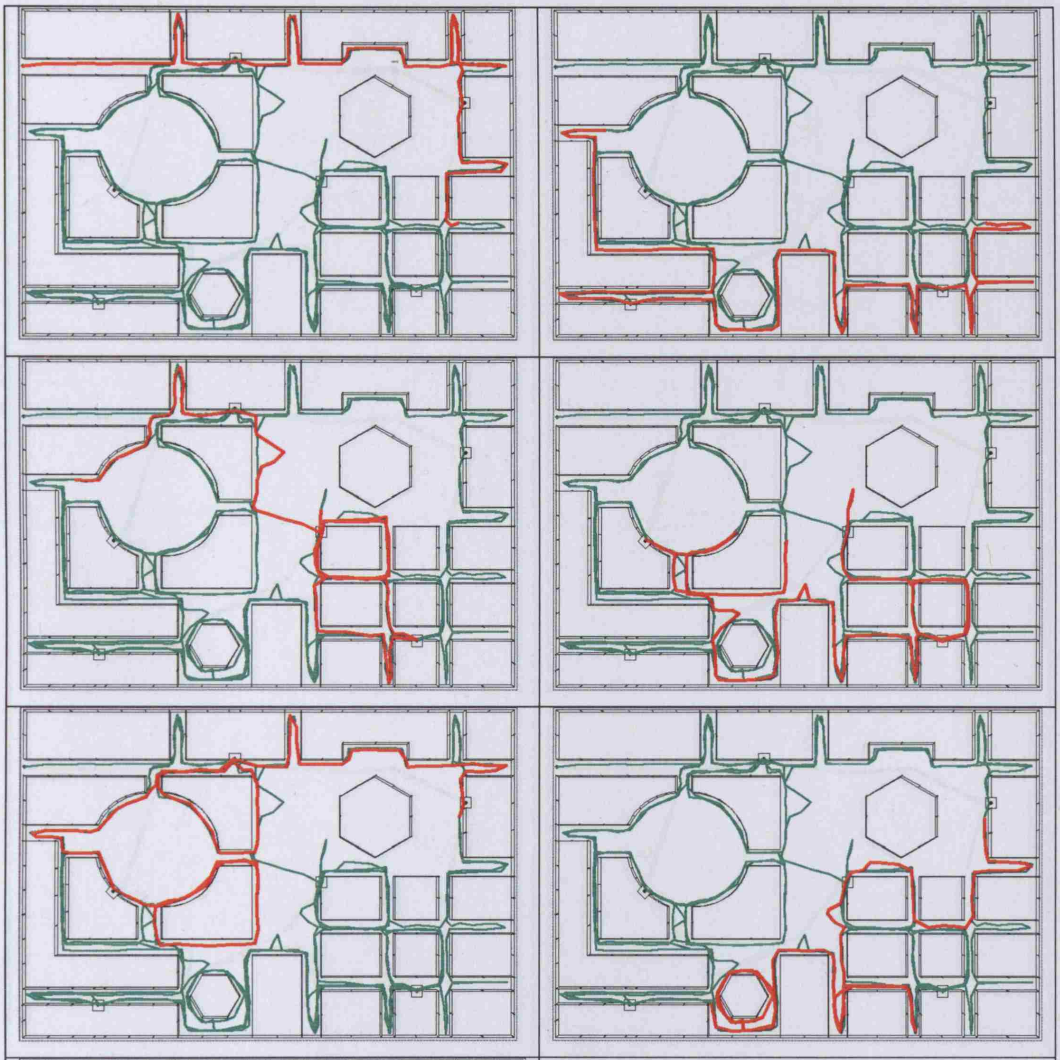
Subject 5

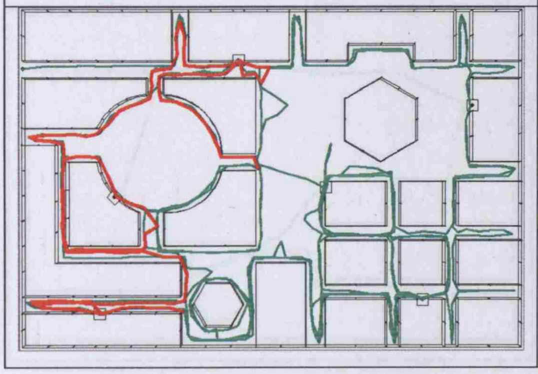




Subject number: 5
Eye condition: Microphthalmos
Group: Blind
Angle error (rank): 26/32
Distance error (rank): 16/17
Distortion index (rank): 21/33
Sum ranks: 18/23
Exploration time: 45:00 minutes
Length: 720.89 meters
Table hits: 15
Strategies: Perimeter-to-object, home-to-object

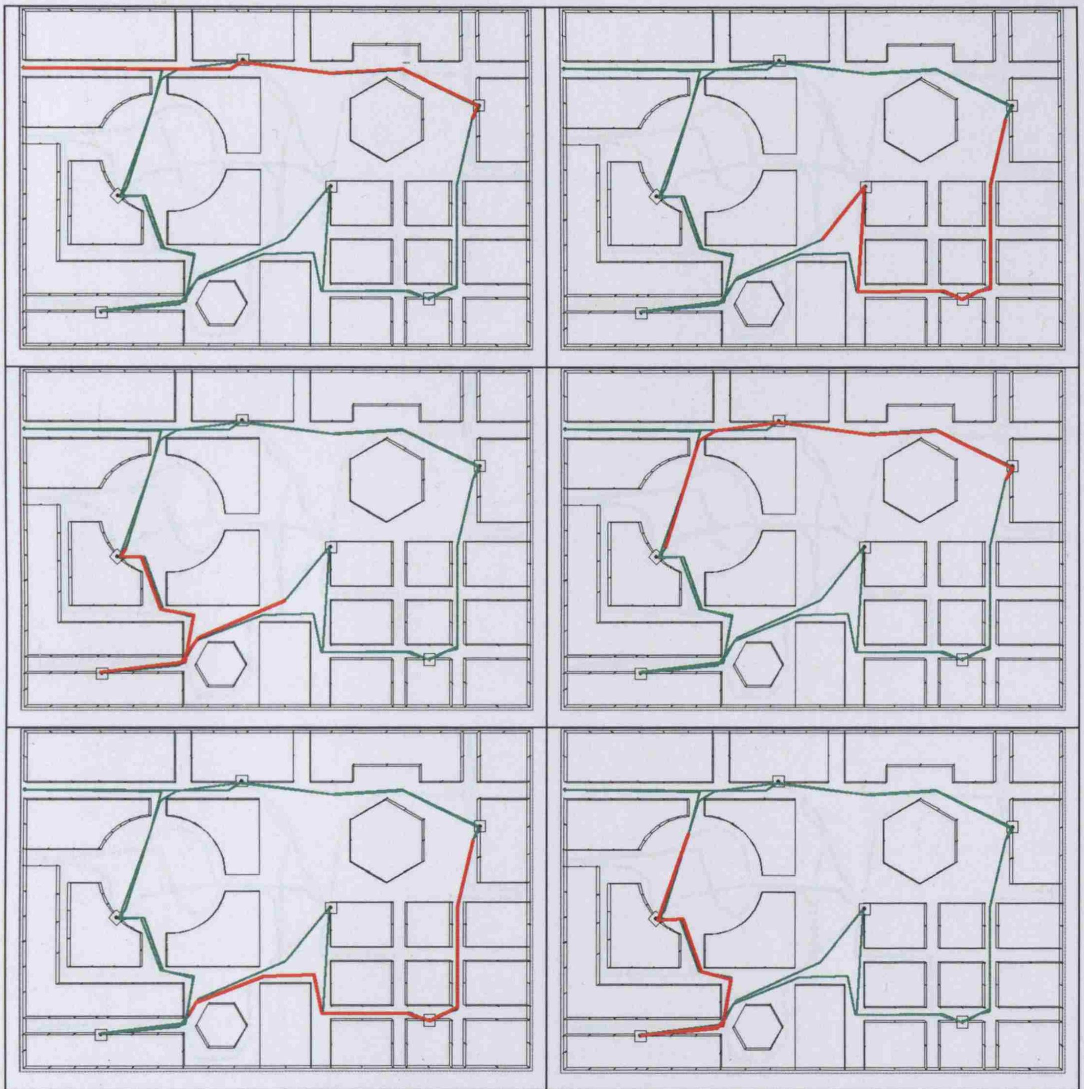
Subject 6

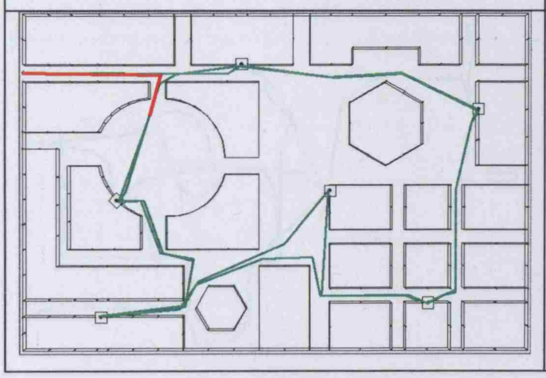




Subject number: 6
Eye condition: Retinopathy of prematurity
Group: Blind
Angle error (rank): 27/32
Distance error (rank): 14/17
Distortion index (rank): 28/33
Sum ranks: 20/23
Exploration time: 45:00 minutes
Length: 992.08 meters
Table hits: 23
Strategies: Perimeter and random

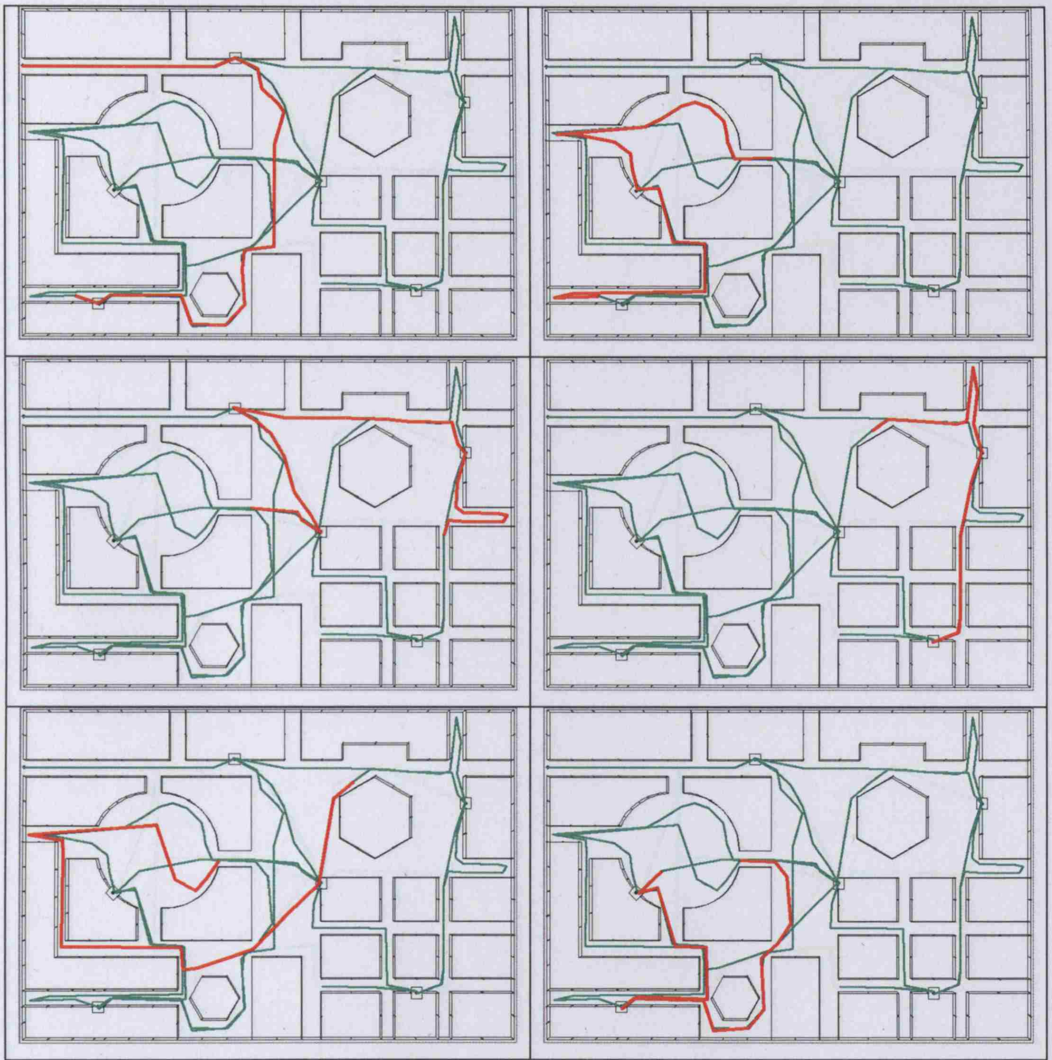
Subject 7

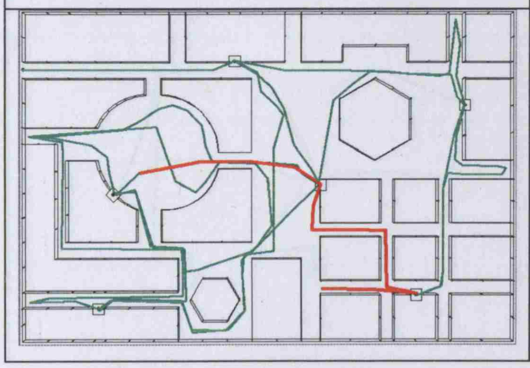




Subject number: 7
Eye condition: Retinitis pigmentosa
Group: MVI
Angle error (rank): 4/32
Distance error (rank): 2/17
Distortion index (rank): 10/33
Sum ranks: 3/23
Exploration time: 3:56 minutes
Length: 268.53 meters
Table hits: 12
Strategies: Cyclic

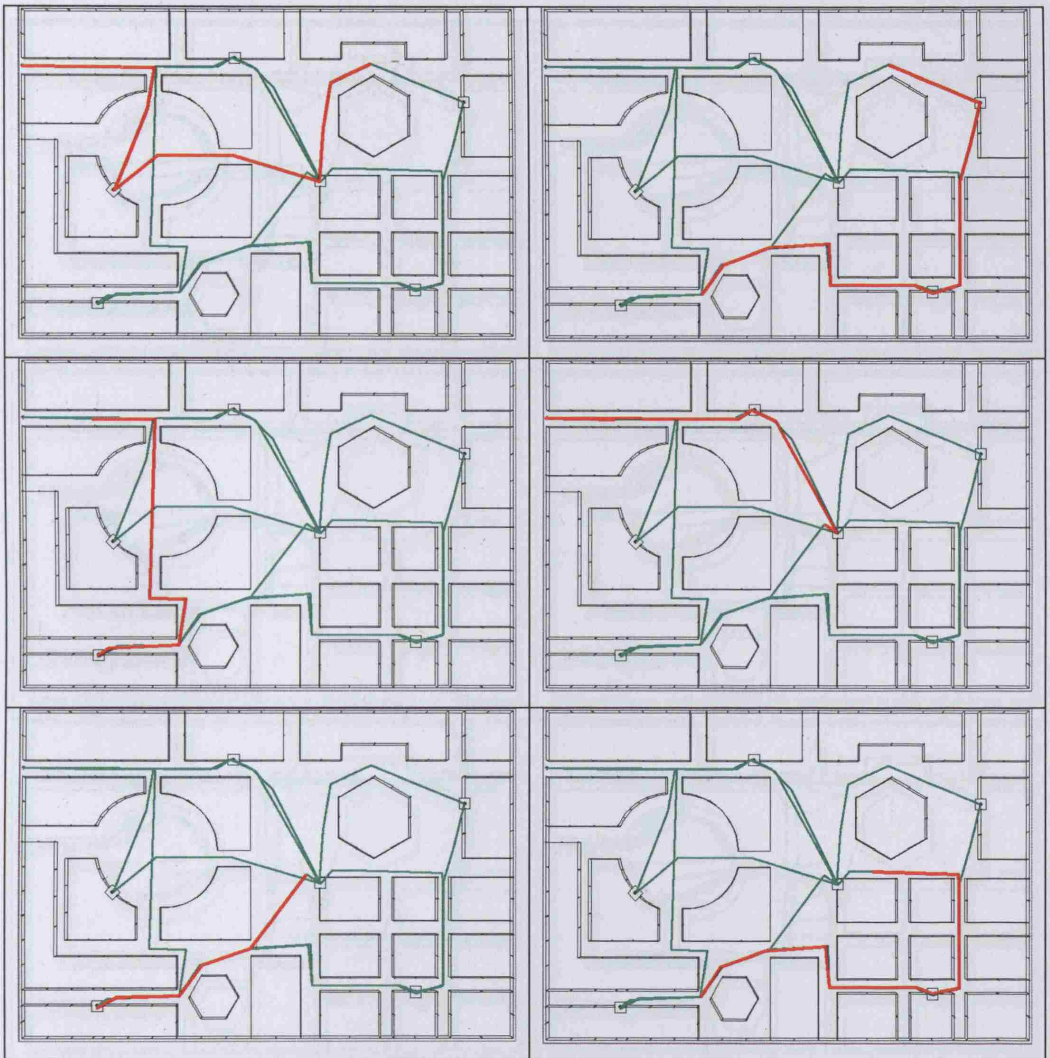
Subject 8

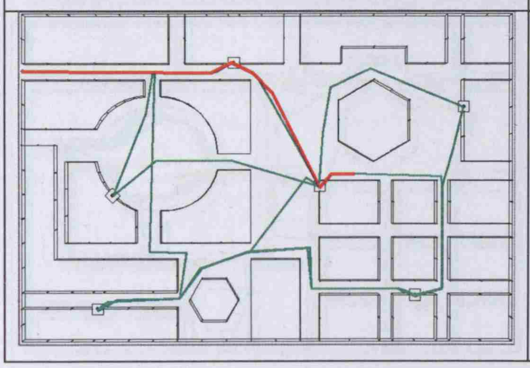




Subject number: 8
Eye condition: Stickler's syndrome
Group: SVI
Angle error (rank): 29/32
Distance error (rank): 16/17
Distortion index (rank): 33/33
Sum ranks: 23/23
Exploration time: 9:55 minutes
Length: 424.41 meters
Table hits: 13
Strategies: Random

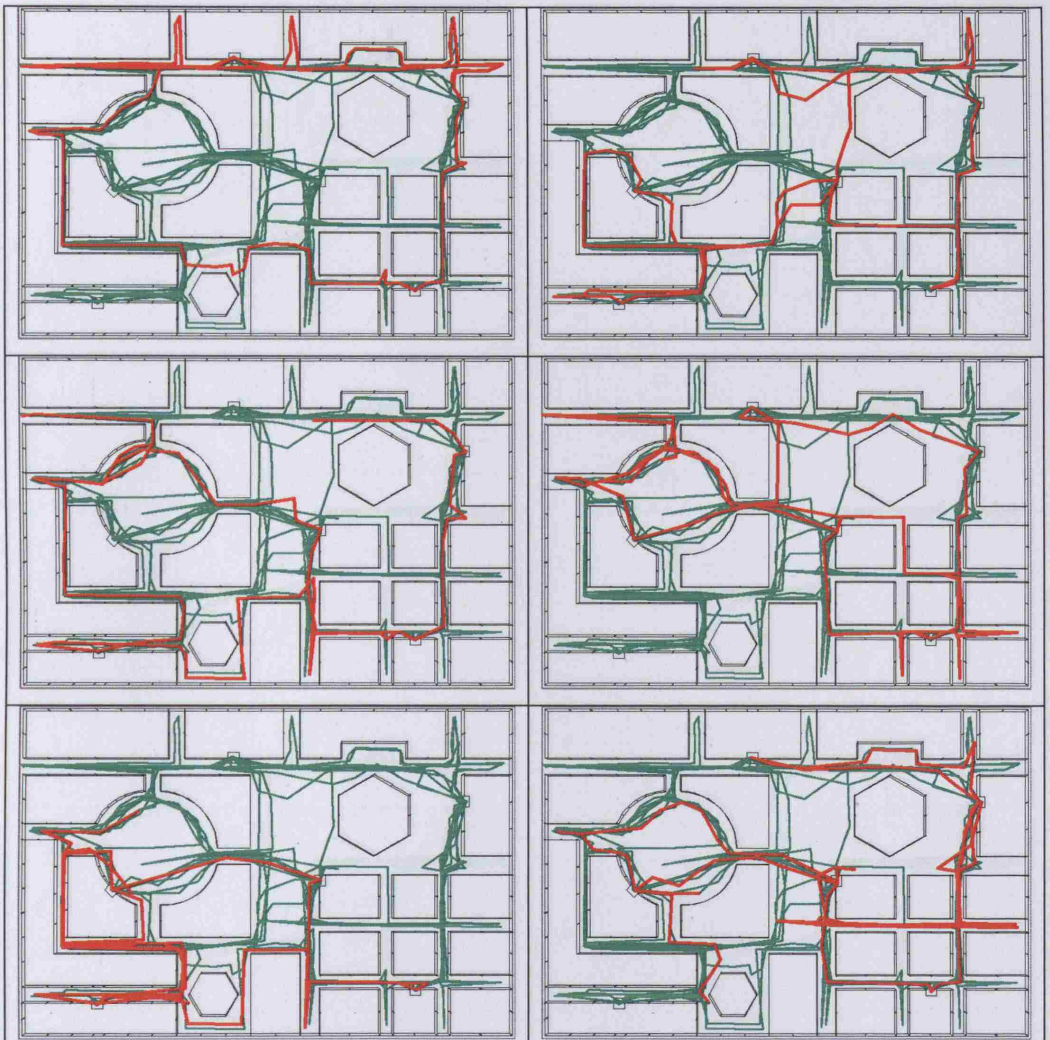
Subject 9

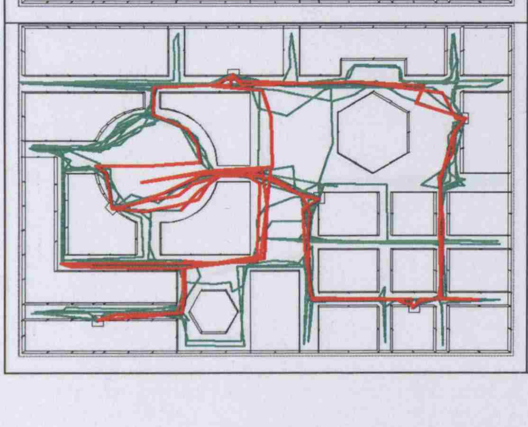




Subject number: 9
Eye condition: Retinitis pigmentosa
Group: MVI
Angle error (rank): 16/32
Distance error (rank): 1/17
Distortion index (rank): 8/33
Sum ranks: 6/23
Exploration time: 5:09 minutes
Length: 321.89 meters
Table hits: 13
Strategies: Home-to-object and cyclic

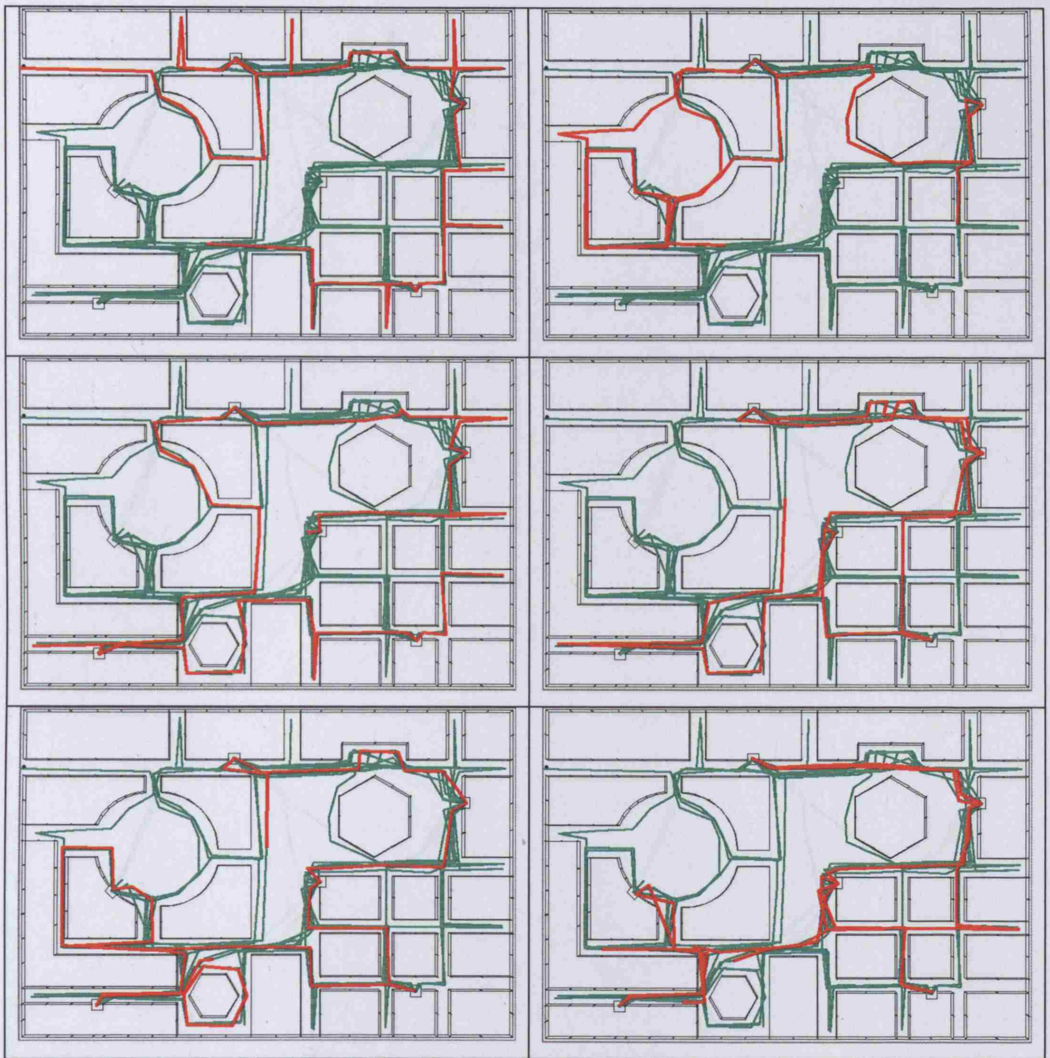
Subject 10

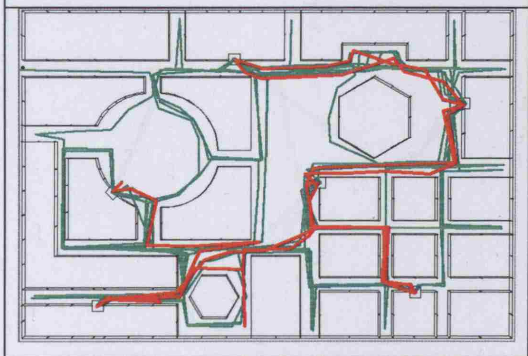




Subject number: 10
Eye condition: Micropthalmic eye, glaucoma
Group: SVI
Angle error (rank): 22/32
Distance error (rank): 9/17
Distortion index (rank): 24/33
Sum ranks: 17/23
Exploration time: 45:00 minutes
Length: 1965.07 meters
Table hits: 52
Strategies: Grid and random

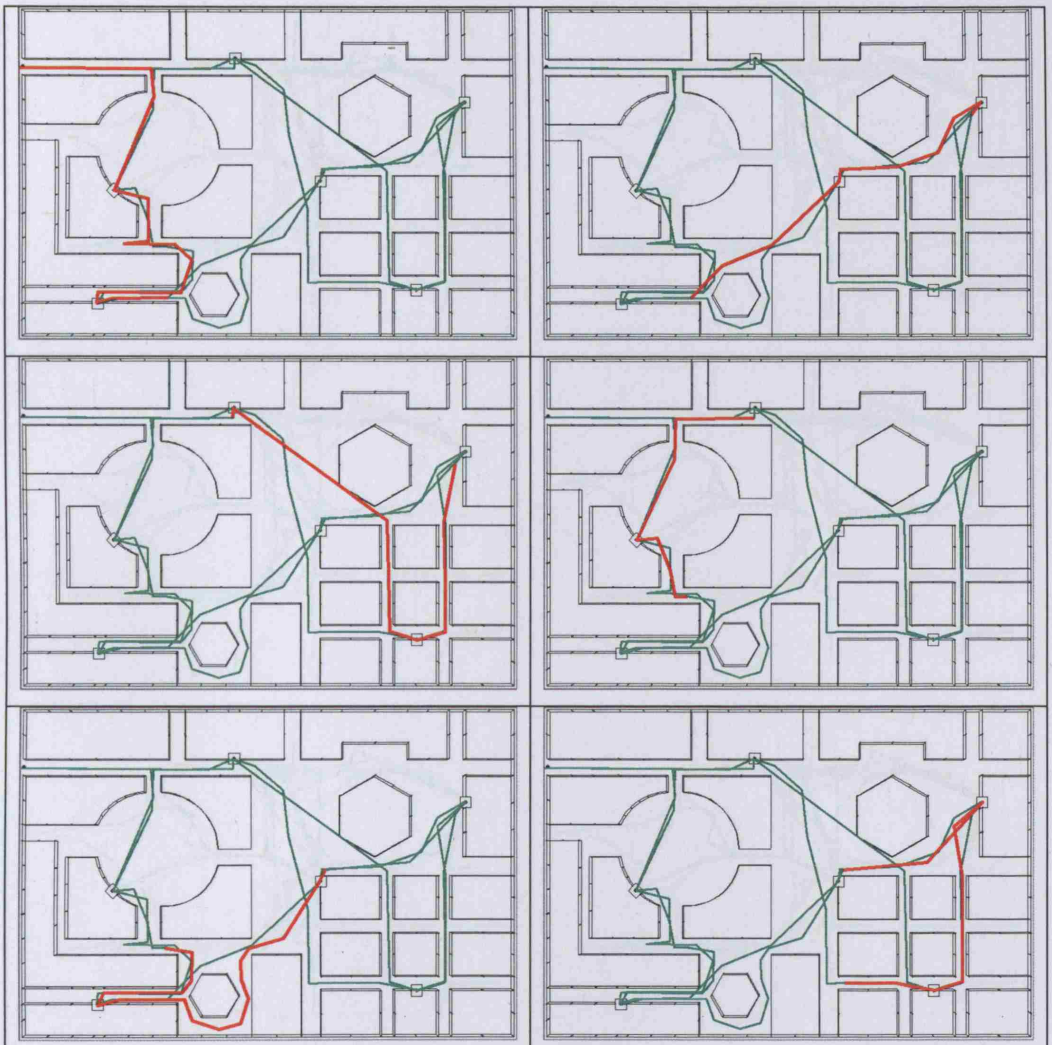
Subject 11

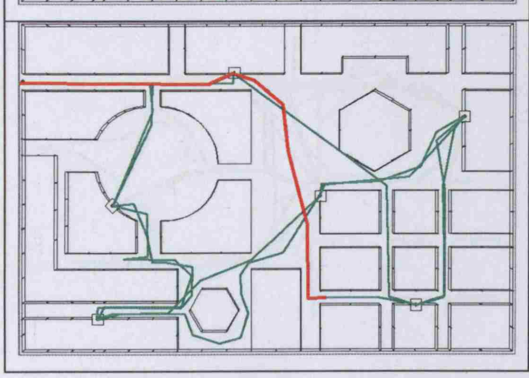




Subject number: 11
Eye condition: Lever's optic neuropathy
Group: Blind
Angle error (rank): 20/32
Distance error (rank): 5/17
Distortion index (rank): 19/33
Sum ranks: 13/23
Exploration time: 32:54 minutes
Length: 1470.56 meters
Table hits: 44
Strategies: Perimeter, perimeter-to-centre, perimeter-to-object, object-to-object and cyclic

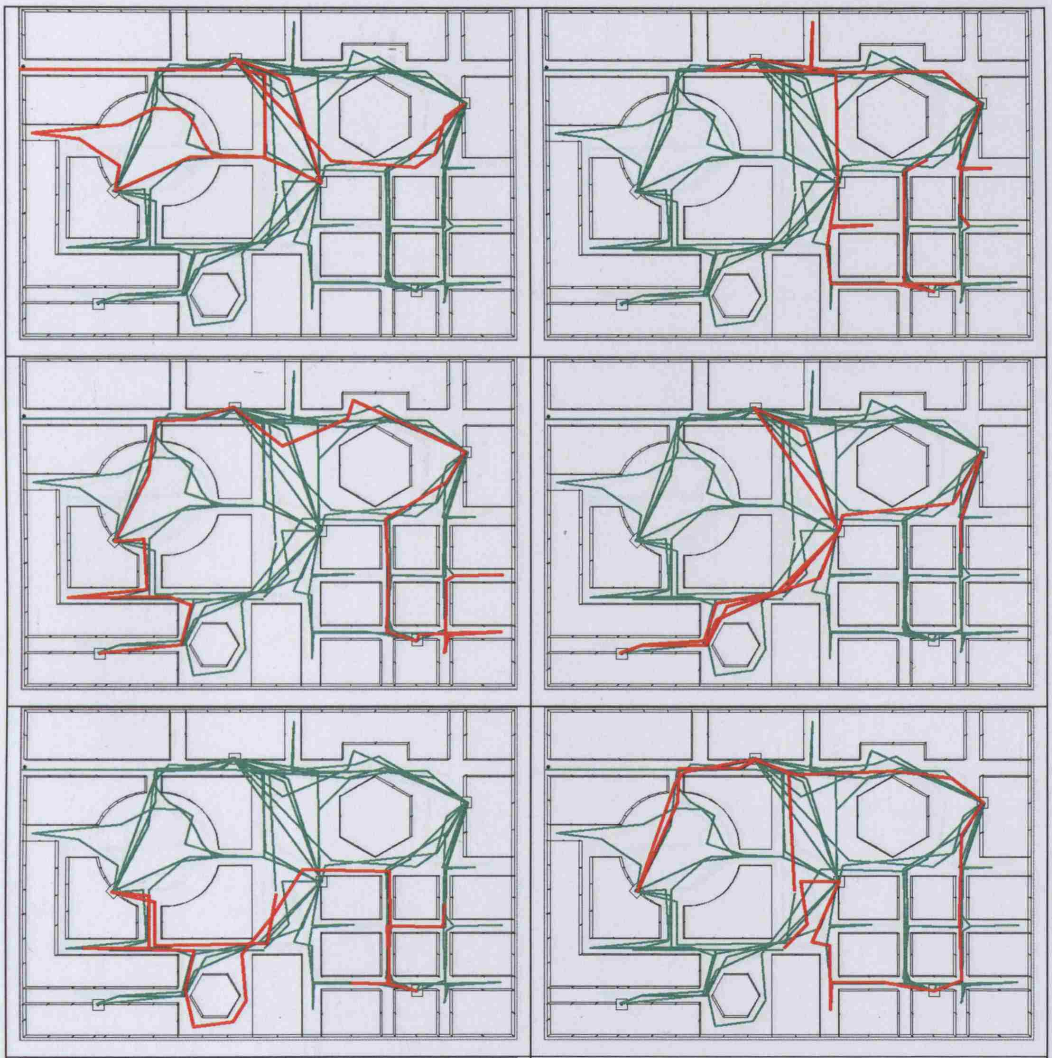
Subject 12

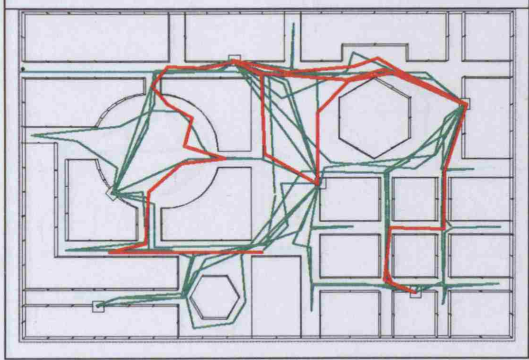




Subject number: 12
Eye condition: Related to brain tumour
Group: MVI
Angle error (rank): 13/32
Distance error (rank): 3/17
Distortion index (rank): 20/33
Sum ranks: 11/23
Exploration time: 5:47 minutes
Length: 312.18 meters
Table hits: 13
Strategies: Grid

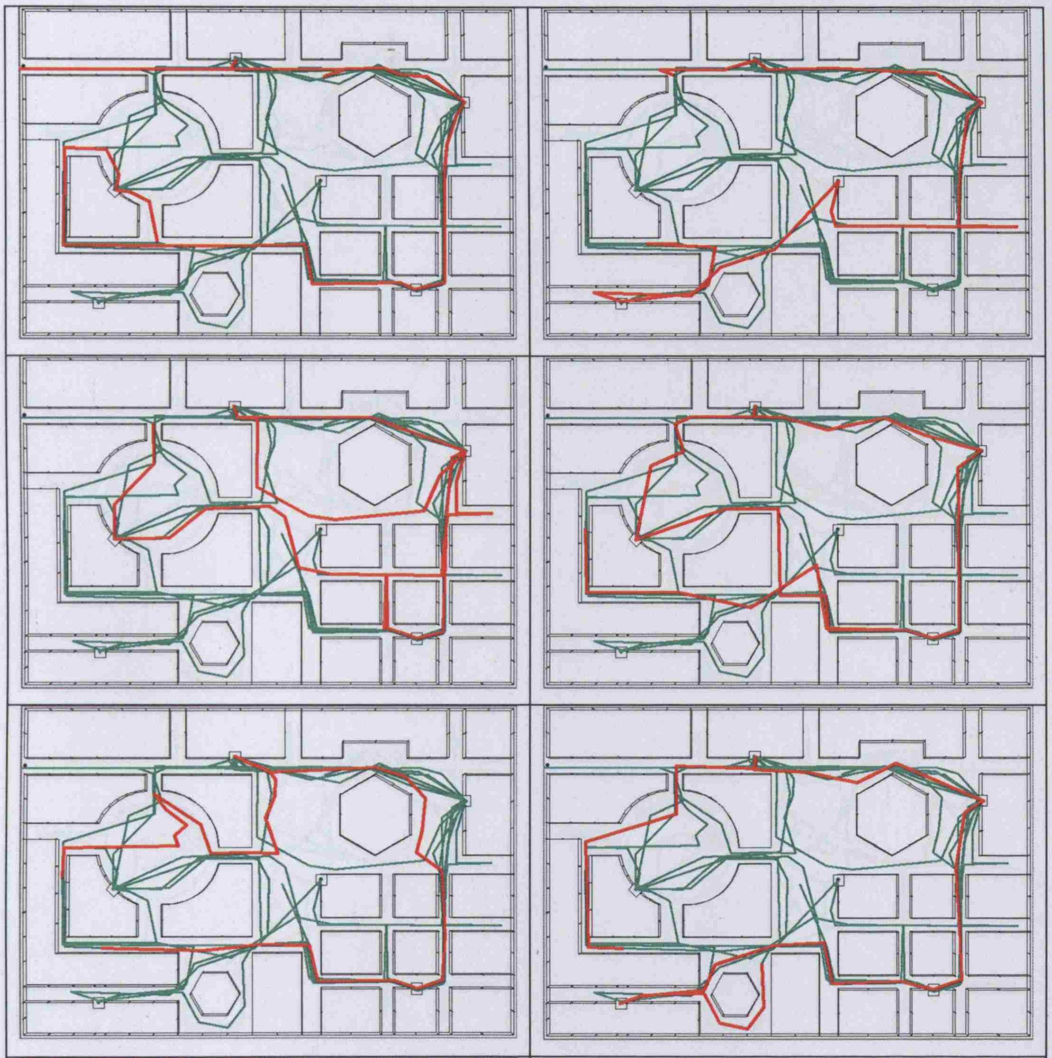
Subject 13

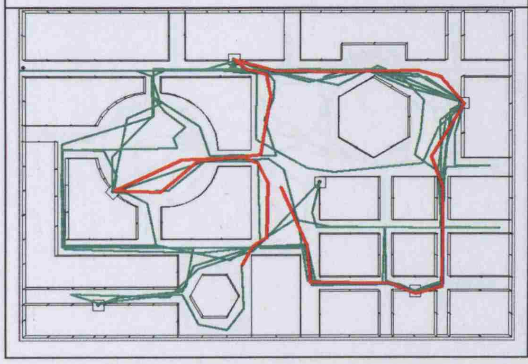




Subject number: 13
Eye condition: Retinal dystrophy, nystagmus
Group: SVI
Angle error (rank): 5/32
Distance error (rank): 7/17
Distortion index (rank): 14/33
Sum ranks: 7/23
Exploration time: 17:58 minutes
Length: 951.60 meters
Table hits: 33
Strategies: Grid, perimeter-to-object, object-to-object, cyclic

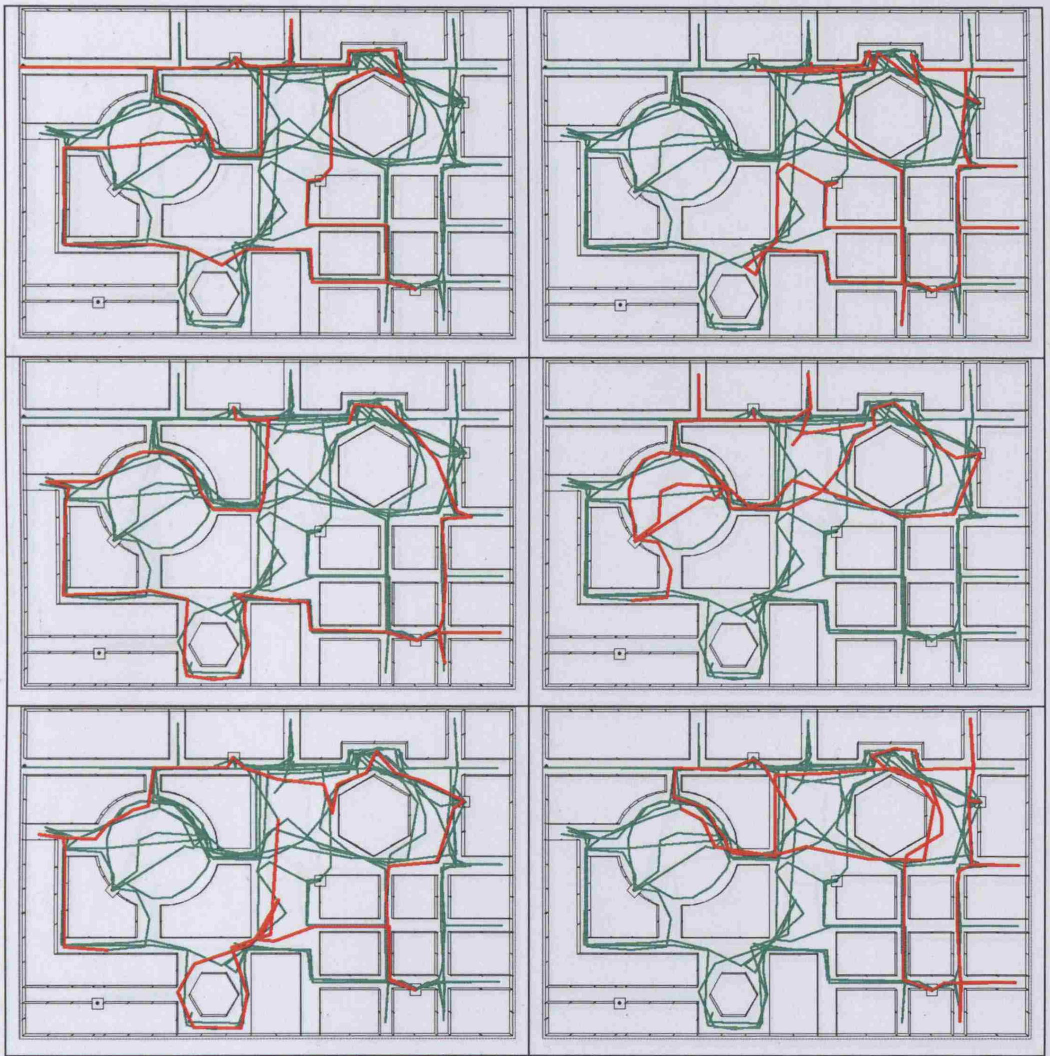
Subject 14

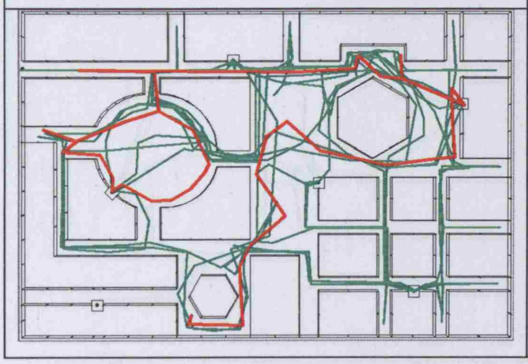




Subject number: 14
Eye condition: Unknown
Group: MVI
Angle error (rank): 15/32
Distance error (rank): 10/17
Distortion index (rank): 26/33
Sum ranks: 15/23
Exploration time: 20:30 minutes
Length: 918.81 meters
Table hits: 26
Strategies: Perimeter and random

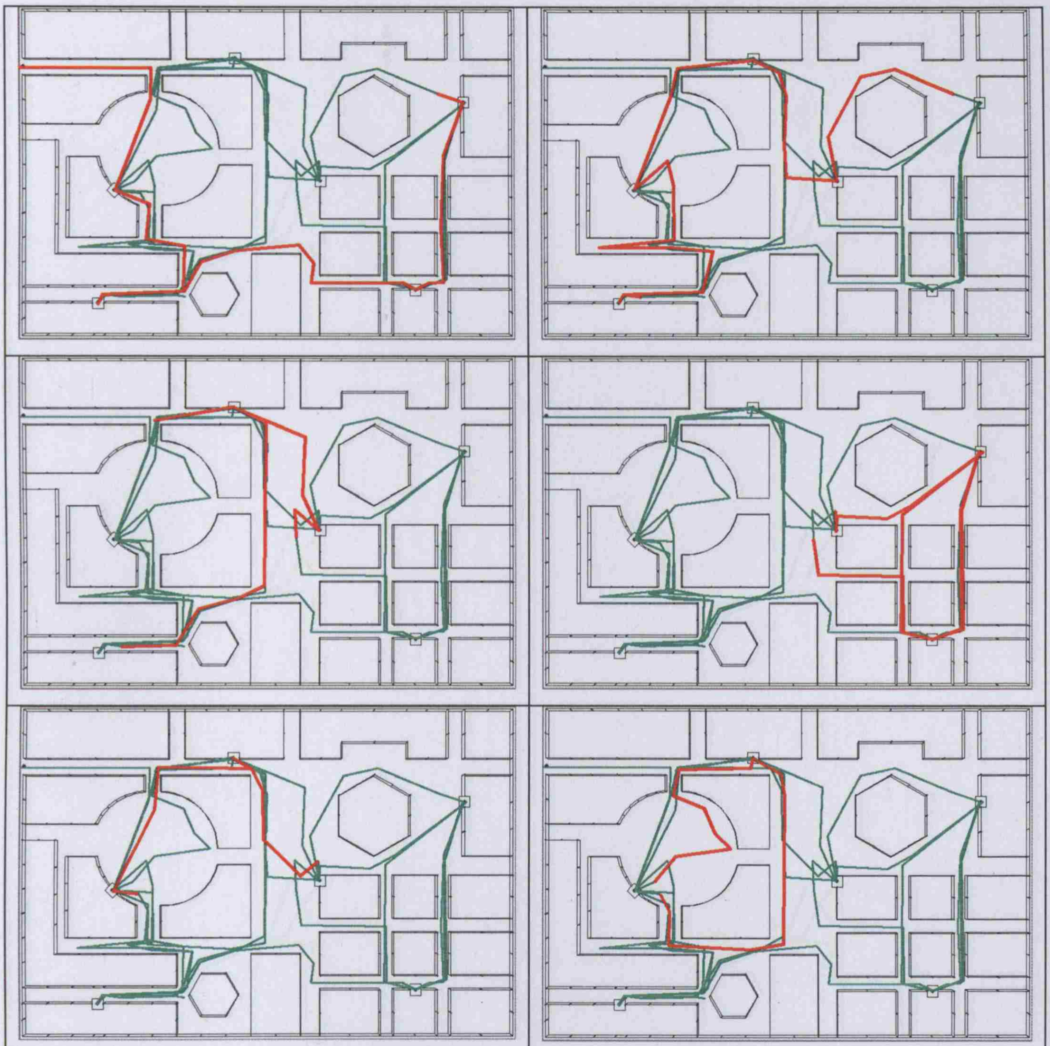
Subject 15

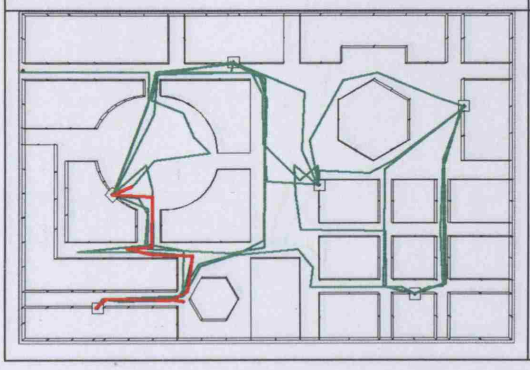




Subject number: 15
Eye condition: Congenital glaucoma
Group: SVI
Angle error (rank): 18/32
Distance error (rank): 8/17
Distortion index (rank): 4/33
Sum ranks: 10/23
Exploration time: 45:00 minutes
Length: 1149.61 meters
Table hits: 21
Strategies: Perimeter, grid, perimeter-to-object, object-to-object and cyclic

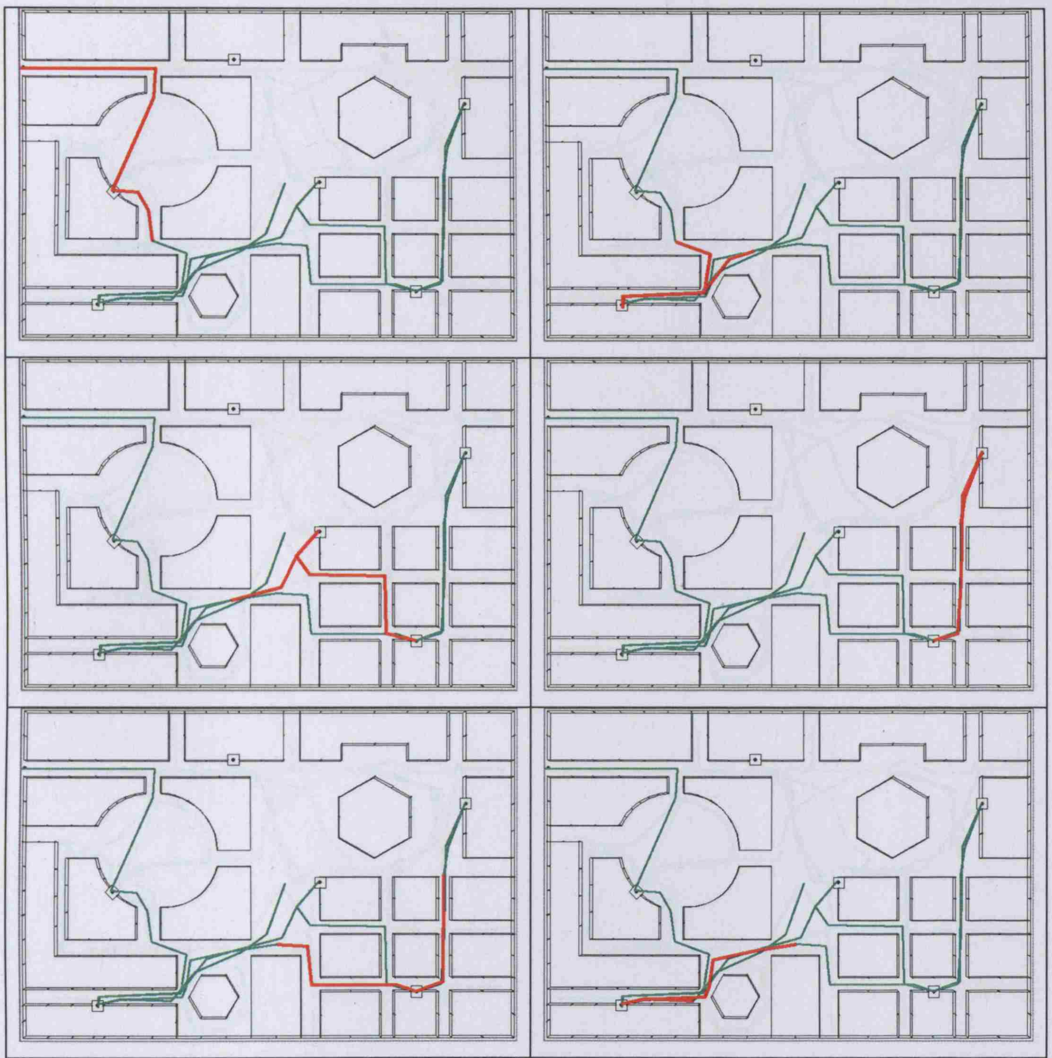
Subject 16

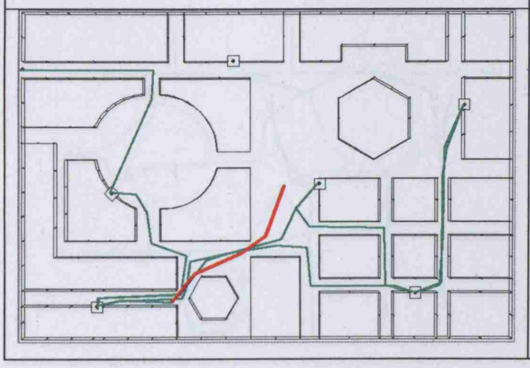




Subject number: 16
Eye condition: Unknown
Group: MVI
Angle error (rank): 12/32
Distance error (rank): 6/17
Distortion index (rank): 9/33
Sum ranks: 8/23
Exploration time: 11:12 minutes
Length: 518.51 meters
Table hits: 18
Strategies: Perimeter, object-to-object and cyclic

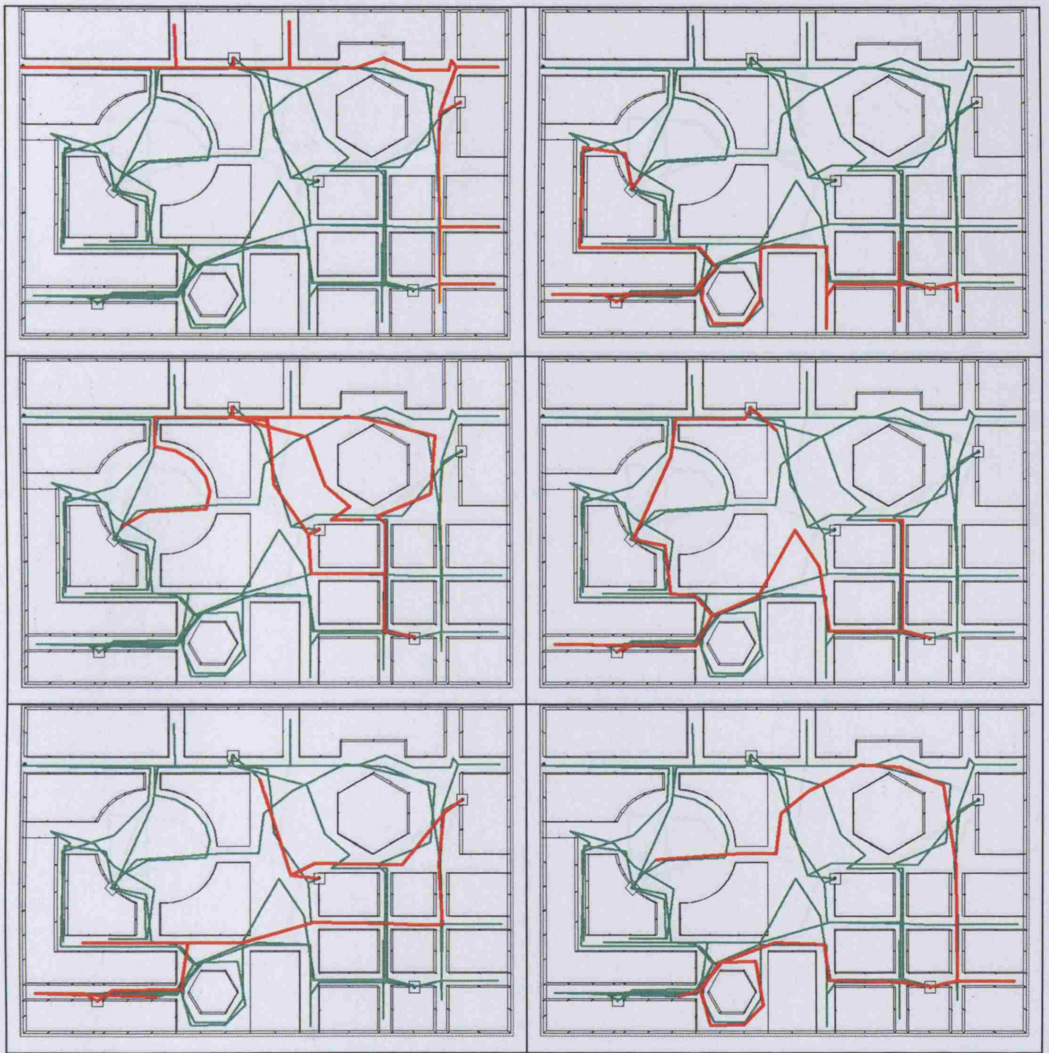
Subject 17

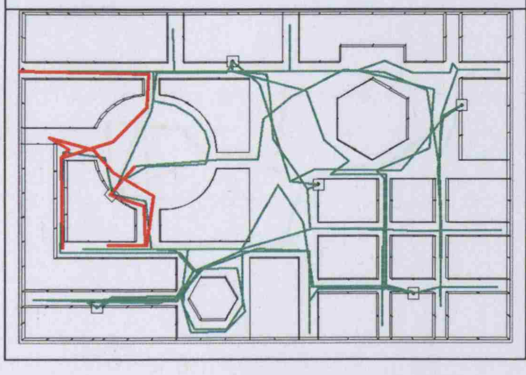




Subject number: 17
Eye condition: Congenital cataracts
Group: MVI
Angle error (rank): 1/32
Distance error (rank): 5/17
Distortion index (rank): 6/33
Sum ranks: 2/23
Exploration time: 3:00 minutes
Length: 191.87 meters
Table hits: 7
Strategies: Object-to-object and cyclic

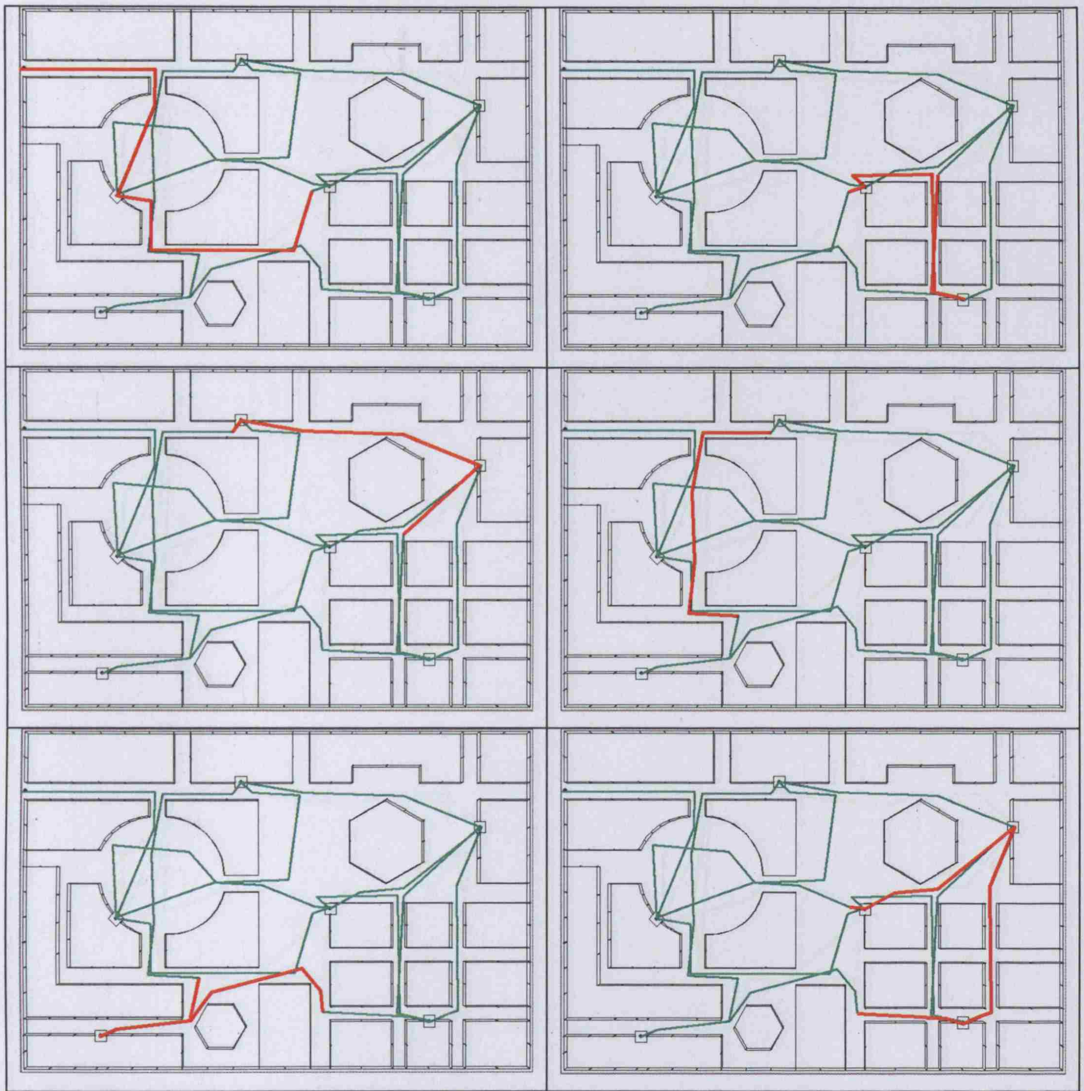
Subject 18

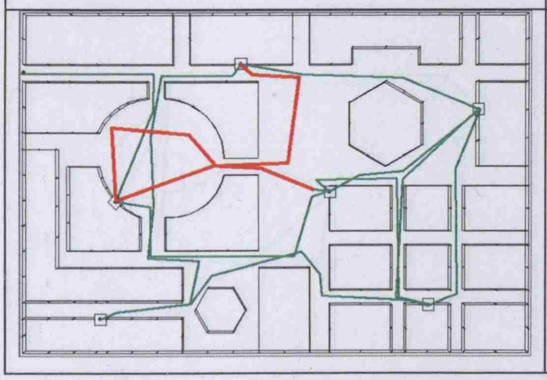




Subject number: 18
Eye condition: Rod/Cone dystrophy
Group: SVI
Angle error (rank): 19/32
Distance error (rank): 3/17
Distortion index (rank): 5/33
Sum ranks: 8/23
Exploration time: 12:30 minutes
Length: 722.96 meters
Table hits: 19
Strategies: Perimeter, perimeter-to-object and cyclic

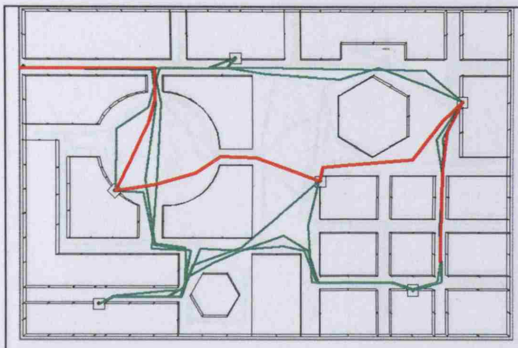
Subject 19

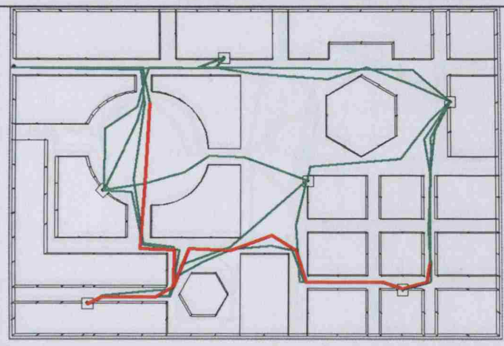


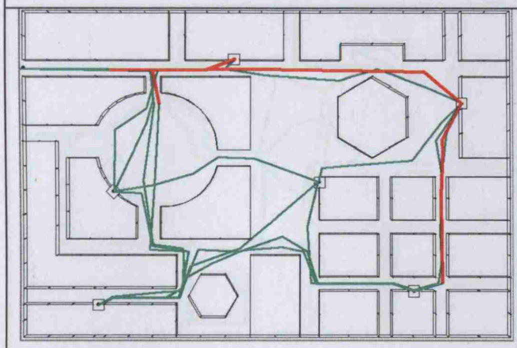


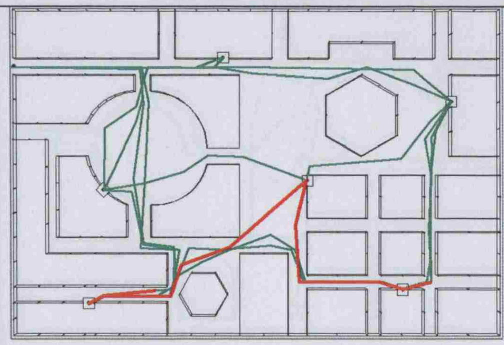
Subject number: 19
Eye condition: Retinitis pigmentosa
Group: MVI
Angle error (rank): 21/32
Distance error (rank): 10/17
Distortion index (rank): 22/33
Sum ranks: 16/23
Exploration time: 5:32 minutes
Length: 284.98 meters
Table hits: 10
Strategies: Cyclic

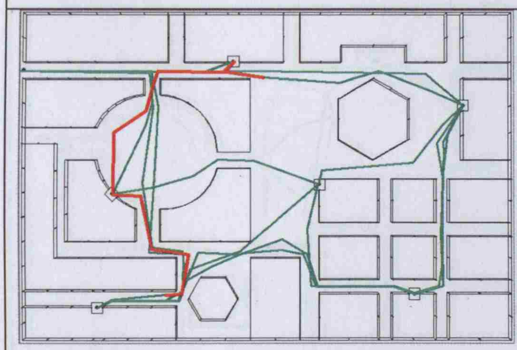
Subject 20

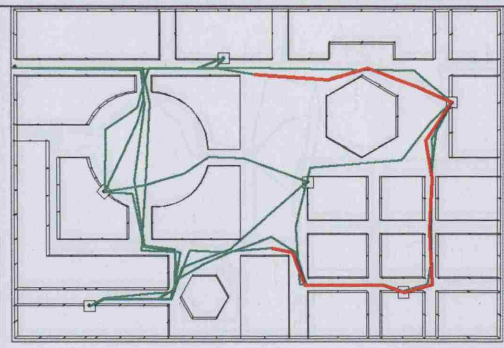


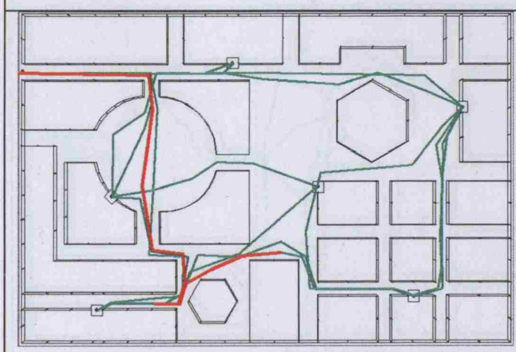






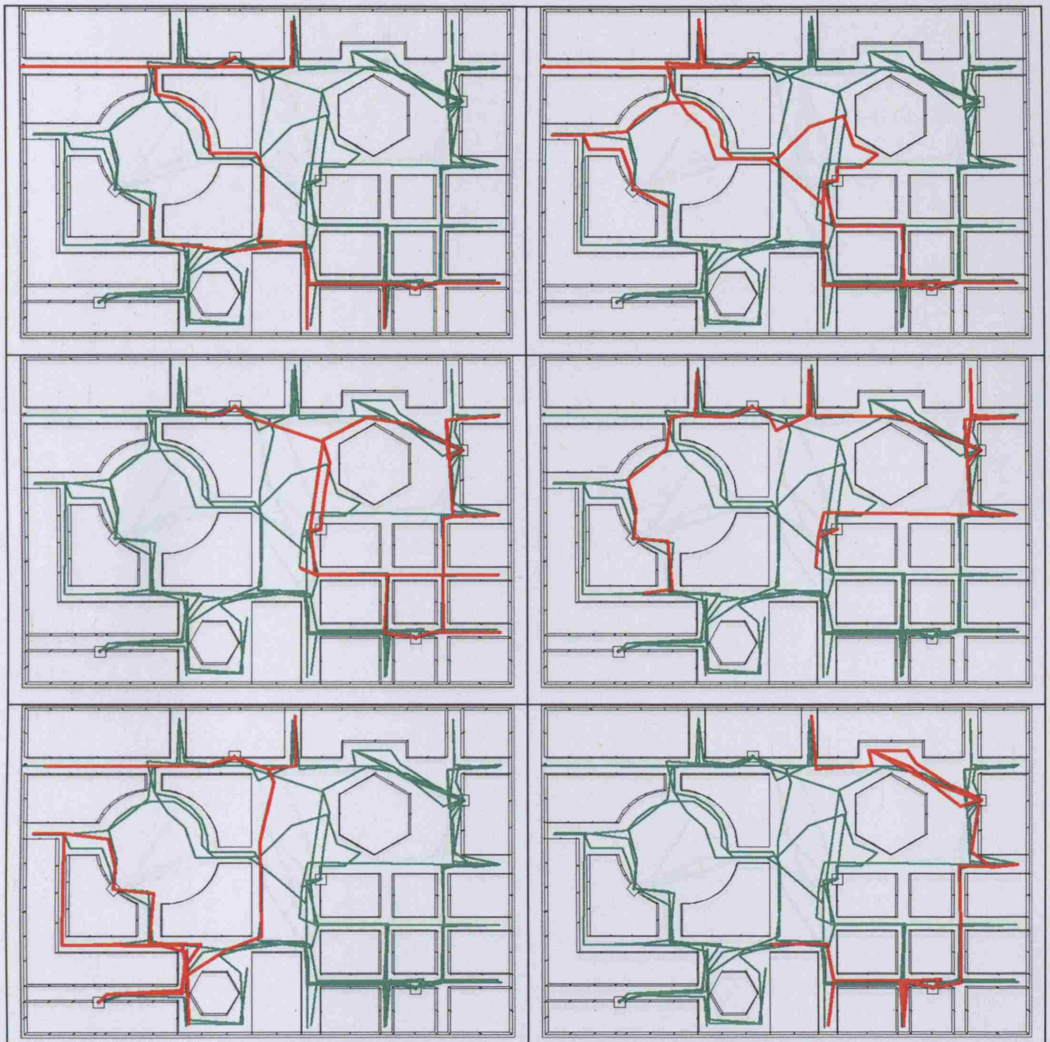


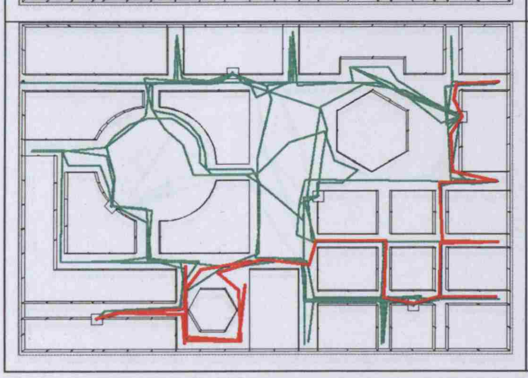




Subject number: 20
Eye condition: Bilateral congenital cataracts
Group: MVI
Angle error (rank): 9/32
Distance error (rank): 6/17
Distortion index (rank): 11/33
Sum ranks: 7/23
Exploration time: 7:30 minutes
Length: 398.93 meters
Table hits: 15
Strategies: Home-to-object and cyclic

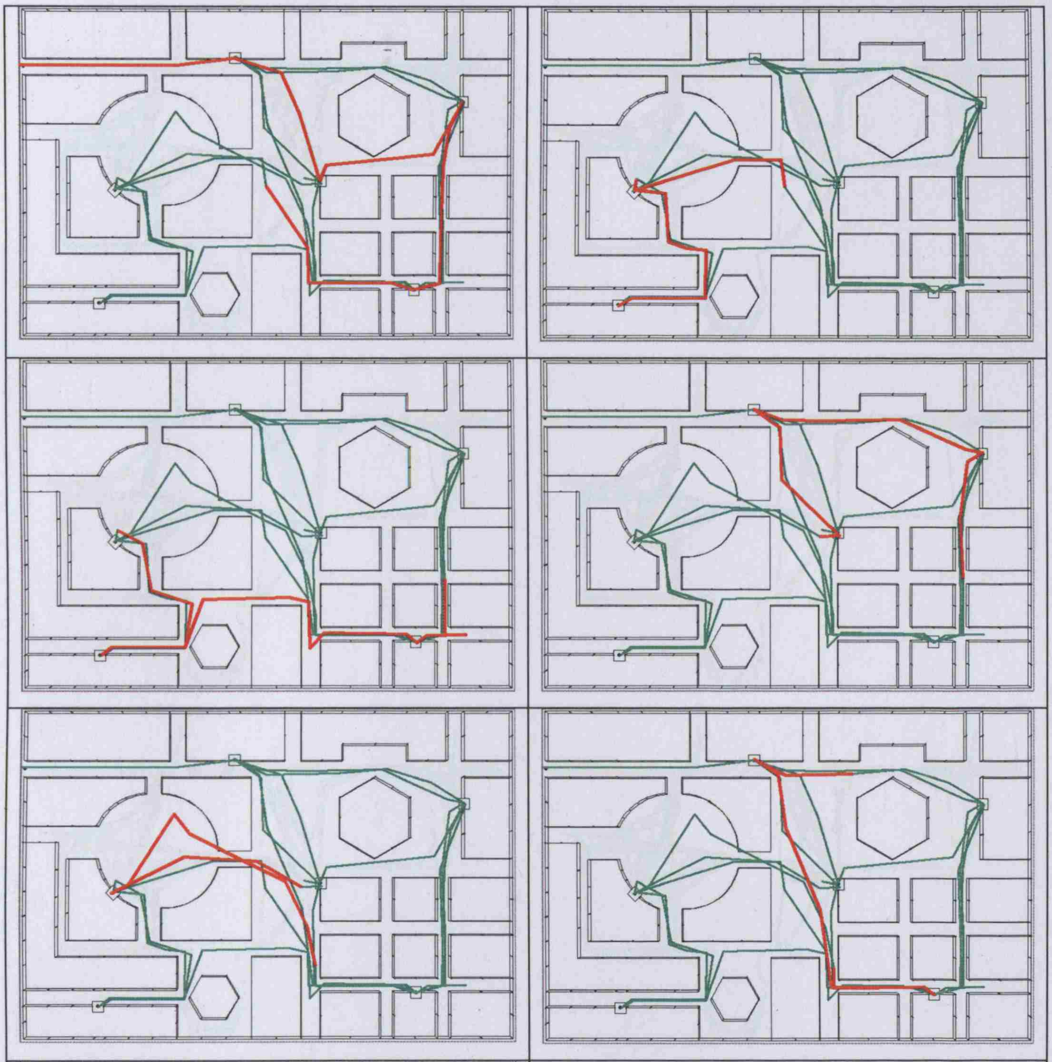
Subject 21

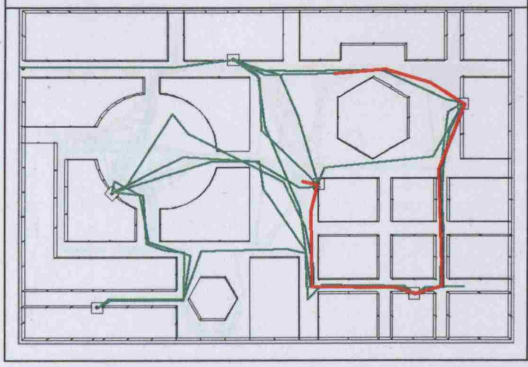




Subject number: 21
Eye condition: Retinitis pigmentosa
Group: MVI
Angle error (rank): 25/32
Distance error (rank): 11/17
Distortion index (rank): 27/33
Sum ranks: 18/23
Exploration time: 45:00 minutes
Length: 1007.89 meters
Table hits: 23
Strategies: Grid, home-to-object and random

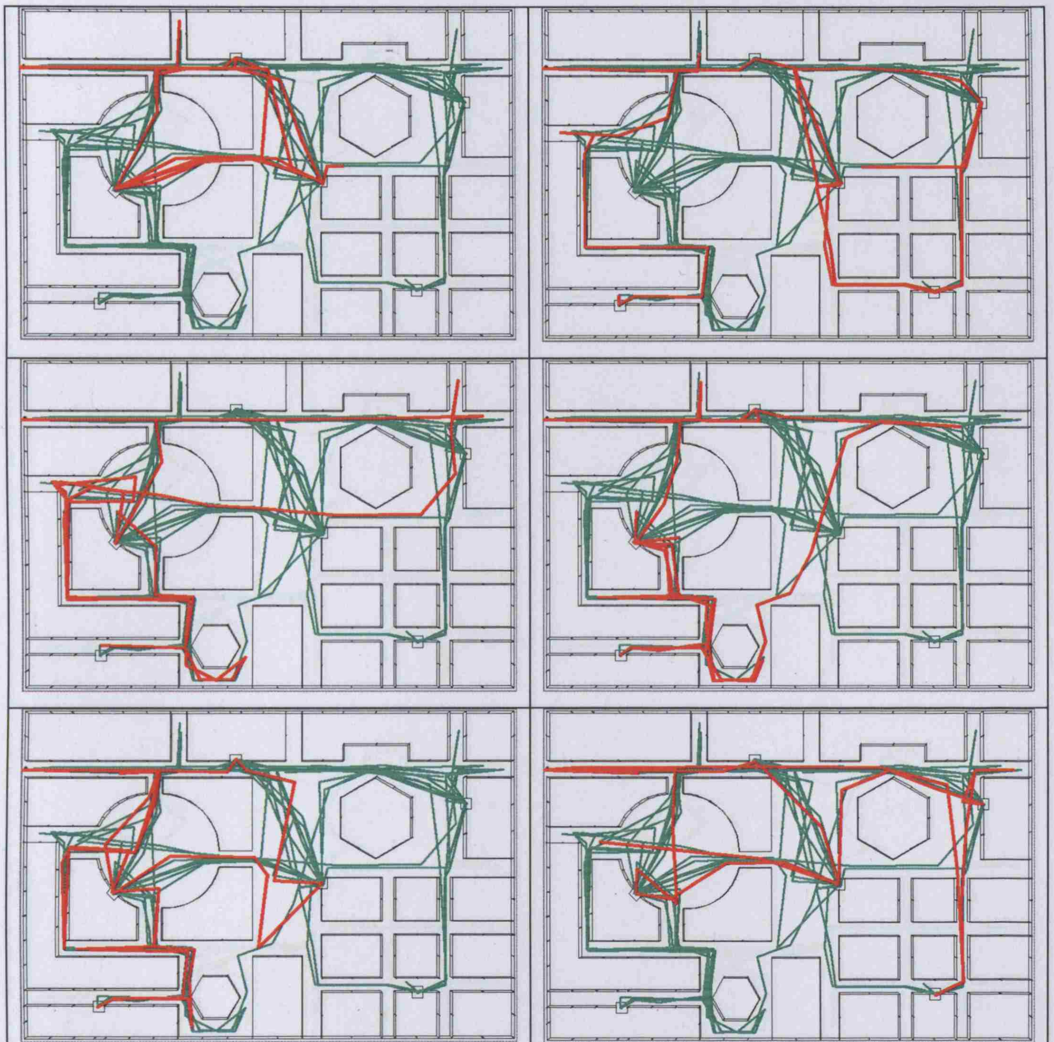
Subject 22

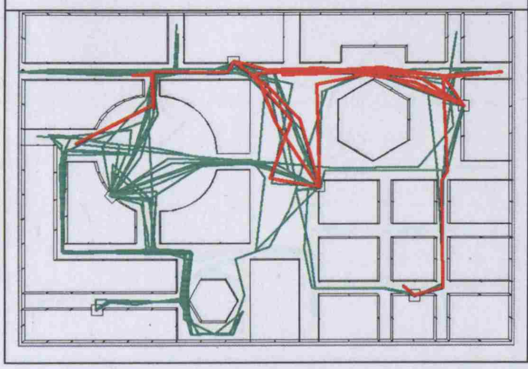




Subject number: 22
Eye condition: Horizontal nystagmus
Group: MVI
Angle error (rank): 10/32
Distance error (rank): 3/17
Distortion index (rank): 16/33
Sum ranks: 9/23
Exploration time: 6:12 minutes
Length: 417.66 meters
Table hits: 18
Strategies: Object-to-object and cyclic

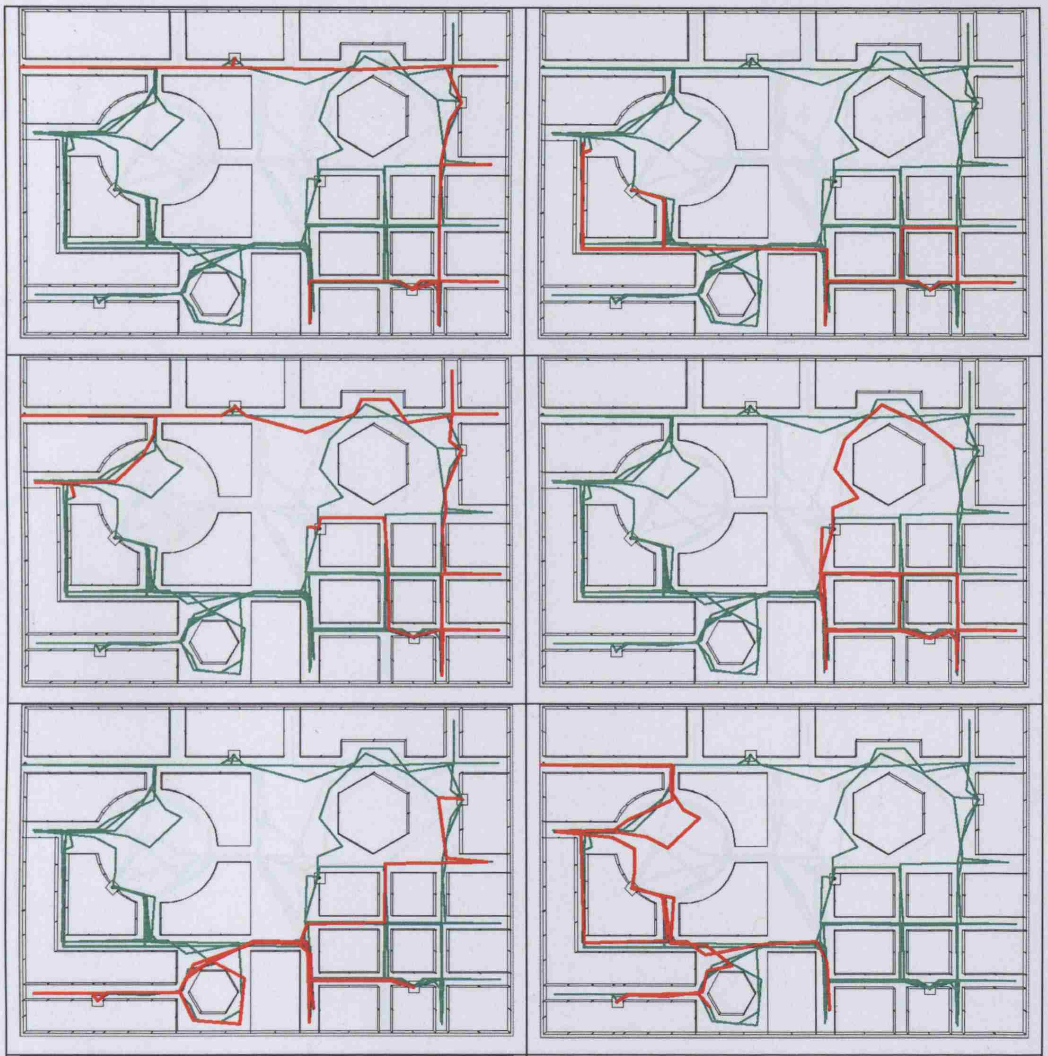
Subject 23

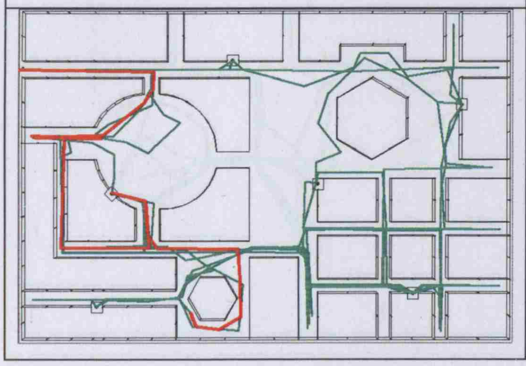




Subject number: 23
Eye condition: Microphthalmos and cataracts
Group: SVI
Angle error (rank): 24/32
Distance error (rank): 10/17
Distortion index (rank): 29/33
Sum ranks: 18/23
Exploration time: 39:20 minutes
Length: 1666.23 meters
Table hits: 49
Strategies: Grid, object-to-object and random

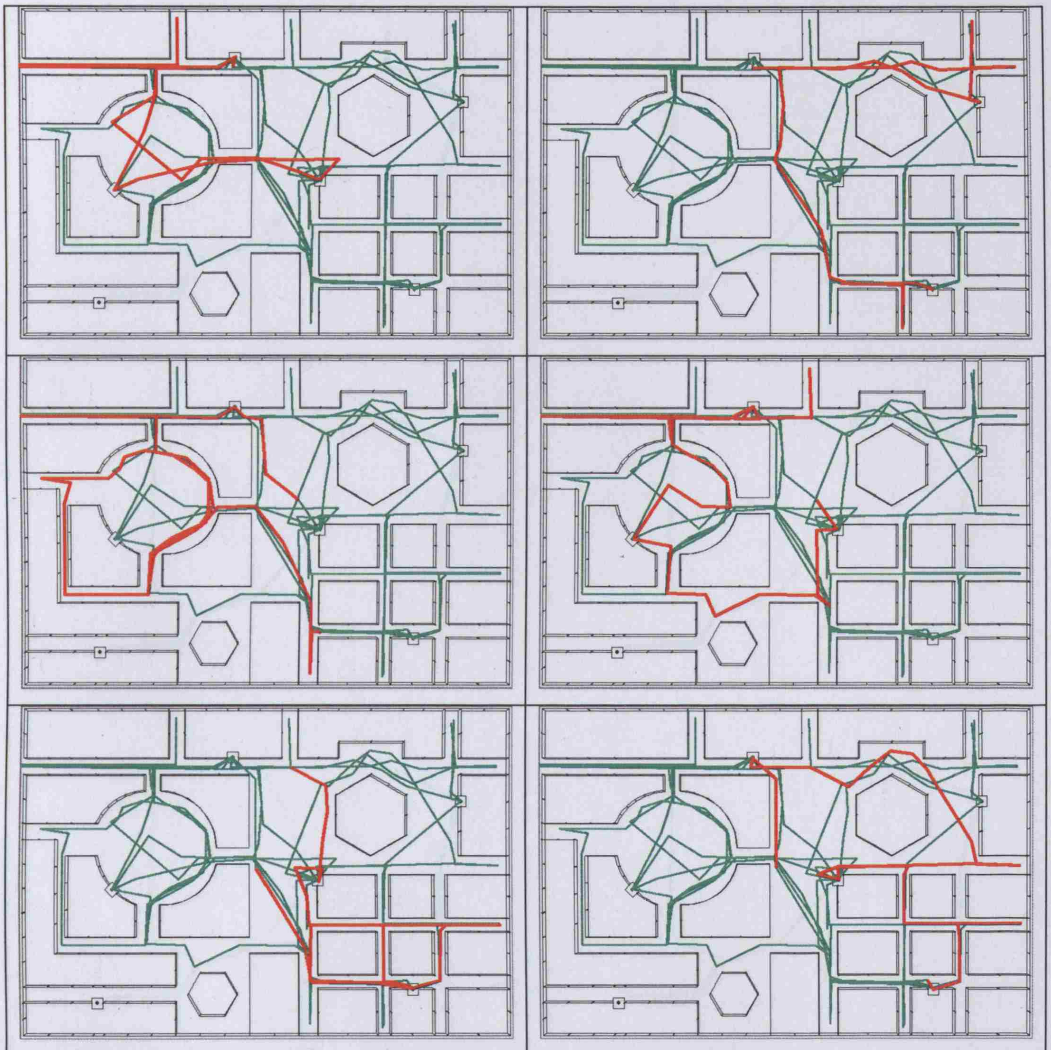
Subject 24

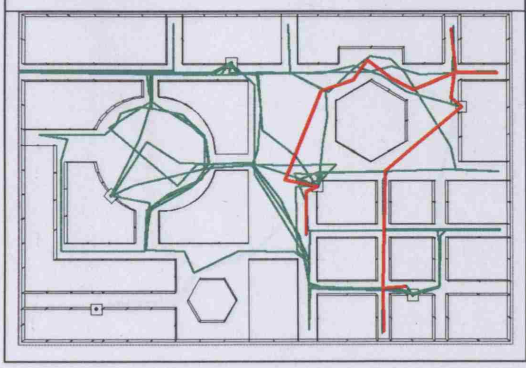




Subject number: 24
Eye condition: Retinopathy of prematurity
Group: Blind
Angle error (rank): 31/32
Distance error (rank): 15/17
Distortion index (rank): 32/33
Sum ranks: 23/23
Exploration time: 41:23 minutes
Length: 945.67 meters
Table hits: 26
Strategies: Perimeter, grid and random

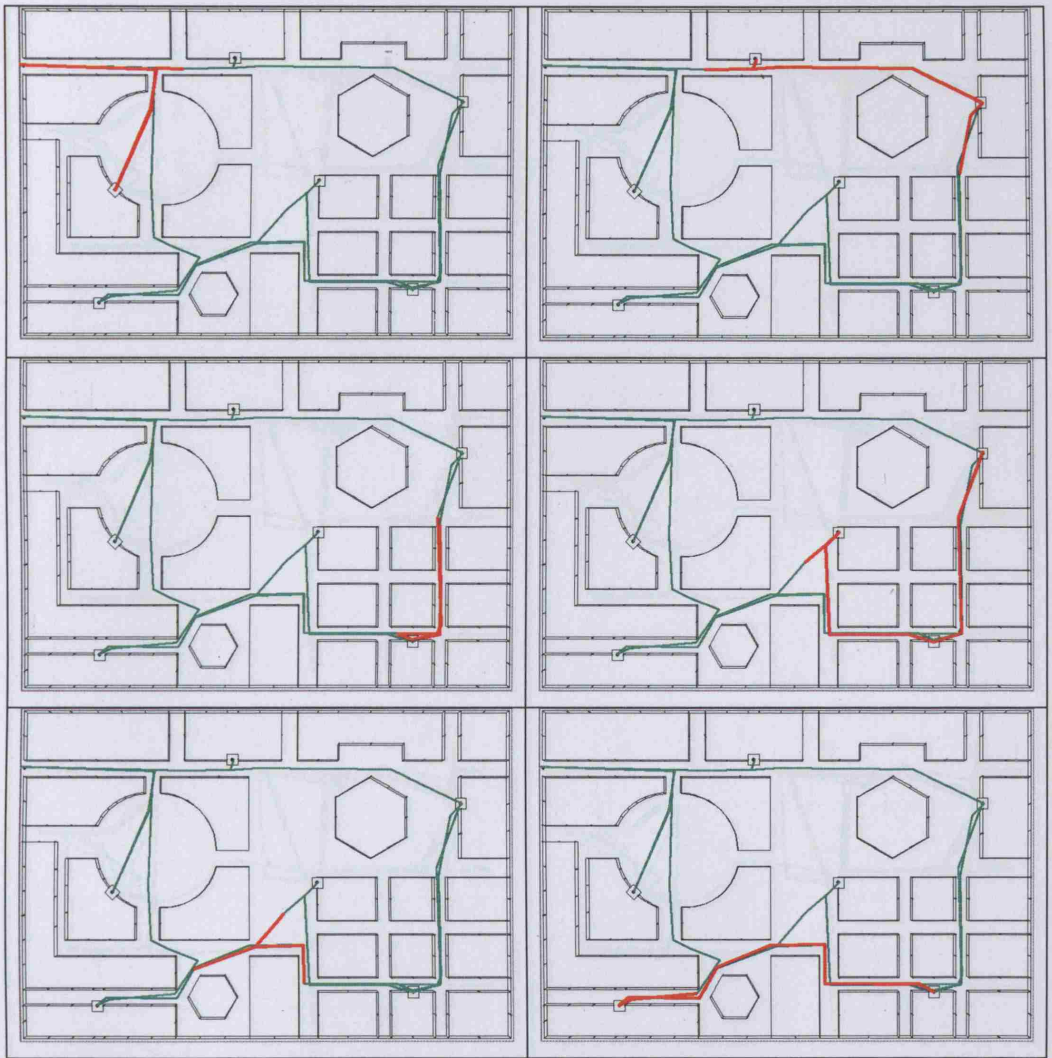
Subject 25

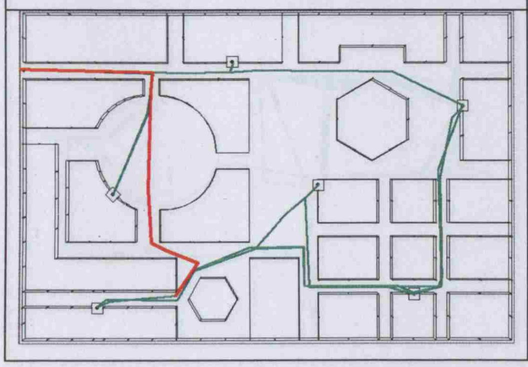




Subject number: 25
Eye condition: Anophthalmia
Group: Blind
Angle error (rank): 30/32
Distance error (rank): 12/17
Distortion index (rank): 23/33
Sum ranks: 19/23
Exploration time: 45:00 minutes
Length: 792.92 meters
Table hits: 21
Strategies: Home-to-object and random

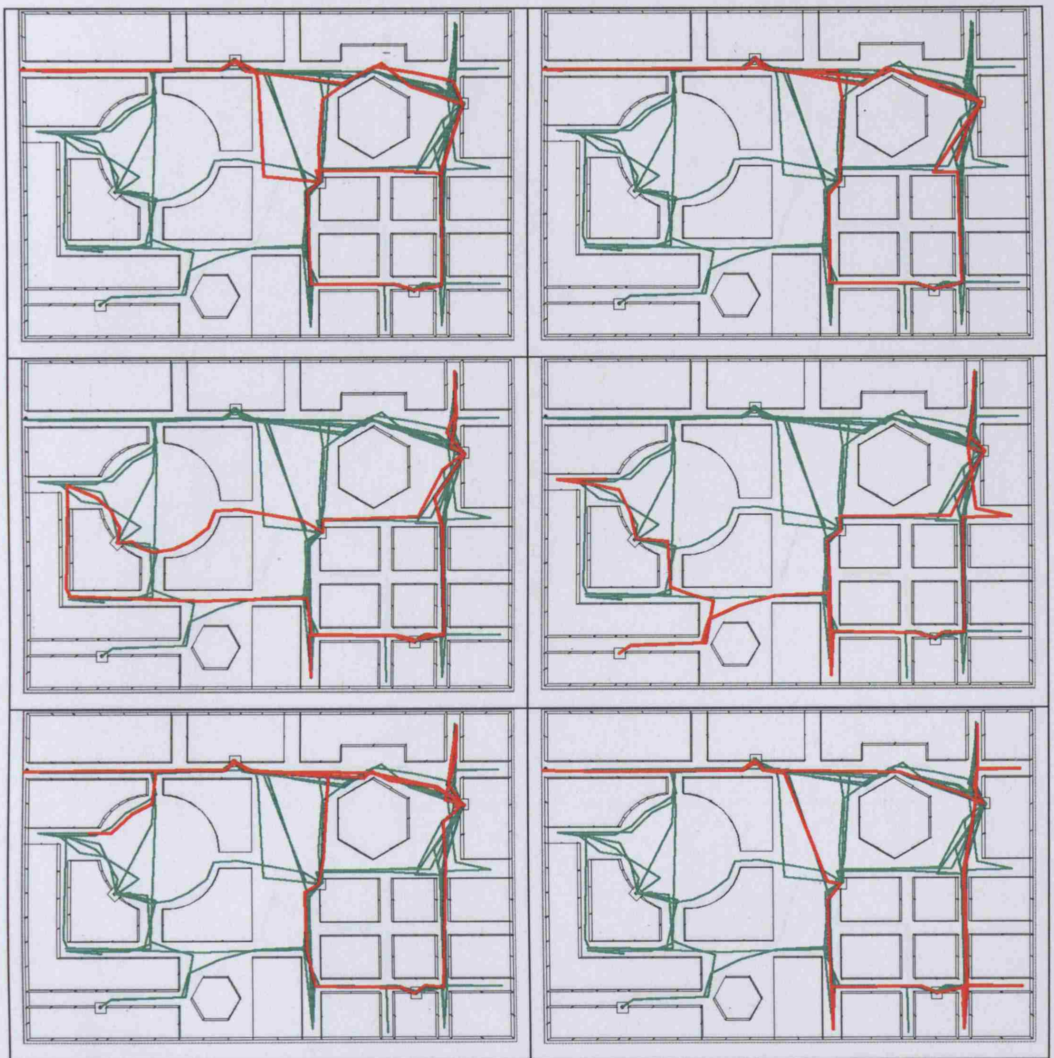
Subject 26

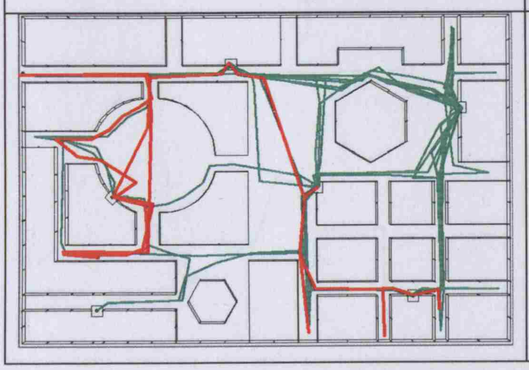




Subject number: 26
Eye condition: -
Group: Sighted
Angle error (rank): 3/32
Distance error (rank): 3/17
Distortion index (rank): 2/33
Sum ranks: 1/23
Exploration time: 4:12 minutes
Length: 256.41 meters
Table hits: 9
Strategies: Home-to-object, cyclic

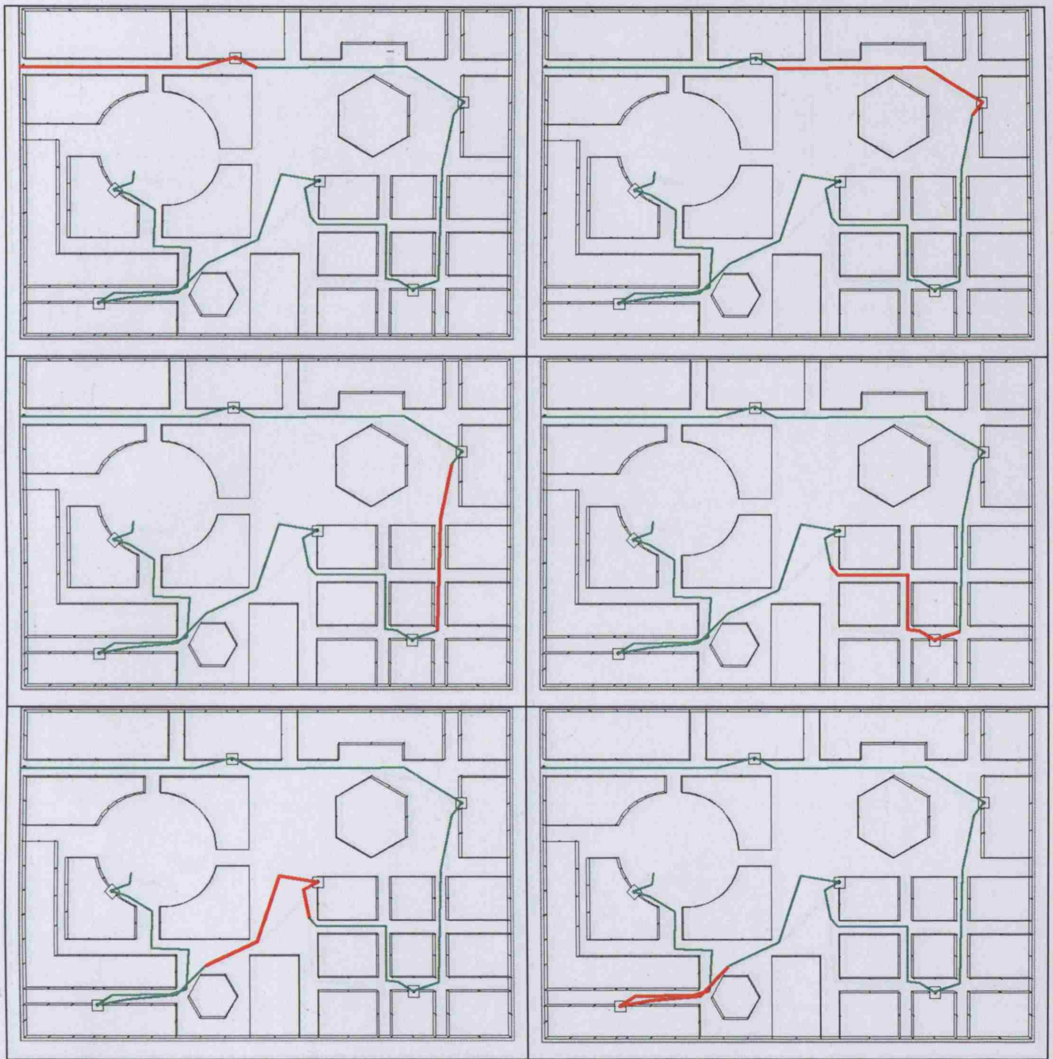
Subject 27

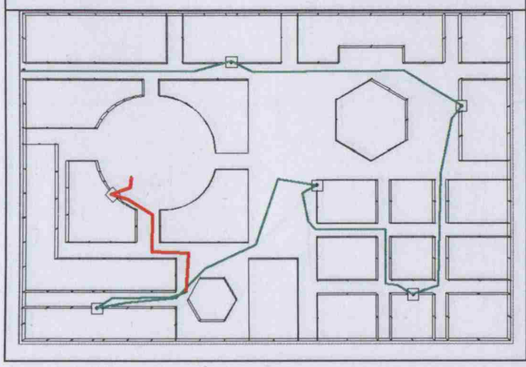




Subject number: 27
Eye condition: Retinitis pigmentosa
Group: MVI
Angle error (rank): 28/32
Distance error (rank): 14/17
Distortion index (rank): 31/33
Sum ranks: 21/23
Exploration time: 45:00 minutes
Length: 1185.02 meters
Table hits: 49
Strategies: Grid, perimeter-to-object and random

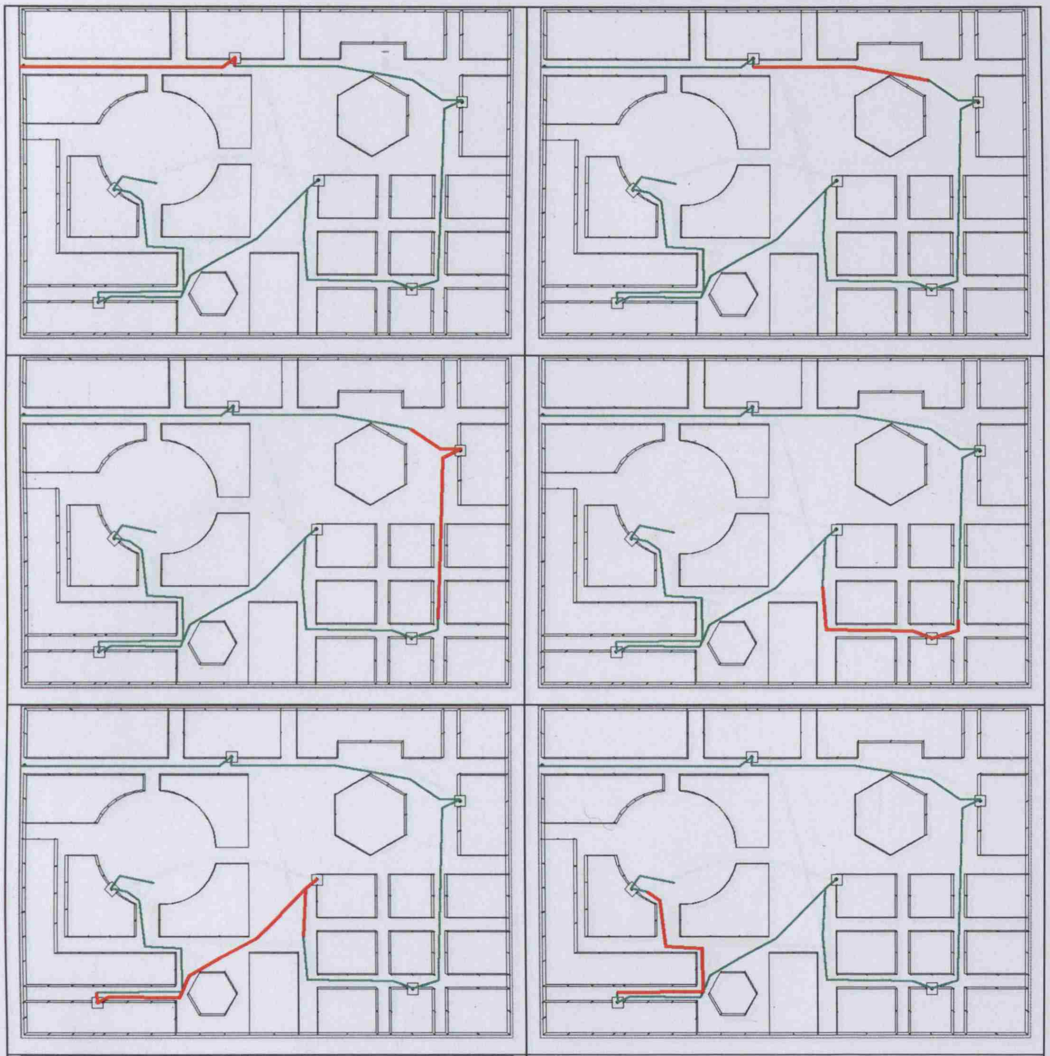
Subject 28

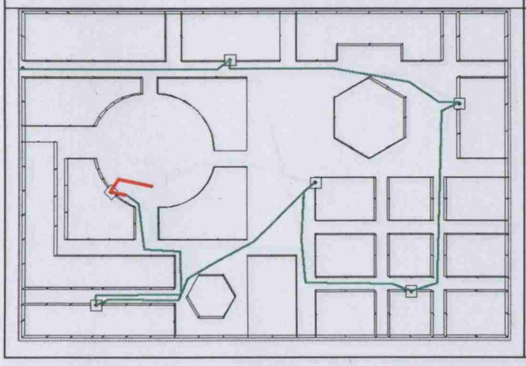




Subject number: 28
Eye condition: -
Group: Sighted
Angle error (rank): 14/32
Distance error (rank): 2/17
Distortion index (rank): 1/33
Sum ranks: 4/23
Exploration time: 2:30 minutes
Length: 135.29 meters
Table hits: 6
Strategies: Cyclic

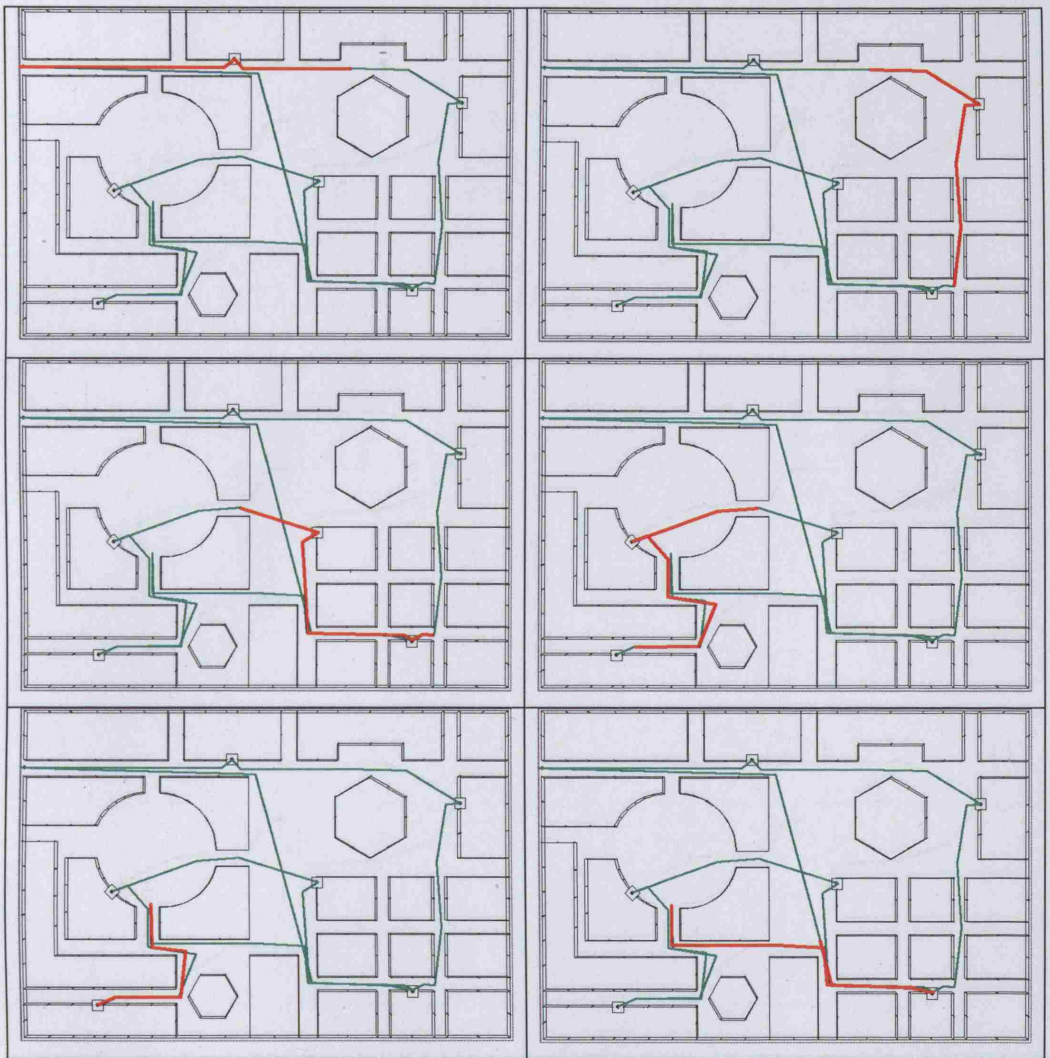
Subject 29

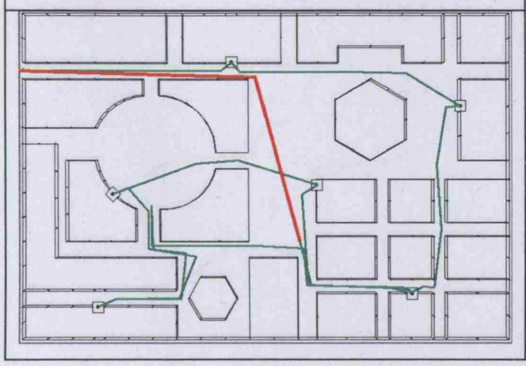




Subject number: 29
Eye condition: -
Group: Sighted
Angle error (rank): -
Distance error (rank): 4/17
Distortion index (rank): 15/33
Sum ranks: -
Exploration time: 2:40 minutes
Length: 135.85 meters
Table hits: 6
Strategies: Cyclic

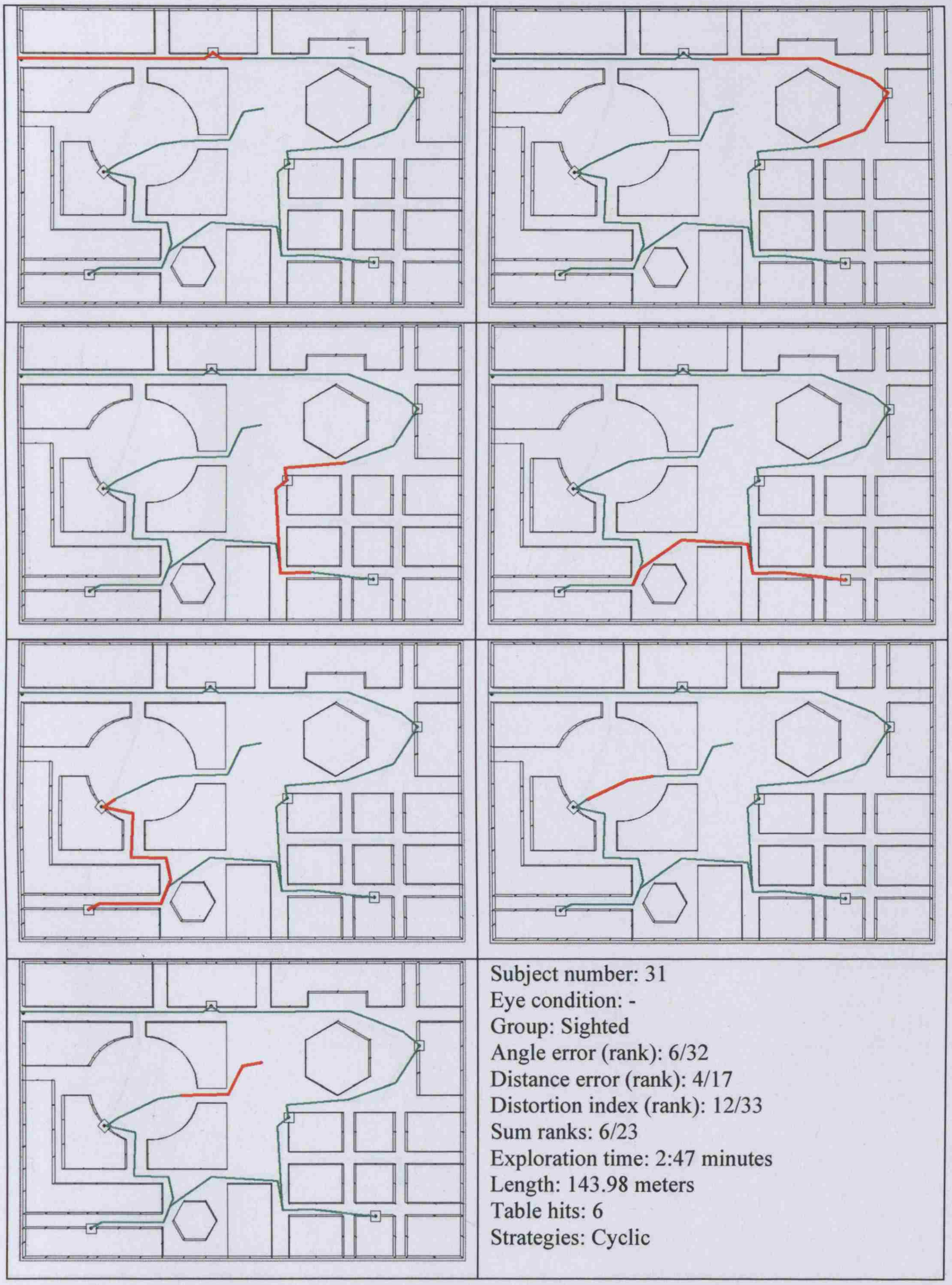
Subject 30





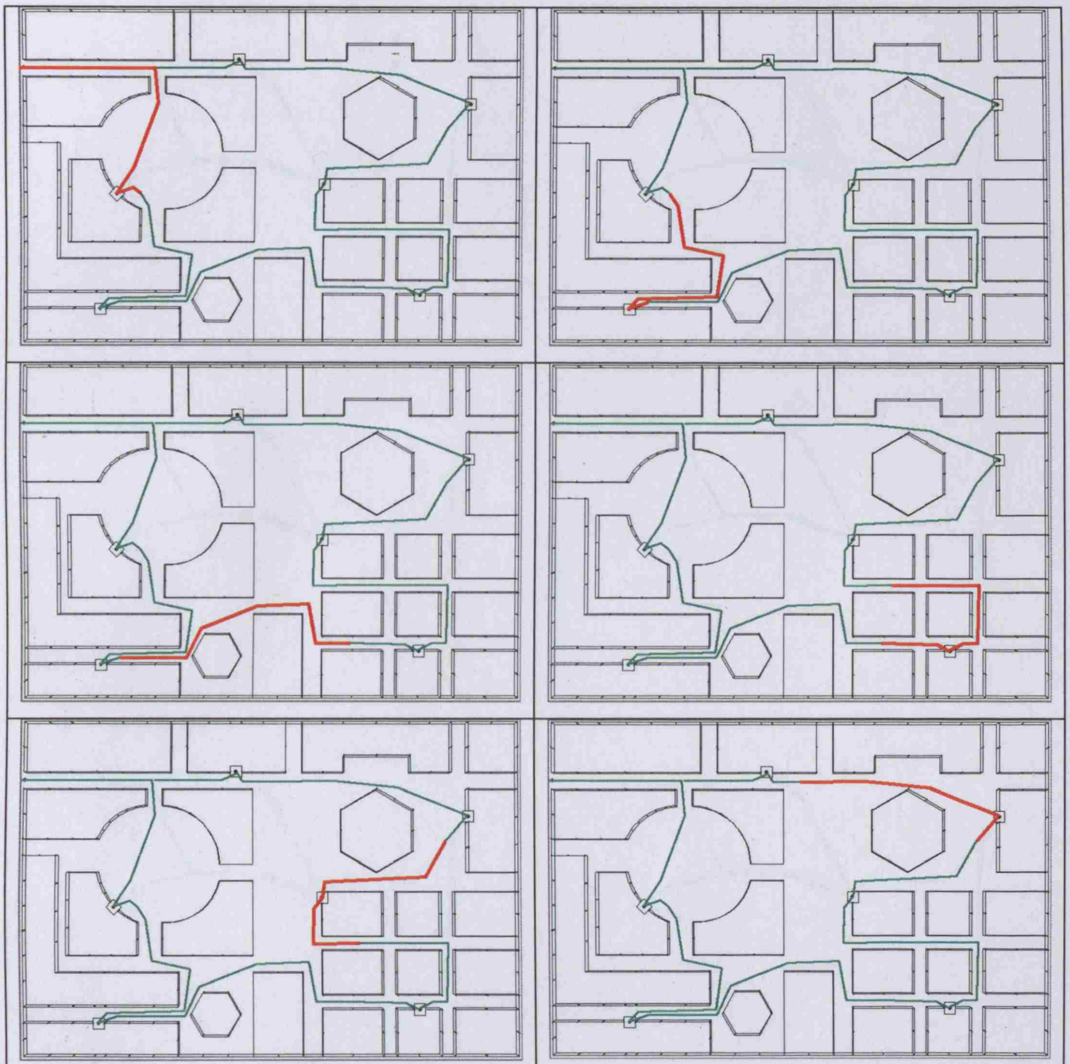
Subject number: 30
Eye condition: -
Group: Sighted
Angle error (rank): 17/32
Distance error (rank): 14/17
Distortion index (rank): 7/33
Sum ranks: 13/23
Exploration time: 3:00 minutes
Length: 229.11 meters
Table hits: 7
Strategies: Home-to-object, object-to-object and cyclic

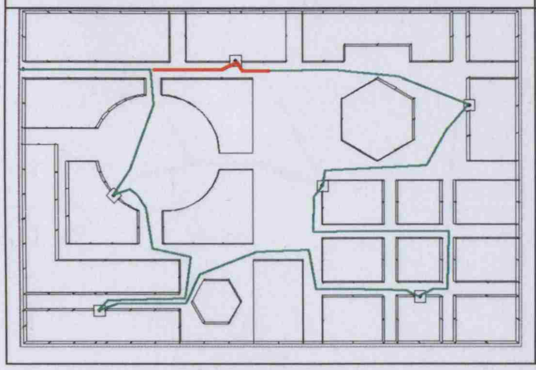
Subject 31



Subject number: 31
Eye condition: -
Group: Sighted
Angle error (rank): 6/32
Distance error (rank): 4/17
Distortion index (rank): 12/33
Sum ranks: 6/23
Exploration time: 2:47 minutes
Length: 143.98 meters
Table hits: 6
Strategies: Cyclic

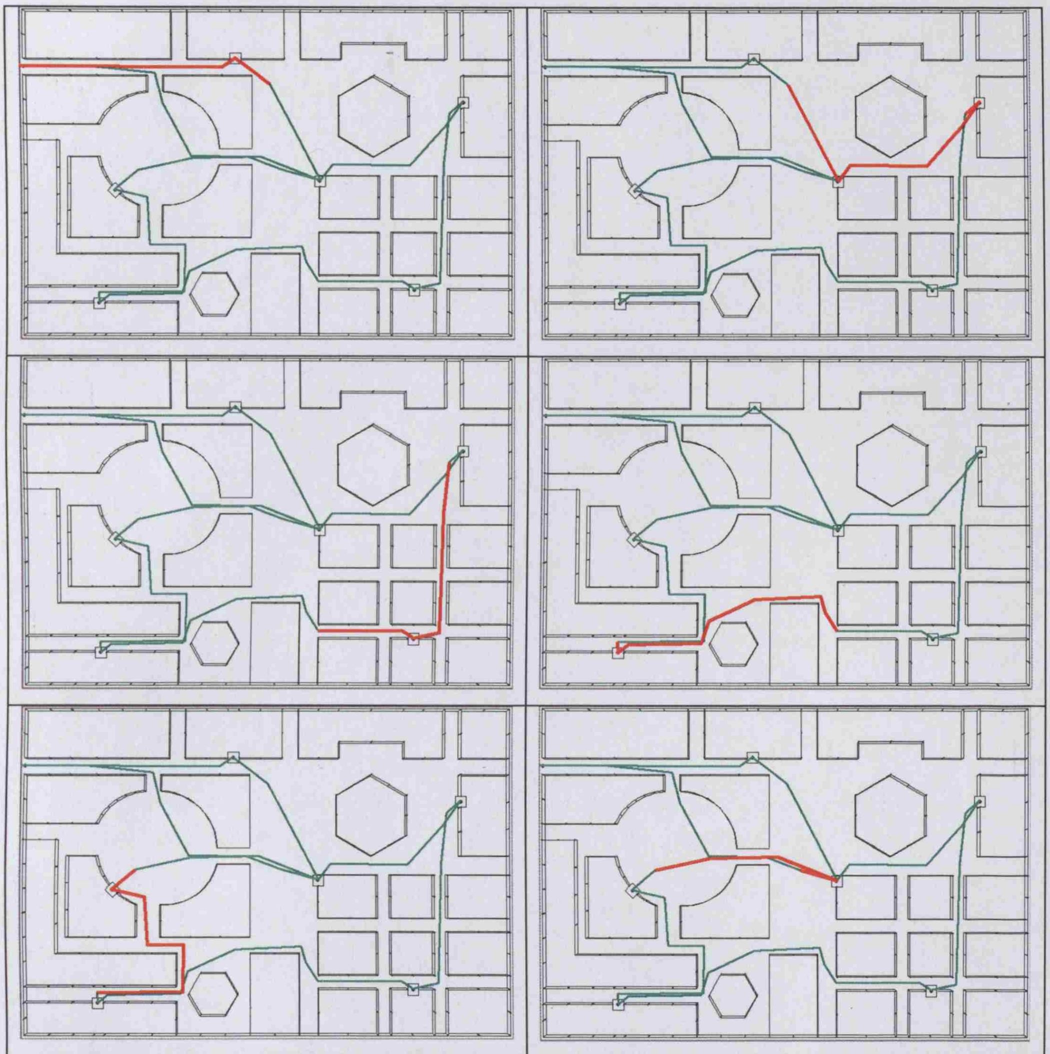
Subject 32

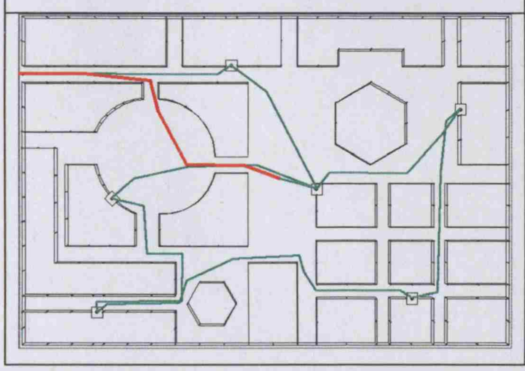




Subject number: 32
Eye condition: -
Group: Sighted
Angle error (rank): 2/32
Distance error (rank): 7/17
Distortion index (rank): 3/33
Sum ranks: 2/23
Exploration time: 2:40 minutes
Length: 155.30 meters
Table hits: 6
Strategies: Cyclic

Subject 33





Subject number: 33
Eye condition: -
Group: Sighted
Angle error (rank): 7/32
Distance error (rank): 2/17
Distortion index (rank): 17/33
Sum ranks: 8/23
Exploration time: 2:26 minutes
Length: 184.02 meters
Table hits: 8
Strategies: Home-to-object, cyclic