THE EFFECTS OF PATHWAY COMPLEXITY AND SYMMETRY ON COGNITIVE MAPS CREATED IN MEDIUM-SCALE SPACE

by

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The effects of pathway complexity and symmetry on cognitive maps created in medium-scale space

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Abstract

Movement through an environment is usually performed with a goal in mind. It was previously assumed to be mainly dependent upon the presence of vision since vision has been shown to be a primary component in achieving both manipulatory and ambulatory goals accurately. The presence of vision is not a requirement however, since many blind individuals are able to navigate relatively successfully through familiar environments to a goal.

A strategy used by both sighted and blind individuals, but in differing degrees, is the creation and utilization of a cognitive map. The cognitive map is usually conceived of as a memorial representation of the environment encountered. The development of a cognitive map of an area allows the blind individual the opportunity to comprehend the space that has been encountered in a manner which does not require the benefit of vision.

The cognitive map is believed by some to be imagery-based and as such is assumed to take on picturelike or map-like qualities. If this is true then certain distortions within the imagery-based cognitive map are expected when the pathway complexity or the degree of symmetry of the mapped environment is manipulated. Three experiments were conducted to evaluate the effects of these properties on blindfolded sighted subjects when learning pathway configurations by ambulatory movements.

Experiment 1 evaluated the ability of subjects to detect the differences in three pathway configurations by means of drawings and judgements of direction and distance. The drawings indicated that successful differentiation of the configurations was possible and more specifically, that the crossing paths can be detected. In orientation judgements, subjects had particular difficulty in the configuration in which paths crossed. No evidence was found that subjects biased the angles turned toward 90 degrees as had been postulated by earlier researchers.

Judgements of distance to the target for different paths were equally accurate but differed in consistency.

Experiment 2 evaluated the equiavailability principle which suggests that all information within a cognitive map, whether learned or inferred, is equally available to the user (Levine et al., 1982; Hanley & Levine, 1983). In addition, the effects of the degrees of symmetry of integrated cognitive maps were investigated. Four groups of subjects were required to integrate two separate pathway configurations and make judgements of orientation and distance to points within and between configurations. The experiment replicated the findings of Levine et al. (1982) that learned or inferred ambulatory movements were made equally well within a configuration when measured by an angular error which did not consider the direction turned to the target. However, subjects were not equally efficient at locating the target when asked to turn through the shortest possible angle. Differences were also found in distance judgements. Limited evidence was found that movements of orientation could be made equally well in between-pathway and within-pathway movements.

Experiment 3 evaluated the distortive effect of symmetry on cognitive maps. The judgements of distance indicated that regardless of the degree of symmetry of the test configurations, the cognitive maps of these configurations became distorted toward a symmetric representation. The symmetric representations were a result of augmenting the shorter of two distances, rather than redividing the total distance.

Dedication

I would like to dedicate this thesis to my family and friends who have endured this process with me and in particular to my wife and best friend, Jane, who has encouraged and comforted me every step of the way.

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I would like to acknowledge my committee members. Dr. John Dickinson, who never gave up on me as a student. Dr. David Goodman, who always challenged me to do my best. Dr. Robert Horsfall who entered late in the process but accepted his role with enthusiasm and was always there when I needed help.

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Chapter I
Orientation and mobility

Humans value independent mobility and the obvious benefits that can come from being efficient at this skill. Mobility can be described as "The skill of traveling through the spatial environment, avoiding obstacles, and traveling directly or indirectly toward goals . . . " (Strelow, 1985, p. 226). In such a case, pedestrians must know " . . . where they are at present, where their goals are, and how to move from their present positions to their goal positions" (Foulke, 1982, p. 57).

Orientation and mobility (Hill & Ponder, 1976; Welsch & Blasch, 1980) has traditionally been the area of study for the perceptual guidance of locomotion and refers to:

> . . . knowing/perceiving spatial relations between the position occupied at each moment and relevant places and objects in the environment, as well as internal spatial relations between these places and objects, and . . . the successful change of position. (Jansson, 1986, p. 104)

Problems of orientation and mobility are significantly increased for the blind and visually impaired population (Hill & Ponder, 1976; Welsh & Blasch, 1980). Due to the lack of vision, blind individuals must incorporate information from the environment differently from the sighted, even though in both cases the goal in question may not be in the immediate surroundings (Strelow, 1985). The information utilized by the blind originates from non-visual sources and is therefore thought by some to be less effective in planning movement. Sensory inputs available to the blind usually restrict the input of information to a sequential nature and involve " . . . relatively slow exploratory contact movements over surfaces and along contours" (Lederman, Klatzky, Collins, & Wardell, 1987, p. 607) as opposed to the benefits of " . . . simultaneous, parallel input . . . " (Strelow, 1985, p. 238) available to a sighted individual.

Blind individuals rely on the ingenuity of the sighted scientific world to develop travel which is safe, comfortable, graceful and most important for blind pedestrians, independent in nature (Foulke, 1971). Orientation and mobility (O&M) specialists attempt to achieve this by developing effective training programs and sensory aids. The O&M specialists' goal is to enhance the remaining sensory systems so that compensation for the benefits of vision during locomotion, in general or to a specific goal, can be achieved. One of the difficulties facing these specialists is that the perceptual and cognitive demands made during egomotion[1] are always changing and, as such, it is unknown at any given point in time which sensory information is most prevalent in assisting the task (Shingledecker & Foulke, 1978). When developing training methods, ideally the development should be based on a mobility theory. However theories have not been successful in providing " . . . testable predictions and viable directions for research" (Shingledecker & Foulke, 1978, p. 274).

Reaching a destination in a locomotor environment can be mediated by the processes involved in maintaining a "sense of direction" as well as by physical attributes of the environment. Both of these factors are influential in wayfinding (Passini & Proulx, 1988). As Passini (1987) pointed out, wayfinding is composed of:

> . . . decision making which, leads to a plan of action to reach a given destination, . . . decision executing, which transforms the plan into overt behavior and movement at the right place in space, . . . information processing, comprising environmental perception and cognition which permits the above two decision related processes to occur. (p. 64)

Wayfinding, at its most efficient, allows one to proceed purposefully from one place to another with what could be considered a low level of consciousness (Gärling, Böök, & Lindberg, 1984).

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[1] Egomotion refers to movement which is initiated and controlled by an individual and involves a displacement of the individual in the environment (Warren, 1976).

There must be integration of data from all sensory and perceptual systems to make this task as effortless as possible.

The components of integration are believed to be involved in the formation of a schema in memory that will direct the pedestrian successfully to a goal. It is obvious that major contributors to the integration of information are visual stimuli and the ability to encode spatial aspects of the environment. As well, encoding of auditory stimuli provides pedestrians with the opportunity to use temporal-sequential order of events to guide locomotion (e.g., listening for a sequence of auditory cues to guide a pedestrian in a business district). Movement generates kinesthetic feedback which can be important both spatially and temporally. The vestibular system can also provide additional spatial information when egomotion is in progress (Potegal, 1982).

An essential part of the schema is a mental representation which acts as part of a "plan" people use in guiding themselves to a goal, especially when vision is unavailable. A representation of the total space in the mind is referred to as a cognitive map (Evans, 1980).

Chapter II
Review of literature

Cognitive maps

Traditional maze learning tasks presupposed that learning the spatial structure of an environment was not necessary to attain the goal through the pathway system successfully. Subjects, whether animal or human, were expected to remember the sequence or series of direction changes that had to be followed at the appropriate decision points during the traversal of the path. When subjects traverse these pathways with the benefit of vision and distinctive choice points, knowledge of the distance between choice points, the amount of time required to traverse between them and the exact directions to be followed would not be necessary (Hart & Berzok, 1982; Strelow, 1985). This associationism, or more specifically a stimulus-response (S-R) explanation of learning, sufficed if the goal or the paths connecting the start to the goal remained unchanged.

More contemporary views have also attempted to support a S-R explanation but have acknowledged that, in addition, a mental representation may be required (Byrne, 1979). Byrne concluded that the strategy used by his subjects only maintained "topological connectedness" and was described as a network-map. A network-map only required that the subjects remember the particular order of the locations to be encountered and the correct turn to be made at such locations. Such a learning strategy has obvious problems when subjects encounter a detour during the task or if they begin at a novel point on the path. In either of these scenarios, one would expect a decrease in performance to occur.

The fact that subjects can make detours and begin at novel points in mazes indicates that a more effective method or strategy must be available. The benefits of learning the larger environmental relationships in a maze become obvious at this point. Tolman's (1948) animal studies suggested that as an animal acquires a greater amount of experience in a particular maze network a mental representation or "cognitive map" of the space is formed. That is, the subject is able to be more flexible in completing the task due to a greater comprehension of the spatial relationships within the maze. In Tolman's original study, it was suggested that the experimental rats which ran through a series of pathways toward a goal box grasped the relationship between the start and the goal and could thus plan novel routes between the two.

A cognitive map can be summarized as:

> . . . a construct that has been proposed to explain how individuals know their environment. It assumes that people store information about their environment in a simplified form and in relation to other information they already have. It further assumes that this information is coded in a structure which people carry around in their heads, and that this structure corresponds, at least to a reasonable degree, to the environment it represents. It is as if an individual carried a map or model of the environment in his head. The map is far from a cartographer's map, however. It is schematic, sketchy, incomplete, distorted, and otherwise simplified and idiosyncratic. It is, after all, a product of experience, not of precise measurement. (Kaplan, 1973, 275-6)

During its initial development, the cognitive map provides the user with information which could be considered somewhat inflexible since it is based on the sequential manner in which it is acquired. Route knowledge, as it is referred to, is initially based on the recognition of landmarks in the environment followed by information with regard to the routes between these landmarks (Siegel & White, 1975). Hart and Berzok (1982) described the progression of route knowledge from a reliance on topological information to the relationship of segment lengths or time observances between landmarks (i.e., routes) without directional information. Once directional information is included, the cognitive map takes on a stimulus-response quality in which the minimum knowledge of appropriate turns is stored (Thorndyke & Hayes-Roth, 1982). As there are obvious limitations with this type of knowledge as the requirements of the traveller change due to detours, the particular relationships between points require a more sophisticated strategy or medium that must be available to the pedestrian.

A more "sophisticated" representation is believed to include information about paths which have not been traversed by the subjects and exist between " . . . *all* the relationships among the critical points [in the pathway] . . . " (Levine, Jankovic, & Palij, 1982, p. 160). This representation contains what is referred to as configurational or survey knowledge and, once developed, the individual has the benefit of being able to extract information from the cognitive map that was not available in earlier versions. The additional properties include knowledge of spatial relationships among points or places not experienced in a sequence, as well as the distances between them.

The essence of survey knowledge is expressed by the equiavailability principle (Levine, et al., 1982). The equiavailability principle implies that judgements of distance and orientation between the relationships of learned or inferred points can be made equally well. Levine et al. (1982) provided evidence to suggest that acquiring survey knowledge of a series of points would allow for movements between points that had not been experienced and that the direction in which the relationships between the points were initially learned would not be a factor. Support for this claim was found in both manipulatory and ambulatory tasks.

Further investigation by Hanley and Levine (1983) appeared to extend the applicability of the equiavailability principle and its relevance to survey knowledge. With the use of a manipulatory task, these researchers investigated the ability of subjects to integrate two independently learned pathways into a composite of one cognitive map. Integration was accomplished by announcing that one point on both pathways represented the same location in the environment. Subjects were found to be equally accurate in judgements of orientation when simple forward (SF) and within-shortcut (WSC) movements were performed in one learned pathway. These movements were collectively referred to as within-pathway movements (WPM). Simple forward movements involved judgements between points that had been experienced previously while shortcuts involved judgements of inferred relationships. The inferred movements made between two integrated pathways (BPM), were found to be imprecise. However, further experimentation revealed that when individual and integrated pathways were matched in terms of their memory rating,[2] within- and between-path movements at the extremes of the rating system were equal in angular error. This implies that survey knowledge of an integrated cognitive map can be achieved if certain properties or strategies exist to extract such knowledge.

There appears to be a progression of the cognitive map in its degree of usefulness or application to environments. Evidence from Hanley and Levine (1983) would go so far as to suggest that survey knowledge, in some degree, also exists between integrated cognitive maps and thus provides an entirely new area of research on the topic.

Factors important to cognitive map research

The scale used in testing spatial ability must be clearly stated since different spatial information processing may be required at different scales (Cleaves & Royal, 1979; Hollyfield, 1982; Brouchon, Joanette, & Samson, 1986). Further evidence of different processing requirements for specific scales occurs in Balint syndrome in which patients are unable to point accurately at objects in near space (within arm's reach) due to a cognitive deficiency but are able to perform well in far space (space in which locomotion is required) as manifested in wayfinding or spatial orientation tasks (Passini, 1987).

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[2] Memory rating was a method used by Hanley and Levine (1983) to equate an individual's knowledge of an individual three-point path and an integrated path from memory based on a scale of 1 (poorly remembered) to 10 (well remembered).

In general, cognitive map research has concentrated on the exploration of large-scale spaces such as neighbourhoods, towns, and cities. Large-scale space has a number of criteria which differentiate it from other spatial scales (Lederman, Klatzky, Collins & Wardell, 1987). A participant in large-scale space is required to be enclosed by this space (Acredolo, 1981) and is not able to observe the environment from a single vantage point (Kuipers, 1978). The latter point thus implies that the observer must make some degree of movement in order to achieve multiple views of the environment. Gärling, Böök, and Lindberg (1985) believed that multiple views could be most easily achieved by whole-body locomotion. Locomotion was suggested to be a medium that was able to maximize the amount of information that could be made available to both the perceptual and the cognitive systems.

During the period in which individuals are learning the large-scale environment, investigators have suggested that there are elements within the environment to which particular attention is paid. There are two major views which appear to contradict each other in terms of the importance of these elements within the environment. Hart and Moore (1973) and Siegel and White (1975) proposed that mental representations of large-scale space are initially landmark-based. Incorporating the information provided from the paths between the landmarks was believed to occur at a later point in time. After this point, the paths and landmarks become clustered in a loose manner before reaching co-ordination into a survey representation or map.

On the other hand, geographers' research from Lynch (1960) and Appleyard (1970), using data collected from drawn sketches, has shown that there is a primary use of paths or routes in learning an environment. When a person becomes more familiar with the environment, landmarks become primarily used for spatial orientation (Evans, 1980) since they can be easily summoned from memory for more elaborate manipulations within the environment (Hollyfield & Foulke, 1983).

An explanation of the differences in the utilization of pathways or routes and landmarks in learning an environment may be due to the physical structure of the environment (Evans, 1980) and where the attention of the subject is focused (Hollyfield, 1982). Also an individualized orientation system of landmark dependence versus path dependence may help to explain the differences in learning strategy (Evans, 1980). Evidence from Trent (1971) suggests that there is also a component of acculturation which determines the learning strategy used by children.

The existence of an intersection in the pathway configuration has been shown to be a significant physical property in the development of a cognitive map. Passini and Proulx (1988) had congenitally blind and matched sighted subjects[3] led over a complex pathway that they would later have to complete alone. As part of the experiment, before they actively traversed the pathway alone, subjects were required to describe the decisions that would be made during their intended trek to reach their goal. Two criteria were used to classify the decisions taken; one was the behaviour they required (e.g., "look for . . .") and the other, the physical place they referred to (e.g., corridor, stair, etc.). It was suggested that regardless of the perceptual ability of the subject, a decision must be made at an intersection.

Evidence of the importance of intersections can also be found from an experiment in which a route was provided to subjects as a series of slides (Allen, Siegel, & Rosinski, 1978). Subjects were asked to identify slides which they would deem as having either high- or low-landmark potential in terms of helping them to navigate through the slide presentation route. It was found that intersections and changes in heading had high-landmark potential.

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[3]Matched sighted subjects were matched with their congenitally blind counterparts in terms of age and sex directly, and socio-economic variables indirectly. These matched sighted subjects were usually acquaintances of the blind subjects.

Sadalla and Staplin (1980b) attempted to determine the effect that increasing the number of intersections in a pathway would have on the subjects' later estimation of traversed distance. Using a ratio-scaling method,[4] subjects consistently estimated pathways which contained more intersections as being longer than routes containing fewer intersections. Also, the number of crosspaths that were varied at each of the pathway intersections did not appear to be a factor in their estimation.

Even though there may be an intersection encountered during the path's traversal, it does not necessarily mean that the pedestrians will change their direction of travel. However, changes in direction are common in urban as well as experimental situations and, as such, deserve consideration in regard to their effect on cognitive maps.

An appropriate beginning for this discussion is a single change of direction or a turn. Sadalla and Montello (1989) explored the influence that a single change of direction at various angles had on the ability of subjects to maintain orientation to the start of the pathway. The angles used varied from fifteen to one hundred and sixty-five degrees. Sadalla and Montello suggested that in fact angular changes were remembered and internally coded relative to an axis directly forward of the subject and another that was orthogonal to the first. This view was based on the pattern of the error data from the estimations of angles traversed and the estimates of the original direction of travel. In each case, as the amplitude of the angles differed from the preferred axes, the error scores increased. An additional finding from the pattern of error scores about ninety degrees suggested a distortion of the estimations in the direction of ninety degrees. Paths with angles of

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[4]Ratio-scaling method refers to a method of estimating a physical distance in terms of a smaller scale usually in "pencil and paper" drawings of the environment encountered. It is performed based on the knowledge of a reference path in real space and a line of specific distance on the paper.

less than ninety degrees were always overestimated while paths with angles of more than ninety degrees were underestimated.

There appear to be some consistent patterns in errors that occur when subjects are requested to estimate angles. This is especially true of urban routes according to Byrne (1979). In his experiment, the subjects, who were all familiar with the area used for testing, tended to bias the drawings of the angles at which roads joined towards ninety degrees. Byrne attributed this discrepancy to insufficient memory of the actual shape of the intersection and a heuristic which did not use spatial representations that encoded vector information but rather only a binary system of left and right turns.

Sadalla and Magel (1980) investigated the perception of traversed distance by manipulating the number of ninety degree turns that would be included in pathways of the same length. Using a ratio-scaling method of measurement, the findings indicated that pathways with a greater number of right-angle turns along pathways of the same length were estimated as being longer than those with a fewer number of turns.

Changes in direction are not necessarily abrupt as described above; they can be gradual. Research has addressed the effect that bends or curves have on mental representation. For example, Byrne (1979) had subjects estimate, using ratio-scaling, the walking distances between a pair of sites. The routes connecting the sites varied in terms of three independent variables: location of the routes in terms of their surroundings, as the routes used were either within the city centre or in suburban areas; the number of major bends or turns in the routes and the actual length of the routes. Main effects were found for all of the independent variables. Routes in the centre of the city and those with several bends were estimated as longer. The author suggested that the finding that the shorter routes were proportionally overestimated when compared to longer ones may have been an artifact of the distances chosen or the ratio-scaling method itself.

Relevance of experience

When investigating the use of a cognitive map by humans, many researchers have used concrete examples such as going to a place of employment, or to any other familiar location that people encounter in their daily activities (e.g., picking up children after school or going to a grocery store). It is then pointed out that little, if any, mental effort is required to arrive successfully at their goals, even though integration of information in a constantly changing environment is encountered. This emphasis on a "Common-sense knowledge of space . . . " (Kuipers, 1978, p. 129) and the familiarity of the journey was purposefully included in these studies because central to the concept of map development is the necessity or benefit of experience. Gärling et al. (1984) went so far as to suggest that as a person acquires more experience in an environment, it becomes " . . . almost superfluous for the traveler to monitor his or her location" (p. 24). As a result, one's ability to adapt to delays due to detours or unexpected breakdowns becomes a much easier task with experience.

In the preceding paragraph, "experience" referred to physical movement within the environment. However the definitive benefits of physical experience are not reflected in the relevance of visual experience. Research evidence both supports and questions the benefit of visual experience in creating a representation of an environment and being able to use this knowledge effectively. For example, on a stylus maze task, Koch and Ufkess (1926) concluded that visual experience of some type, whether it be immediately present or had existed at some earlier point in time, was advantageous to the learning of spatial relations. Others, notably Rieser, Lockman, and Pick (1980), have also found that visual experience is a factor in the accuracy of Euclidean judgements and spatial tasks. Cleaves and Royal (1979) also supported the importance of visual experience in pointing to maze locations in which the mazes retained their originally learned orientation (unreflected mazes), and in mazes which were rotated about the horizontal or vertical axis (spatially transformed mazes). However, in an additional experiment, manipulating the amount of information available to the subjects, resulted in the interpretation that in simple mazes, late blind and sighted subjects use an exact localization strategy. Congenitally blind subjects adopted a general area plus distance strategy in simple and complex mazes. This strategy was also used by the other subjects when the maze became more complex. Such a finding appears to suggest that exact localization is only possible when vision has been available to a subject and that the strategy used by the congenitally blind can only result in a " . . . general area or directional spatial localization" (Cleaves & Royal, 1979, p. 19).

On the other hand, Jüürmaa (1973) concluded from his experiments with subjects congenitally and adventitiously blind, and blindfolded sighted individuals, that spatial orientation was not reliant upon prior visual experience. In support of this, Hollyfield (1982) concluded that prior visual experience was not essential for success in forming spatial representations of a residential neighbourhood since success rates in the early and the late blind groups had been equal. Passini and Proulx (1988) found when analyzing sketch maps of the complex routes learned by congenitally blind and sighted individuals that there was no difference in errors of disposition (incorrect placement of objects in the environment) or composition (inclusion of contents of the encountered environment) and concluded that spatial recording of the route between the groups was comparable.

Several investigators have questioned the ability of the visually impaired to adapt to new situations on a route such as when a detour or a shortcut is to be made. Hollyfield and Foulke (1983) found that there was no relationship between the visual status of an individual and the effectiveness of traversing a detour. In this experiment, however, there was no degree of effectiveness measured, only a qualitative measure of a successful or unsuccessful detour. This may have biased the conclusion drawn by the experimenters. Other researchers such as Passini and Proulx (1988) have supported the notion that visually impaired individuals are capable of performing shortcuts in complex routes through their development of a cognitive map of the area. Further support was provided by Jüürmaa (1973) in finding that there was no difference between congenitally and adventitiously blind subjects in taking shortcuts and that both of these blind groups performed better than blindfolded sighted individuals. As evident in Jüürmaa (1973), experimentally produced visual impairment has occasionally been "induced" by blindfolding sighted individuals. However, there may be compensatory heuristics adopted by the blind that are not immediately available or not frequently used by the sighted individual that aid in traversing a route, such as environmental regularities or the use of echolocation (Strelow, 1985).

There have been suggestions from researchers in this field of study that the comparison of blind and sighted individuals on tasks of spatial cognition and cognitive maps is not warranted (Hollyfield & Foulke, 1983). The sensory data used by each are different in nature with the sighted relying on spatially oriented data from vision and the blind utilizing data from sensory systems that are not normally associated with spatial understanding, such as audition and haptics (Strelow, 1985; Foulke, 1982).

Another consideration is the fact that the sighted pedestrian has the distinct advantage of being able to utilize information that is encountered while the task is occurring as well as from a memorial representation. Contemporaneous information is used to a lesser degree by the blind because of their inability to pick up spatial information as effectively during egomotion. Thus, the blind individual must rely to a greater degree upon a memorial representation, one which is, unfortunately, based on a representation of lesser quality than that of the sighted (Hollyfield &

Foulke, 1983). However, the sighted, because they are always able to utilize contemporaneous information, may tend to use this information as a "crutch" and therefore may occasionally be unable to form an effective memorial representation or may form one which is more schematic in nature (R. B. Horsfall, personal communication, June 17, 1991).

From the evidence presented above, it would appear that cognitive mapping by blind persons is possible but involves additional processes in order to achieve relative equality in performance with sighted subjects. Passini and Proulx (1988), for example, found that blind individuals, when guided through an architectural setting, plan subsequent journeys in more detail, make more decisions during the journey (implying an increased index of difficulty) and depend on more units of information than a matched group of sighted subjects. However, in the same study, a cognitive mapping exercise using model construction of the route found that a congenitally blind person and a sighted person did not differ in terms of the number of errors of disposition or composition. This exercise suggests that the congenitally blind are able to record a spatial pathway mentally and that vision is not a necessary prerequisite for creating a cognitive representation of the space encountered.

Another example of these additional processes could be provided by the effect an interruption can have on the cognitive map formed during the traversal of the pathway, especially by blind individuals. Due to the lack of previewing skills and effective scanning, the blind pedestrian is subject to his or her attention being abruptly redirected away from attaining the goal of the journey whenever an unexpected incident occurs. A pedestrian, in this situation, can easily lose orientation in the environment and be unable to relocate effectively. However, there appear to be compensatory strategies available that can counteract the interruption's effect.

Investigators have implied that there is a compatibility between the stimuli provided to vestibular and somatosensory modalities in navigation strategies (Potegal, 1982). Kinesthetic information has been suggested as an overriding component in the updating of position during an interruption of walking a path. Blind individuals may have to use this navigation strategy more often in order to achieve relative success compared to sighted counterparts.

Extraction of internal representations

Due to the "internal" nature of the cognitive map, different methods have been utilized to "externalize" the map so that direct quantitative and qualitative measurement of its properties can be made. Much of the research on cognitive maps of environments has used a handful of methods.

Introspection was considered by some, in the early 1900's, to be an effective method of describing representations of space (Lee, 1976). When one attempts to use verbal recall as a method of investigation there are inherent confounding factors. The most obvious problem of concern is the possible lack of linguistic ability, especially for children (Siegel, 1981). Also, there is the additional problem of the " . . . *simultaneous*. . . . input [being] transform[ed] into *successive* output" (Siegel, 1981, p. 171). Any attempt to draw significance to the order in which subjects present their image of the encountered environment lacks scientific validation. Verbal recall, or in other words, introspection, is not considered a valid way to externalize the internal representation of space (Neisser, 1976).

The simplest and most frequently used technique of externalized cognitive maps is the use of hand-drawn sketches of the areas encountered (e.g., Lynch, 1960; Appleyard, 1970). Even though such a method may provide information on the basic physical elements included in their map and possibly the order in which subjects rely on these elements in their developmental strategies, a number of factors must be considered.

First of all, the technical drawing ability of the subject can have a profound effect on the map from which the investigators will derive their conclusions (Byrne, 1979). Kosslyn, Heldmeyer and Locklear (1977) suggested that, especially with children, the externalized drawn map is not an accurate representation of what they know of their environment. Also, the technical drawing ability of congenitally blind subjects, who may not understand the concept of drawing, renders this method questionable (Dodds, Howarth, & Carter, 1982).

Secondly, the parameters of the task, such as scale, may result in methodological problems. Siegel (1981) believes that the "translation" between the scale in which the map was developed to the externalized method of a smaller scale may have an effect on the findings. Scale has also been said to affect the sketches of subjects since they are dependent on " . . . the size of the drawing surface and the order in which things are drawn" (Evans, 1980, p. 264). Evans (1980) further pointed out that the size of the drawing surface would have an effect on the sketch-map since more detail and representative scale of items may be produced on larger surfaces as fewer limitations are encountered by the subjects. In support of this, Byrne (1982) pointed out that the final configuration of the map will be determined by the starting point of the drawing because cumulative errors will distort the map in a particular direction.

Occasionally areas of a map are drawn disproportionately larger, as is the case with Inuit hunters (Pelly, 1991). It has been suggested that this may be due to the drawer having a better comprehension of a particular area. Another possible explanation may be due to the inconsistent nature of the terrain experienced and the subsequent differences in the amount of energy and time that is expended to traverse the area.

Another commonly used method of externalizing cognitive maps is the construction of small-scale models of the environment encountered (e.g., Passini & Proulx, 1988). This method has the benefit of not relying on the drawing ability of the subjects, but is still confounded with the change in scale from which cognitive maps were developed to the construction of the model of a different scale (Siegel, Herman, Allen, & Kirasic, 1979). These researchers provided evidence that children were successful at reconstruction of models at the same scale as their original learning environment, but transitions between scales were not as effective. Other important factors include the placement of the models in testing rooms of bounded and unbounded space as external cues have been shown to benefit the learning sequence (Herman & Siegel, 1978).

Form of the representation

One of the major discussions about cognitive maps centres on or around the form of representation. Generally, there are two models which attempt to explain how the physically explored environment is represented cognitively. A propositional model (e.g., Pylyshyn, 1973) suggests that all information is coded and stored as a series of lists based on abstract concepts (e.g., political, geographical, geometrical). On the other hand, an imagery-based model proposes spatial information is stored in a format which is similar to the physical structure of the actual environment (e.g., Kosslyn, 1975). Only the latter model will be considered in this review.

By using the term "map", Tolman (1948) may have inadvertently directed the progression of research on the "map" toward its more commonly used connotation from geographers as being cartographic in nature. As Downs (1981) pointed out, when one discusses a map " . . . the modifier cartographic . . . [is] implicitly assumed" (p. 144). Many researchers, including Gärling et al. (1984), believe that as a pedestrian becomes more knowledgeable about the environment, the cognitive map developed becomes a simplified representation and thus takes on more properties of a cartographic map.

As mentioned earlier, if a survey representation of an area is developed, one is not required to have encountered all of the components of the environment. A similar situation was described by Downs (1981) with regard to cartographic maps in which he states "As Toulmin argues, not all of the retrievable information is deliberately "put" into the [cartographic] map in the first place. We can "read off" new information. Maps can help us to discover ("see") previously unsuspected patterns of relationship (structures)" (p. 158). This statement has direct relevance to the cognitive map and the form that it is suspected to take.

There appears to be some evidence that certain properties which are thought to exist in studying cognitive maps correspond to measurable physical and spatial attributes (distance, shape, and direction) of actual maps and geographical settings. One such finding was that of Evans and Pezdek (1980) in which subjects were to decide on which of two pair of campus buildings were closer in physical distance to each other. As the ratio of the interpair distances approached one, the decision time increased linearly. This finding was replicated with the use of two pairs of American states. Further evidence has shown that scanning times across visual images increased as the correspondence to actual physical distances increased (Kosslyn, Ball, & Rieser, 1978).

A cognitive map has also been described as picturelike and, as such, takes on imaginal properties (Levine et al., 1982), as well as measurable and manipulative properties normally associated with pictures (Kosslyn, 1975). Klatzky, Loomis, Golledge, Cicinelli, Doherty, & Pellegrino (1990) investigated the acquisition of survey knowledge without vision and found support for the existence of an imaginal representation as shown by the similarities in the turning errors across a change in scale in a series of walking tasks. Furthermore, neither a homing-vector nor a trigonometric-computation model could account for the configurational effects encountered in performing the navigation tasks. However, these investigators felt that imaginal processing of the information would be sensitive to the configurational properties.

Other examples of the use of imaginal representations were found in experiments conducted by Lederman et al. (1987). Blindfolded subjects judged the straight line distance between path endpoints of a triangle using either their hands or feet and were asked what strategy if any was used to complete the judgement of the Euclidean distance. Most of the subjects reported forming a visual or mental image of the pathway and then estimating the length of the missing portion of the triangle.

Horowitz (1983) would suggest that the visualization of appropriate images would be extremely useful in solving the geometric problems experienced by subjects in Lederman et al. (1987). However, images are not " . . . merely imitations, but rather memory fragments, reconstructions, reinterpretations, and symbols . . . " (Horowitz, 1983, p. 4). In this description there is a sense that images are not perfect, stable entities and are modified by idiosyncratic information that the imager may contain in memory and thus are expected to be subject to distortion. The same could be said of imagery-based cognitive maps.

The nature of distortion in imagery-based cognitive maps appears to be toward a ". . . simpler and more organized form . . . " (Lloyd, 1982, p. 537). For example, there is evidence to suggest particular distortions in estimating angles between urban routes (Byrne, 1979) and laboratory routes (Sadalla & Montello, 1989) as being closer to ninety degrees than they actually are. Also, there appear to be certain systematic distortions that occur when people draw maps of areas that are familiar to them (Evans, 1980). Gradual curves tend to be straightened and nonparallel streets become aligned (Appleyard, 1970; Byrne, 1982; Lynch, 1960).

Symmetry as a factor in the creation of cognitive maps

Evidence of symmetry is readily available in nature, architecture and art. "Balance, agreement, order and harmony . . . " (Martin, 1982, p. 168), are some of the adjectives that have been used to describe what symmetry provides. While there are examples of the investigation of symmetry in many areas of psychology, particularly in perception (Howard & Templeton, 1966; Corballis & Roldan, 1975; Rock, 1973; King, Meyer, Tangney, & Biederman, 1976), there has only been limited attention devoted to its relevance in cognitive maps (e.g., Lloyd & Heivly, 1987; Tversky, 1981). One could assume that the above descriptors of symmetry are also appropriate to describe the underlying purpose of simplification of imagery-based cognitive maps toward a preferred or stable state. Such a conclusion is supported by Rosen (1983) in which he states " . . . it is generally agreed that symmetry contributes greatly to simplicity" (p. 136) and by the Stability Principle (Leyton, 1992) which states "The more symmetric a configuration is, the more stable it is understood to be" (p. 13).

The Stability Principle is only one of a number of principles that Leyton (1992) developed in terms of substantiating the importance of symmetry in cognitive activity. The two cornerstone principles include the Asymmetry and Symmetry Principles. Restated in the context of cognitive maps, the Asymmetry Principle would suggest that an experienced asymmetric configuration would likely distort itself toward a more symmetric representation. On the other hand, the Symmetry Principle suggests that when a symmetric configuration exists, distortion is minimized since it is already in the preferred state.

Horowitz (1983) suggested that images are adapted to " . . . familiar patterns and forms [which] serve as schemata or templates . . . " (p. 188). These schemata or templates are influenced by symmetry (Horowitz, 1983). In the simplification of cognitive maps, symmetry is suspected to be a factor in the distortion process and this would be especially evident in pathway configurations which are considered complex.

There are several other factors that need to be kept in mind when one discusses symmetry and its properties. There are certain imperfections or accepted distortions which have been allowed to remain unscrutinized. As Bunch (1989) discussed: " . . . mathematicians and scientists have agreed that when one part looks just like the other, they will use the word symmetry to describe the situation even when one part is <u>not</u> [underline added] a mirror reflection of the other" (p. 74). Thus, even though there are deviations from the mathematically precise reflective properties, some distortion is accepted as inherent in the system (Shubnikov & Koptsik, 1974) and yet remains described as symmetrical as long as these deviations remain within a certain acceptable range. There is concern, however, that as these distortions increase, the degree of symmetry must decrease in some yet unknown inverse relationship.

Thus far symmetry has only been discussed in terms of its potential distorting nature in imagery-based cognitive maps. However, one would suspect that a cognitive map which is formed from a configuration that is more symmetric is expected to provide a greater amount of redundant information which allows for greater ease of encoding and retrieval of relevant information. If such is the case, only a minimum amount of distortion would be expected and the production of more accurate judgements of distance and orientation result.

Quantification of symmetric properties allows one to prioritize, or at least produce a hierarchy of symmetry in comparing one figure with another. The measurement tool to be used assumes that each type of symmetry does not have a differential importance or magnitude over other symmetries (Rosen, 1983). Thus, a system of ordering the degree of symmetry of a figure can be determined by the number of symmetric transformations that can be performed on it.

There are a number of different types of symmetry which can be described within a figure. The degree of symmetry is determined by the number of symmetrical transformations which can occur. These transformations can occur either by translation, rotation or reflection of the figure (Bunch, 1989).

The first and simplest form of symmetry to be considered is reflection symmetry. This form of symmetry is most common to the layperson due to its frequency of occurrence in nature. It is obvious that the use of a mirror and the properties of reflection are inherently important in symmetry. In certain figures, the mirror can be considered the "symmetry plane" since only one placement divides the image into two equal parts, each a "mirror image" of the other (Shubnikov & Koptsik, 1974). Translation symmetry can be explained by the movement of a group of points in a figure an equal distance along a straight line such that those points map onto themselves on another portion of the figure. This line is referred to as the "translation axis". This type of symmetry is very common on the exterior of architecture, usually shown in the form of ornamentation. A less common type of symmetry is determined by a rotation of the figure about a line, a symmetry axis, which causes the figure to map onto itself more than once. Appropriately, this is called rotational symmetry. Of concern in this type of symmetry is the number of times that a figure can be rotated onto itself in one 360 degree rotation. The number of coincidences is referred to as the "order of the axis".

Based on the determination of the degree of symmetry, an equilateral triangle produces three transformations by the presence of rotational symmetry and three transformations by reflective symmetry. Therefore the order of the object is the total of these transformations, six. In a square there would be eight transformations that may be observed, and an infinite number in a circle, each resulting in an increase in symmetric content.

In cognitive maps, it may be possible to maximize the ease with which relationships of orientation and distance can be performed by manipulating the symmetric properties of the pathways so that greater amounts of redundant information are available for use.

Chapter III

Experiment 1 - The effect and detection of differences in configurations

In the review of the literature on cognitive maps, there have been several areas discussed which provide an opportunity for further investigation. There are two main areas of concern investigated in the experiments which follow; complexity of path configurations and symmetry.

A number of assumptions were made in the experiments conducted. First, it was expected that a cognitive map of the spatial configurations would be formed. Second, that the created cognitive map would be imagery-based and contain survey knowledge. Third, that individuals use a similar strategy to learn the spatial configurations encountered. Fourth, that the use of blindfolded sighted individuals would alleviate many of the confounding factors associated with using and finding an adequate number of blind or visually impaired individuals (e.g., problems with mobility, vestibular damage, neurological diseases). Fifth, that by using blindfolded sighted subjects only information from the proprioceptive system was available for creating a cognitive map and that external cues were minimized. Last, that the conclusions of these experiments could be generalized to individuals which have had some visual experience and thus application to adventitiously blind individuals would be appropriate, but no relevance to the situation of congenitally blind individuals is assumed.

Rationale

Throughout the previous chapters, findings have been cited from several researchers who have investigated properties within the cognitive map environment to promote a better understanding of the map itself (Passini & Proulx, 1988; Sadalla & Staplin, 1980; Sadalla & Montello, 1989;

Byrne, 1979; Klatzky et al., 1990). Few have dealt with pathway configurations which are considered complex.

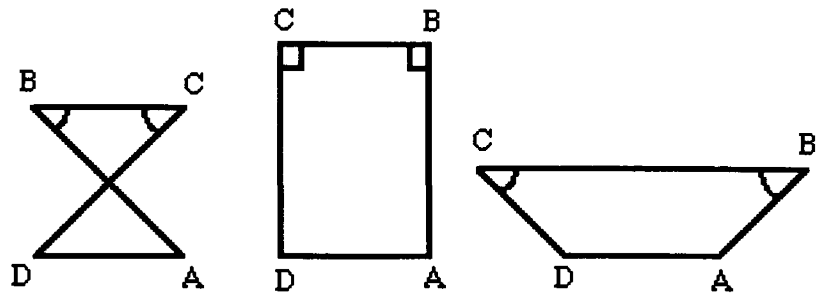
The complexity of experimental configurations has been increased by increasing the number of segments in a configuration as well as by manipulating the angular relationship of the segments to each other (Klatzky et al., 1990). In a complex navigational walking task conducted by Klatzky et al. (1990), one of the experimental configurations had paths which crossed each other during the course of the learning sequence. The investigators commented that the specific characteristic of the crossing of paths was not detected by all subjects and this failure resulted in large errors in judging the orientation to the target. However, other experimental methods of extraction, namely drawings, may provide evidence that the detection of such characteristics of the configurations is possible.

The detection of the crossing of paths in a configuration also brings into question the internal angles created by the cross and whether these angles have some effect on the ability to detect the crossing itself. If angles are remembered as being distorted towards ninety degrees as has been suggested (Sadalla & Montello, 1989; Byrne, 1979), then the chances of detecting the crossing of the pathways is decreased.

Research Hypotheses - Drawings

1) It was hypothesized that the unique features of experienced pathway configurations are detectable and thus drawings of such configurations would indicate these features. A "success" occurs if at least two of three drawings of each configuration are correct according to established criteria.

Figure 1. Criteria for scoring drawings of configurations as correct.



	Treatment 1 (T1)	Treatment 2 (T2)	Treatment 3 (T3)
Internal Angles	Acute	Ninety +/- 5 degrees	Acute
Crossing Paths	Yes	No	No

Statistical Test Proportion of Success where $p_{expected} = 0.125$.

Statistical Hypothesis $H_o : p_{obtained} \leq p_{expected}$

2) It was hypothesized that after experiencing a configuration in which paths crossed, the detection of this property is possible and thus drawings would reveal this feature. A "success" occurs if three of three drawings are correct according to established criteria.

Statistical Test Proportion of Success where $p_{expected} = 0.125$.

Statistical Hypothesis $H_o : p_{obtained} \leq p_{expected}$

3) Ratio-scale drawings can be used as a means of evaluating the perception of segment lengths. It was hypothesized that the complexity of pathway configurations would affect the judgement of paths of equal length and thus differences in the signed deviations from the "correct" length (CE)[5] would indicate greater errors for more complex paths. The variability (VE) of this measure was

[5]In all three experiments an individual's score of absolute or signed deviation error was based on the mean value of the trials. Measures of variability were calculated based on these trials.

also evaluated. Two ratio-scale drawing tasks were completed. The first task required that the angles between the segments be included in the drawing. If significant differences were found, then the analysis of the drawings with segment lengths drawn end to end in a straight line would be assessed.

Statistical Test Contrast of Treatment means

Statistical Hypothesis $H_o : \overline{error_{T1}} = \overline{error_{T2}}$

4) It was hypothesized that inferred distance would be affected by the complexity of the pathway configuration and, as such, ratio-scaled drawings would indicate greater errors for the more complex configurations.

Statistical Test ANOVA

Statistical Hypothesis $H_o : \overline{error_{T1}} = \overline{error_{T2}} = \overline{error_{T3}}$

5) Drawn angles would shift toward 90 degrees and therefore errors would be larger for the configurations with internal angles of 45 degrees (Treatment 1 and 3) when compared to 90 degrees (Treatment 2). Error was determined by the signed difference between the target angle and the drawn angle. The variability of the error was also evaluated.

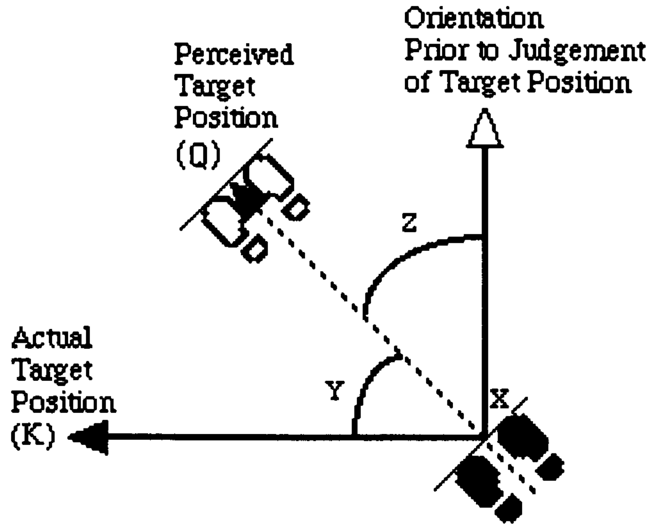
Statistical Test: Contrast of Treatment means (one-tailed test)

Statistical Hypothesis $H_o : \overline{error_{T1+T3}} \leq \overline{error_{T2}}$

Research Hypotheses - Locomotor Movements

1) The judgements of angular movements and distance are affected by the complexity of pathway configurations. It was hypothesized that greater errors would appear in more complex configurations. Errors to be used in the evaluation of the judgement of angular movements and distance are illustrated in Figure 2 and are used in all three experiments.

Figure 2. Measurement of error for ambulatory tasks.



The minimum absolute turning error (MAE) referred to the minimum number of degrees a subject was from the target orientation regardless of the direction turned. In the above example this is represented by the absolute value of Y. The error turned to the target (CETT) referred to the signed angular deviation from the target orientation. Judgements made which overshot the target were recorded as positive values; negative values resulted from judgements short of the target. In the example above CETT would be -(Y). The variability of this measure was also evaluated (VETT).

The magnitude of the turn was recorded (MAG). In the example above, the MAG value would be Z. The signed angular deviation to the magnitude turned (CEMAG) was calculated based on the signed difference between the target magnitude (Z+Y) and MAG. In the above example, CEMAG would be -(Y). The variability of this measure was also evaluated (VEMAG). An additional angular movement error was calculated based on the CEMAG value divided by the target magnitude to be turned and will be referred to as the percentage error (CEPER). In the above example CEPER would be -(Y/(Y+Z)). The variability of this error was also evaluated (VEPER).

A measure of distance error was calculated as the signed deviation from the target distance (CEDIST). In the above example CEDIST would be -(KX-QX) since QX < KX. The variability of the distance error was also evaluated (VEDIST).

Statistical Test ANOVA

Statistical Hypothesis $H_o : \overline{error}_{T1} = \overline{error}_{T2} = \overline{error}_{T3}$

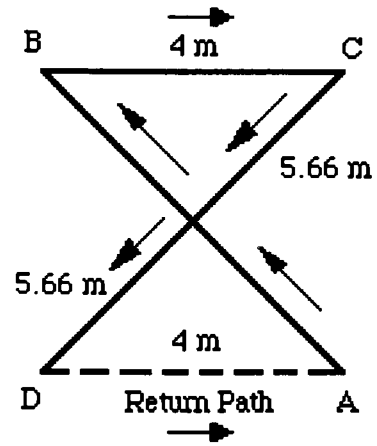
Method

Subjects. Thirty-six sighted university students were paid for their participation in the experiment. The subjects reported no physical disabilities. All had normal vision or corrected vision with glasses or contact lenses. An equal number of males and females was used. The subjects' ages ranged from 18 to 37 with the mean age being 23.3 years.

Design. A balanced crossover design with repeated measures on three levels of pathway configuration was employed. The subjects were distributed into six different sequences of learning the three configurations. An equal number of male and female subjects were in each sequence. Otherwise distribution was random.

Stimuli. Three pathway configurations were used for this experiment. All configurations were composed of four segments which totalled 19.32 metres in length in what was considered medium-scale space (Gärling et al., 1984; Evans, 1980). The paths were all labelled A, B, C, and D from the starting to the stopping point, respectively. The test path was always represented on the configurations as a four metre distance from D to A. The first pathway configuration, Treatment 1 (see Figure 3) had the paths AB and CD cross each other. Arrows on the figures indicate the direction of travel. The length of paths AB and CD were 5.66 metres, while BC and DA were four metres in length. This created a configuration with angles ABC and BCD of forty-five degrees.

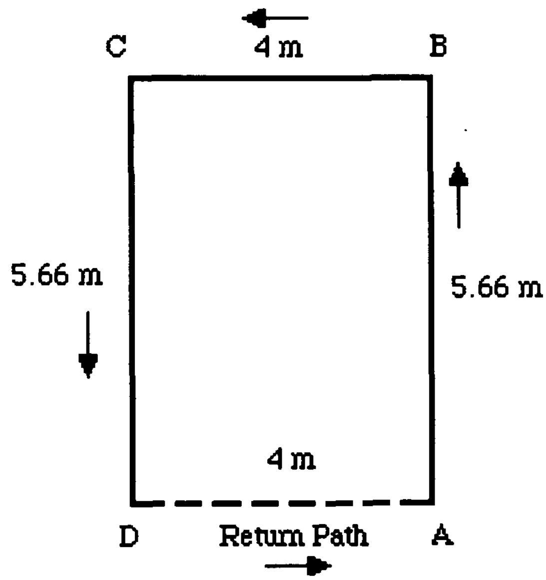
Figure 3. Experiment 1 - Treatment 1 test configuration.



Scale: 1 cm = 1 m

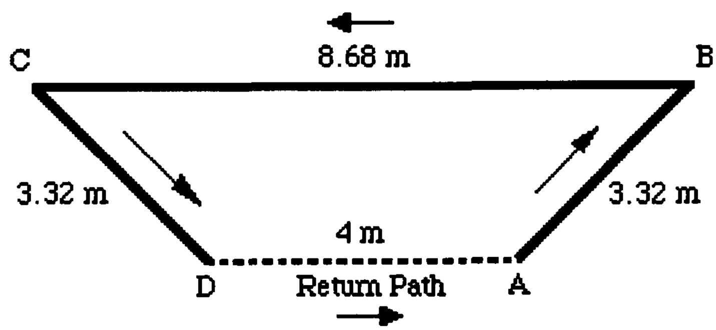
The second configuration, Treatment 2 (see Figure 4) had the same path lengths as Treatment 1, however the internal angles of ABC and BCD were ninety degrees and thus crossing of paths did not occur. Lastly, Treatment 3 (see Figure 5) had internal angles of forty-five degrees as in Treatment 1, however the segments did not cross each other. The lengths of AB and CD were 3.32 metres while the length of BC was 8.68 metres. The three path configurations were marked on the floor of a gymnasium measuring 24 by 12 metres. A reference path three metres in length was also marked on the experimental area.

Figure 4. Experiment 1 - Treatment 2 test configuration.



Scale: 1 cm = 1 m

Figure 5. Experiment 1 - Treatment 3 test configuration.



Scale: 1 cm = 1 m

Apparatus. Measuring devices included a steel measuring tape and an orientation device (see Figure 6). The orientation device attached to the feet of the subject and had a support which protruded directly in front of the subject's midline, at ground level. Attached to this support was a light pointer, which emitted a light beam in the same orientation as the subject, and a compass

(Brunton Pocket Transits, Dial Graduations: 1 degree) which was used in the measurement of orientation. A flat surface, situated approximately ten to fifteen metres from the light pointer, was positioned perpendicularly to the projected beam and was used to determine the line on which a steel tape measure was laid. A pencil, an eraser, two straightedges and paper were used in collecting the data for the ratio-scaling drawing tasks.

Figure 6. Orientation device.

Procedure. All subjects were met outside the testing area where detailed instructions and consent forms were provided (see Appendix A). Instructions were verbally reiterated to the subjects regarding the nature of the tasks to be performed.

After hearing the description of the tasks, the subjects were blindfolded, seated in a wheelchair and brought into the testing area. Upon entering the testing area, the subjects were brought to the beginning of the reference path.[6] Subjects were asked to stand and the experimenter led the subjects along the length of the reference path while maintaining the midline of the subject's body to the centre of the path. The experimenter led the subjects through the pathways using the method described in leading the visually impaired (see Appendix B). Again, it was explained to the subjects that remembering the length of this path would be important in two ratio-scaling drawing tasks that had been described previously. During the experiment, an assistant moved the wheelchair to an appropriate position each time a subject was walking along a path. Upon completion of walking the reference path, subjects were again seated in the wheelchair and brought to the starting position of the first path configuration and asked to stand.

During the training trials, subjects began at point A, and were led to points B, C, and D. The labelled points along the pathway were announced when the subjects were stationary at these points, prior to turning. At point D, the subjects were told to think about where the starting point of the pathway was relative to their present position. After approximately five seconds, the subjects were then seated in the wheelchair and pushed to the beginning of the reference path and asked to stand. The subjects were then led upon the reference path, seated in the wheelchair and brought to the starting position of the path configuration and led through four additional times. Between each training trial, subjects were disoriented while in the wheelchair.

For the first test trial on a particular configuration, the subjects walked through the experimental pathway as usual, however this time at point D, they were asked to establish an orientation to the starting point or goal. This was accomplished by turning their entire body in the direction of the starting point (A) so that their head, chest and feet were aligned in the same direction. The

[6] In each of the experiments, when subjects were seated in the wheelchair prior to a walking task (either on a pathway configuration or the reference path) or a drawing task, they were disoriented by being pushed around the experimental area in a meandering fashion for approximately 10 seconds. This procedure was followed in all three experiments.

subjects were instructed to turn in the direction of the smallest angle to the goal. After the subjects made the turn and felt that they were oriented properly to the goal, the experimenter measured the orientation of the subjects using the orientation device and mapped out the intended line of travel. Once this had been completed, the subjects were led along this path and told to stop walking when they felt they had reached the position of the goal. A measurement of the distance walked was made at this time.

Upon completion of the first test walking task, the subjects were seated in a wheelchair and brought to the reference path. Once the reference path was walked, subjects were brought to a desk situated within the experimental area. At the desk, the blindfold was removed and two ratio-scaling tasks were performed. The first task involved drawing the pathway configuration that they had just been trained and tested on with the appropriate angles between segments. The length of the paths between turns were to be represented based on a scale present on the paper and their knowledge of the reference path. The subjects were told that the length of the line on the paper marked J-K represented the length of the reference path. The length of J-K was also marked on one straightedge used for drawing. Subjects were instructed to draw the pathways, using the straightedge, as accurately as possible with the use of vision.

In a second ratio-scaling task, subjects attempted to estimate the segment lengths of the pathways without the angles, as experienced in the actual walking task. On a separate piece of paper, a line marked L-M was used to estimate the length of each segment such that they connected in a straight line. In both ratio-scaled drawing tasks, subjects were asked to label the points of the segments from the starting position (A) to the stopping position (D) and then continuing to the starting position (A). Subjects were not informed of the actual lengths of the J-K or L-M segments which were four and three centimetres, respectively.

In each drawing task, the subjects had approximately 90 seconds in which to complete the drawing. Once one set of drawings had been completed, the blindfold was re-applied and the subject performed the walking task on the pathway configuration. After this test trial, subjects were brought to the desk without walking the reference path and asked to draw the configurations based on the two ratio-scaled drawing tasks. The walking task and drawing tasks were repeated one additional time on the configuration. This process completed the testing of the first configuration. Once the subjects had been on the reference path during the testing procedure of one configuration, from this point onward they were asked prior to and after the first training trial of a configuration and immediately following the five training trials whether they wanted to walk the reference path an additional time. If requested, an additional "walk" was granted. The entire procedure was followed on the remaining test configurations.

During the experiment, no feedback was given to the subjects with regard to the error in degrees and distance to the target. Once all three of the testing trials had been performed (both walking and drawings), subjects were then asked to respond to the following question: "Was there any particular strategy you used in making your judgements? Drawing and walking tasks." The entire testing session took approximately one hour and fifteen minutes.

Results

In the calculation of main effects and interactions, gender was included as a factor in this experiment. Gender is not, however, the focus of the present series of experiments but has been included to provide evidence to support potential future experiments. If significant gender effects occur or gender interacts with other factors, these findings are mentioned but not discussed in detail.

All reported F values are given with their associated significance levels. A significance level of $p \leq 0.05$ was used in rejecting the null hypotheses. When post hoc analysis was appropriate, the Bonferoni method of correction for familywise error was used to determine significant differences.

The calculation of the proportion of success for the detection of the specific features of the pathway configurations revealed a significant difference between the proportion of success determined from the sample and that of H_o, $P(Z>4.28) = <0.0001$ (See Appendix C).

The calculation of the proportion of success for the ratio-scaled drawings of Treatment 1 was conducted to establish whether subjects were able to detect the crossing of the paths. The test of the proportion of success indicated a significant difference between the proportion of success of the sample and that expected under H_o, $P(Z>10.79) = <0.0001$ (See Appendix C). Subjects were able to detect the crossing of the paths in the configurations as indicated by ratio-scaled drawings.

Angled ratio-scaled drawings

Table 1. Contrast of adjusted treatment means for segments in angled drawings

Segment	Error	T1	T2	P-value
One	CE	-0.296	-0.526	0.2295
One	VE	0.238	0.235	0.9705
Two	CE	-0.364	-0.521	0.4337
Two	VE	0.215	0.169	0.6801
Three	CE	-0.820	-0.792	0.8895
Three	VE	0.289	0.276	0.8724

In the above analysis of treatment means, no significant differences were indicated. Differences between the "correct" lengths of the segments were not found. Additional analysis using the second ratio-scale drawing data was not warranted. For this experiment, examples of the statistical output from which the tabular data were derived are in Appendix C.

Table 2. Analysis of adjusted treatment means for the fourth segment in angled drawings

Segment	Error	T1	T2	T3	P-value
Four	CE	0.121	-0.663	-0.471	0.1207
Four	VE	0.443	0.350	0.537	0.2200

In the analyses conducted with the fourth segment, it should be noted that the judgement of this distance was not based on walking this length during the learning of the configurations but was inferred. No significant main effects for Treatment were found in the accuracy or consistency of drawing the fourth segment length.

Table 3. Contrast of adjusted treatment means for angles drawn (one-tailed)

Angle	Error	$\frac{T1+T3}{2}$	T2	P-value
First	CE	2.0	-2.6	0.3563
First	VE	6.3	3.5	0.1507
Second	CE	5.3	-2.3	0.1961
Second	VE	5.9	4.1	0.0970

In the angled drawings, there were no differences found between the combination of Treatments with 45 degree angled turns when compared to the Treatment with 90 degree turns.

Orientation judgements

Table 4. Analysis of adjusted treatment means for angular movement judgements

Variables	T1	T2	T3	P-value
MAE	54.2	25.4	42.4	0.0112‡
CETT	-79.4	-7.2	-0.8	0.0001‡†
VETT	35.9	9.9	16.4	0.0114‡
MAG	120.3	90.5	65.7	0.0001‡
CEMAG	-14.7	0.5	20.7	0.0004‡
VEMAG	17.3	8.6	11.2	0.0100‡
CEPER	-0.125	0.007	0.471	0.0001‡†
VEPER	0.127	0.096	0.244	0.0010‡†

‡ Significant main effect for Treatment ($p \leq 0.05$)
† Post hoc analysis reveals main effect difference due to a particular Treatment

There was a significant difference between the Treatments on the minimum absolute error (MAE) turned in degrees to the target, $F(2, 66) = 4.81$, $p = 0.0112$. Post hoc comparisons of the treatments found Treatment 2 had significantly lower error than Treatment 1, $t(66) = 3.08$, $p = 0.0030$. Post hoc comparisons used the corrected per comparison alpha value of $p = 0.0167$.

The signed angular deviation to the target orientation (CETT) indicated significant differences between the Treatments overall, $F(2, 66) = 10.42$, $p = 0.0001$, while the post hoc comparisons revealed Treatment 1 had significantly greater error than Treatment 2, $t(66) = 3.78$, $p = 0.0003$ and Treatment 3, $t(66) = 4.11$, $p = 0.0001$. The consistency of producing this angle (VETT) indicated significant differences between Treatments, $F(2, 66) = 4.79$, $p = 0.0114$. Post hoc comparisons revealed Treatment 1 had significantly greater error than Treatment 2, $t(66) = 2.98$, $p = 0.0041$.

Magnitude of the movement (MAG) revealed significant main effects for Treatment, $F(2, 66) = 21.04$, $p = 0.0001$. Post hoc comparisons revealed that there were significant differences between Treatment 1 and Treatment 2, $t(66) = 3.53$, $p = 0.0008$, Treatment 1 and Treatment 3, $t(66) = 6.48$, $p = 0.0001$, and Treatment 2 and Treatment 3, $t(66) = 2.95$, $p = 0.0044$. Treatments 1, 2 and 3 produced decreasing magnitudes of movement.

There was a main effect for Treatment, $F(2, 66) = 8.82$, $p = 0.0004$, in analysis of the angular error to the target magnitude (CEMAG). Post hoc comparisons revealed differences between Treatment 1 which undershot the target and Treatment 3 which overshot the target, $t(66) = 4.19$, $p = 0.0001$. A main effect for Treatment was found in the consistency of angular error to the target magnitude (VEMAG), $F(2, 66) = 4.95$, $p = 0.0100$. Post hoc comparisons found Treatment 1 was less consistent in the magnitude of the movements than Treatment 2, $t(66) = 3.06$, $p = 0.0032$.

The analysis of the percentage error (CEPER) indicated a main effect for Treatment, $F(2, 66) = 10.28$, $p = 0.0001$. Post hoc comparisons showed that in Treatment 3 errors were larger than those in Treatment 1, $t(66) = 4.32$, $p = 0.0001$, and Treatment 2, $t(66) = 3.36$, $p = 0.0013$. The variability of the percentage error (VEPER) was found to have a main effect for Treatment, $F(2, 66) = 7.69$, $p = 0.0010$. Differences were found between the greater variability of Treatment 3 when compared to Treatment 1, $t(66) = 2.93$, $p = 0.0046$, and Treatment 2, $t(66) = 3.72$, $p = 0.0004$. Expressed as a percentage, 45 degree angled turns were made more poorly than either 135 or 90 degree turns.

Distance judgements

Table 5. Analysis of adjusted treatment means for distance judgements made

Variables	T1	T2	T3	P-value
CEDIST	0.031	0.188	0.239	0.7808
VEDIST	0.706	0.288	0.597	0.0051‡*

‡ Significant main effect for Treatment ($p \leq 0.05$)
* Significant main effect for Residual ($p \leq 0.05$)

No differences were found in the signed deviation from the target distance (CEDIST). The variability of the distance error (VEDIST) revealed differences between the Treatments, $F(2, 66) = 5.47$, $p = 0.0051$. In addition, Residual effects, $F(2, 66) = 3.84$, $p = 0.0264$, were found to be significant for this variable. A Residual effect was defined as the effect that performing a preceeding Treatment had on a succeeding Treatment's performance (i.e., a carryover effect). The post hoc comparisons revealed differences existed between the larger error of Treatment 1 when compared to Treatment 2, $t(66) = 3.26$, $p = 0.0018$.

Discussion

This experiment was designed to evaluate the ability of subjects to detect differences in complex configurations as evident in ratio-scaled drawings, and the effects of these differences on actual angular movement and distance judgements made in medium-scale space. In addition, the experiment investigated whether subjects, when asked to judge the orientation to a target, produced angular movements which distorted angles towards 90 degrees.

Ratio-Scaled Drawings

As subjects were led through the pathway configurations, they were expected to develop cognitive maps. When the cognitive maps were externalized in the form of drawings, the unique properties of the configurations were expected to be evident. Based on the scoring system utilized, it can be concluded that subjects were able to detect the appropriate characteristics of the configurations. The suggestion by Klatzky et al. (1990) that errors in judgements were due to the subjects' inability to detect the specific nuances of the configurations does not appear to be supported.

The drawings also provided evidence that subjects were able to detect that two of the paths within a particular configuration crossed each other. This contradicts the suggestion made by Klatzky et al. (1990) with regard to poorer performance on orientation tasks due to an inability of subjects to detect that paths had crossed. The use of a drawing task shows that, in fact, the crossing of paths can be detected, but whether this information is used effectively when the actual judgements to targets are made in terms of angular movement and distance in ambulatory tasks remains to be evaluated.

The drawing of the configurations also evaluated whether configurations with the same segment lengths experienced in the learning phase would differ in the recall of these lengths because of the differences in the nature of the configurations. The present results did not support this view. All of the segments were drawn equally well in terms of accuracy and consistency. Accuracy and consistency were equivalent for the drawn length of the fourth segment in each configuration. This would suggest differences in the nature of the configurations did not affect the ability to draw the resultant path length.

The final analysis involving the ratio-scaled drawings evaluated whether subjects produced angles of 45 degrees and 90 degrees equally well. No differences were found in the drawing accuracy or consistency of the two internal angles considered. Therefore the angles drawn provided no evidence of a bias toward ninety degrees. This is contrary to the findings of Byrne (1979) that angles which are not ninety degrees are distorted towards ninety degrees in sketch drawings of familiar large-scale environments.

The findings from the drawing data seem to indicate that subjects were able to recognize the specific characteristics of the configurations. The external representation of the cognitive map by means of ratio-scaled drawings shows some evidence that the cognitive map was a veridical representation of the experienced configurations.

Orientation Judgements

The ambulatory tasks evaluated whether differences in the pathway configurations would result in differences in the ability of subjects to judge the relationships between two points that had not been experienced during the learning sequence. Based on the angular movement variables, subjects were found to be unable to judge the orientation to the target position equally well in the three configurations.

Differences were found in how closely subjects oriented to the target position. Post hoc analysis indicated that when subjects were performing the judgements in Treatment 1, they had a much poorer idea of the target position when compared to judgements being made in Treatment 2. Judgements of orientation made in Treatment 2 were probably more accurate due to the familiarity of the angles turned. The fact that Treatment 2 was performed the most accurately is not surprising given the subjects' comments with regards to estimating angular judgements relative to a 90 degree criterion.

The signed deviation from the target orientation suggested that subjects differed in their accuracy in determining the orientation to the starting position. Treatment 1 was found to be less accurate than either Treatment 2 or Treatment 3. The interpretation of this variable is important to understanding the behaviour of the subjects. Subjects had been instructed to orient themselves to the target with the shortest turn possible. Thus in order to be successful, and therefore achieve greater accuracy and consistency, subjects would be expected to turn in the correct direction most of the time.

Subjects in Treatment 2 and Treatment 3 turned considerably less often in the incorrect direction. Approximately 7.4 % and 11.1% of the attempts were in the incorrect direction in Treatment 2 and Treatment 3, respectively. When subjects performed the orientation task in Treatment 1, they turned in the incorrect direction 29.6 % of the time. Thus, there is a greater percentage of turns made in the incorrect direction in Treatment 1 and it can be suggested that this is a result of the inability to detect the crossing of the paths. The comments of Klatzky et al. (1990), with regard to subjects being unable to detect the crossing of paths, may find some support from these findings. This is contrary to the findings with respect to ratio-scaled drawings.

Evidence suggests that regardless of the direction of the turn made to orient themselves to the target, subjects were able to recognize that the necessary magnitudes to turn were different in each configuration and therefore were not recalling the angles to be turned as 90 degrees. Consistent with other evidence concerning the judgement of targets of varying magnitudes (Poulton, 1979), the greater angles required in Treatment 1 produced negative deviations from the target angular movement while the smaller angle required in Treatment 3 produced positive deviations. The signed deviation to the target magnitude shows that 90 degree movements were made extremely accurately. Expressed as a percentage of the magnitude to be turned, the forty-five degree turns required in Treatment 3 were considerably less accurate than either of the other movements.

Distance Judgements

Finally, the effect of differences in the configurations was considered in judgements of inferred distance. The distance judgements from D to A revealed that the differences in the configurations did not result in differences in accuracy. However, the consistency of walking the required distance was found to be different and therefore the differences in the configurations did have some effect on the judgements of distance. Greater variability in the distance judgement of Treatment 1 may be attributed to the fact that subjects developed an image of routes with crossing paths which tended to "fluctuate". In Treatment 2 the ability to reproduce the distance is dependent upon the recognition of the ninety degree turns which subjects had admittedly used as a bench-mark from which turns were judged. When a cognitive map was created for Treatment 2, the relationship of the paths to each other was expected to be more easily recognized.

It appears subjects are able to detect the characteristics of the configurations when asked to overtly express this in drawings, however translating this information into successful actions in an appropriate ambulatory behaviour may not be achieved.

Chapter IV

Experiment 2 - Symmetry and equiavailability in integrated cognitive maps

Rationale

In the second experiment, the main area of concern involved the presence or the influence of symmetry on the pathway complexity of cognitive maps and its relationship to the equiavailability principle. Missing or unavailable information about a system can be inferred from other relevant facts by a subject's intuitive knowledge of geometry, trigonometry and symmetry (Byrne, 1982). Knowledge of these properties " . . . allows one to deduce and construct facts which are not initially known . . . " (p. 242) during the transformation to a drawn map. In the construction of cognitive maps, it is possible that one may also use these deductive properties.

Developing survey knowledge of an environment is believed to be independent of the manner in which the environment is learned (Levine et al., 1982). If such is the case, and if the integration of two separate cognitive maps within that environment is successful, subjects would be expected to make distance and orientation judgements between cognitive maps as accurately as those made within an individual cognitive map. This act would affirm the applicability of the equiavailability principle beyond its present limitation to sequentially learned pathway relationships.

The research of Hanley and Levine (1983) attempted to look at the equiavailability principle. Several confounding factors were evident in this experiment and may have influenced the investigators' ability to extend the applicability of the equiavailability principle. First of all, the angles between the segments and the length of the segments within a pathway varied, even though the distance between the test points was equivalent. Inconsistency of the angles and lengths may have resulted in increased difficulty for the subjects in making the orientation and distance judgements. Thus, there was an increased likelihood of forgetting due to increased information necessary to remember a particular configuration. This problem was increased considerably when the integration of the two configurations was required.

However, there is a property of the configurations that may have been overlooked as a contributing factor and that is the symmetric nature of the integrated pathways themselves. If there is the potential to produce equivalent angular and distance error in both types of movements, regardless of the grouping by the memory rating, then an integrated pathway configuration that is more symmetric than another would be expected to produce a helpful memorial representation. The cognitive map created would be expected to aid in making the judgement of the position and distance between points on an integrated pathway configuration. Thus in the Hanley and Levine (1983) experiment, there is the possibility that the differences that were originally found were due to differences in the symmetry of the configurations created by the integration of the two independent pathways or some interaction between the type of movement that was to be made and the degree of symmetry of the configuration learned.

Research Hypotheses

1) The equiavailability principle states that when survey knowledge of an environment is present, movements made between learned (SF) and inferred (WSC) points will produce equal errors in terms of angular movement and distance. This hypothesis was evaluated utilizing two movement types made within one pathway.

Statistical Test ANOVA

Statistical Hypothesis $H_o : \overline{error}_{sf} = \overline{error}_{wsc}$

2) Differences in errors between types of movements (WPM and BPM) are not expected in symmetric configurations and thus some support for the applicability of the equiavailability principle may be found if significant interactions exist between the Type of Movement and Configuration using the error measures of angular movement and distance discussed previously. Where a significant interaction existed, the source of this interaction was determined.

Statistical Test ANOVA Interaction of configuration & movement type

Statistical Hypothesis $H_o : \overline{error}_{c1*mt} = \overline{error}_{c2*mt} = \overline{error}_{c3*mt} = \overline{error}_{c4*mt}$

where c1 refers to a configuration with a symmetric value of 2, c2 and c3 to the configurations with a symmetric value of 1, and c4 to the configuration with no symmetric value

3) Hanley and Levine (1983) suggested that the applicability of the equiavailability principle could be extended to movements made between- and within-pathways when an integration of two separate cognitive maps was performed. In the evaluation of this premise, errors of angular movement and distance discussed previously should be equivalent.

Statistical Test ANOVA

Statistical Hypothesis $H_o : \overline{error}_{wpm} = \overline{error}_{bpm}$

4) Differences in configuration symmetry should lead to differences in the errors of angular movement and distance.

Statistical Test ANOVA (Configuration is a Between subjects factor)

Statistical Hypothesis $H_o : \overline{error}_{c1} = \overline{error}_{c2} = \overline{error}_{c3} = \overline{error}_{c4}$

Method

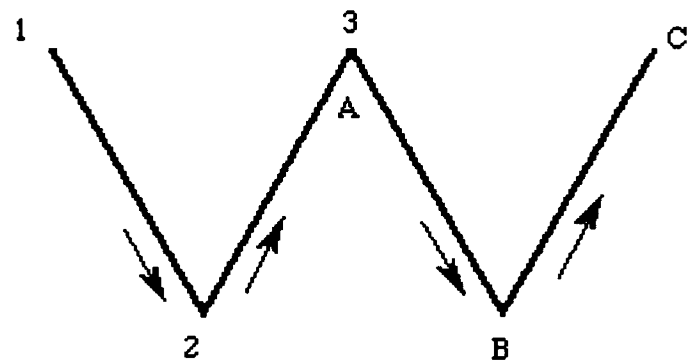
<u>Subjects</u>. Thirty-two sighted university students were paid for their participation in the experiment. The subjects did not report any physical disabilities. All had normal vision or corrected vision with glasses or contact lenses. An equal number of males and females was used. The subjects' ages ranged from 17 to 36 with the mean age being 24.3 years old. The subjects used in this experiment had not participated in Experiment 1.

<u>Design</u>. A three-factor between-subjects design with repeated measures on the nature of the movements was used. The within-subjects factor was the three levels of test movements, two based on within-pathway movements and the other based on a between-pathway movement. Each of the movements types was performed twice. The two within-pathway movements were either described as a simple forward (SF) or a within-pathway shortcut (WSC). The third test movement, between-pathway movements (BPM), involved making judgements of points between two paths created from the integration of two pathway configurations. One between-subjects factor was the four levels of pathway configuration which differed in the degrees of symmetry. The other between-subjects factor was gender. Subjects were distributed into one of the four levels of pathway configurations. The sequence of the test movements produced was determined in a random manner.

<u>Stimuli</u>. Four pathway configurations were marked out on a gymnasium floor and are illustrated in Figures 7, 8, 9, and 10. These paths were created, based on the configuration of an equilateral triangle, with sides 4 metres in length. In each configuration, the two separate pathways were made up of two equilateral triangles, each with one side missing, oriented in different relationships to each other. In one pathway, the starting position was labelled as A, the connecting point between the two paths as B, and the end of the second path as C. In the other

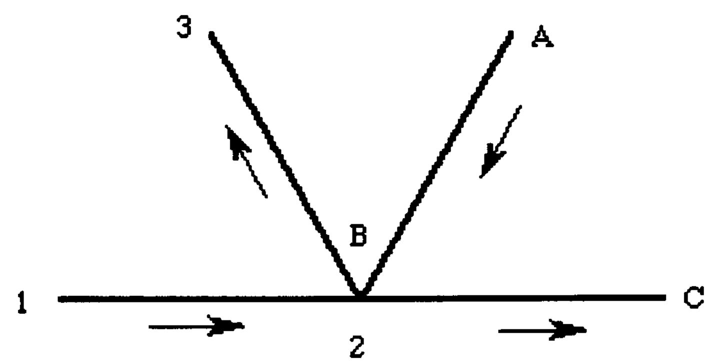
pathway, the paths were labelled with numbers 1, 2, and 3. Based on the number of symmetric transformations present in the integrated cognitive map, the configurations differed in terms of their degree of symmetry. Treatment 1 had a symmetric value of two, Treatment 2 and Treatment 3 a symmetric value of one, and Treatment 4 was assigned a symmetric value of zero.

Figure 7. Experiment 2 - Treatment 1 - Symmetric value of 2.



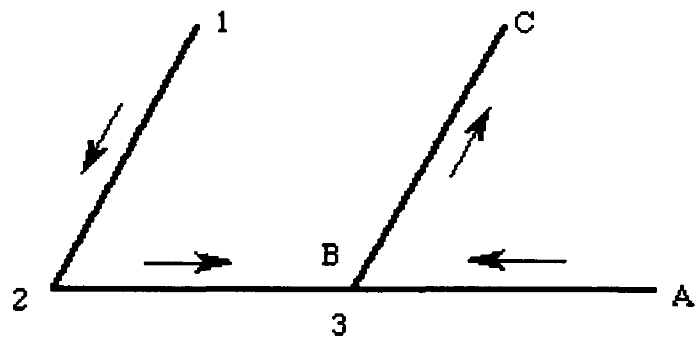
Scale: 1 cm = 1 m

Figure 8. Experiment 2 - Treatment 2 - Symmetric value of 1.



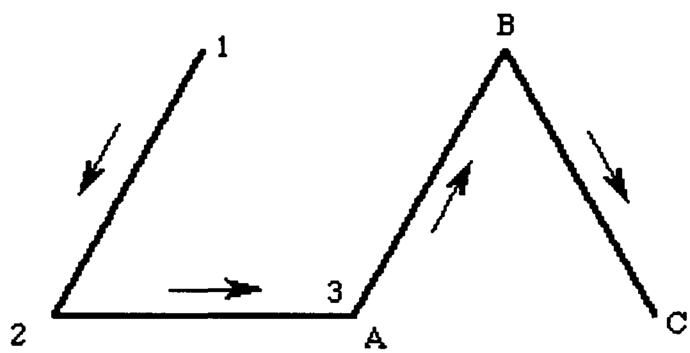
Scale: 1 cm = 1 m

Figure 9. Experiment 2 - Treatment 3 - Symmetric value of 1.



Scale: 1 cm = 1 m

Figure 10. Experiment 2 - Treatment 4 - Symmetric value of zero.



Scale: 1 cm = 1 m

Apparatus. Measuring devices included a steel measuring tape and the orientation device used in Experiment 1.

Procedure. While outside of the experimental area, subjects were briefed on the nature of the tasks that were to be performed (see Appendix D). Subjects were blindfolded, seated in the wheelchair and brought into the experimental testing area to the beginning of an experimental pathway system. Subjects remained blindfolded during the entire experiment.

During the training trials, the order in which the lettered and the numbered pathways were learned was alternated between subjects. Once at the configuration, subjects were asked to stand and be prepared to be led along a series of paths. The experimenter led the subjects through the pathways using the method described in leading the visually impaired (see Appendix B). It was emphasized to the subjects that it was important to learn the relationship between the start and the goal and all other possible relationships between points.

Beginning at A or 1, the subjects were led along the path until a one hundred and twenty degree change of direction occurred and then continued until they reached either C or 3, respectively. Labelled points along the pathway were announced when the subjects were stationary at these points prior to turning. Once the subjects reached the final position, they were told to think about where the starting position of the pathway was relative to their present position and all the other relationships in the pathway. After approximately five seconds, the subjects were seated in a wheelchair and led to the beginning of the same pathway configuration. During the experiment, an assistant moved the wheelchair to an appropriate position each time a subject was walking along a path. This process was repeated a total of three times for each pathway series (lettered and numbered).

Upon completion of learning both the numbered and the lettered pathways, the testing commenced. Subjects were wheeled to a position on one of the pathways and asked to stand. A briefing was given to the subjects as to where they were on the test pathway, what point was directly behind them, and which two points in the lettered and numbered pathways coincided with each other. For example, when subjects were asked to make judgements requiring SF movements in the lettered portion of Treatment 1, they were told that point A was directly behind them, while they were standing at point B and that points A and 3 represented the same point in space. The task involved the judgement of orientation and distance to point C. Within-shortcut movements were always made from C to A and from 3 to 1. The subjects were always given their orientation information relative to points within the same labeling system.

For the between-pathway movements, additional information was given to the subjects so that orientations could be made to other points in an integrated cognitive map. When between-pathway movements were attempted, similar information was given to the subjects with regard to where they were standing relative to other points within the same labeling system (lettered or numbered) and which point in the other labeling system corresponded to that in the present system. Once that had been established, subjects' bodies were rotated by the experimenter in a direction so as to orient them to a second point (other than the test point) on the adjacent pathway in the smallest degree of turning. Subjects were then given the required information again, returned to their initial orientation, given the required information a third time, and asked to judge the orientation of the test point. Subjects were presented with a strategy which was thought to help the subjects in making their judgements of the positions between-pathways. The subjects were told to think of the relationship of the paths as if they were being presented relative to a grid that had been superimposed on the gym floor. Any instructions were repeated when requested by the subjects.

In the between-pathway movements, the actual movements differed in each figure. The between-pathway movements in the example above were made from point 2 to point B and in the reverse direction. In Treatment 2, the between-pathway movement was made from point 3 to point A, in Treatment 3, from point 1 to point C and lastly in Treatment 4, from point 1 to point B and in their respective reverse directions.

The orientation of the subjects was measured and then subjects were asked to walk along the path and to stop when they felt they had reached the position of the testing point. A distance measurement was taken. After finishing each walk, the subjects were seated in the wheelchair and brought to the next test position of the pathway and the procedure was repeated for another movement.

During the experiment, no feedback was given to the subjects with regard to their error in degrees and distance to the target. The time taken to complete Experiment 2 was approximately forty minutes.

Results

All reported F values are given with their associated significance levels. A significance level of $p \leq 0.05$ was used in determining the rejection of the null hypotheses. When post hoc analysis was appropriate, the Bonferoni method of correction for familywise error was used to determine significant differences.

Simple Forward and Within-Shortcut movements

Table 6. Analysis of simple forward (SF) and within-shortcut (WSC) movements means for measures of angular movement error

Variables	SF	WSC	P-value
MAE	27.6	39.7	0.1214
CETT	-25.5	-62.7	0.0459‡
VETT	25.2	50.8	0.0599
MAG	119.7	127.1	0.2161
CEMAG	-0.3	7.1	0.2161
VEMAG	13.3	15.1	0.6476

‡ Significant main effect for Type of Movement ($p \leq 0.05$)

Only the analysis of the signed deviation to the target orientation (CETT) was found to be significantly different between the movement types, $F(1, 24) = 4.43$, $p = 0.0459$. The SF movements were made with a greater degree of accuracy than the WSC movements. In general, the results indicate that there were no differences between the Types of Movements. For this experiment, examples of the statistical output from which the tabular data were derived are in Appendix E.

Table 7. Analysis of simple forward (SF) and within-shortcut (WSC) movements means for measures of distance error

Variables	SF	WSC	P-value
CEDIST	-0.049	0.387	0.0113‡
VEDIST	0.203	0.408	0.0082‡

‡ Significant main effect for Type of Movement ($p \leq 0.05$)

The signed deviation from the target distance was found to be significantly different, $F(1, 24) = 7.53$, $p = 0.0113$. In the SF conditions, subjects were more accurate at completing the necessary distance required to walk to the target. The variability of the distance error was also found to be significantly different, $F(1, 24) = 8.30$, $p = 0.0082$, such that SF movements were less variable than those of WSC movements. Based on the above finding, one must doubt the equiavailability principle in terms of distance judgements.

Within-Pathway and Between-Pathway movements

Table 8. Analysis of within-pathway (WPM) and between-pathway movement (BPM) means for measures of angular movement error

Variables	WPM	BPM	P - value
MAE	33.7	82.00	0.0001‡
CETT	-44.1	-93.7	0.0013‡•°
VETT	38.0	56.7	0.0930
CEMAG	3.4	-26.0	0.0016‡
VEMAG	14.2	27.2	0.0070‡
CEPER	0.028	-0.213	0.0042‡
VEPER	0.118	0.261	0.0017‡

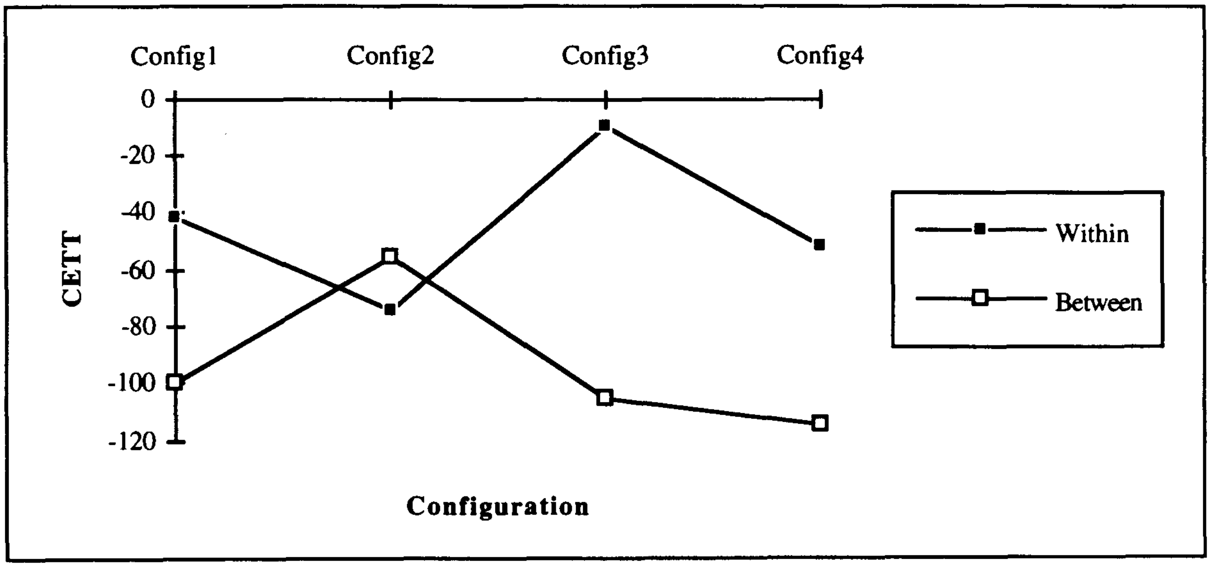
‡ Significant main effect for Type of Movement ($p \leq 0.05$)
• Significant interaction between Type of Movement and Config ($p \leq 0.05$)
° Significant interaction between Type of Movement and Gender ($p \leq 0.05$)

Significant differences were found between the minimum absolute error (MAE) turned to the target orientation of the within- and between-pathway movements, $F(1, 24) = 39.01$, $p = 0.0001$. Within-pathway movements were made more accurately when attempting to orient to the target.

A Type of Movement by Configuration interaction was found in the signed angular deviation to the target orientation (CETT), $F(3, 24) = 3.14$, $p = 0.0438$. Graphically, the interaction is shown in Figure 11. Significant differences were found between the types of movements in Configuration 1, $F(1, 6) = 6.69$, $p = 0.0414$, Configuration 3, $F(1, 6) = 15.33$, $p = 0.0078$, and

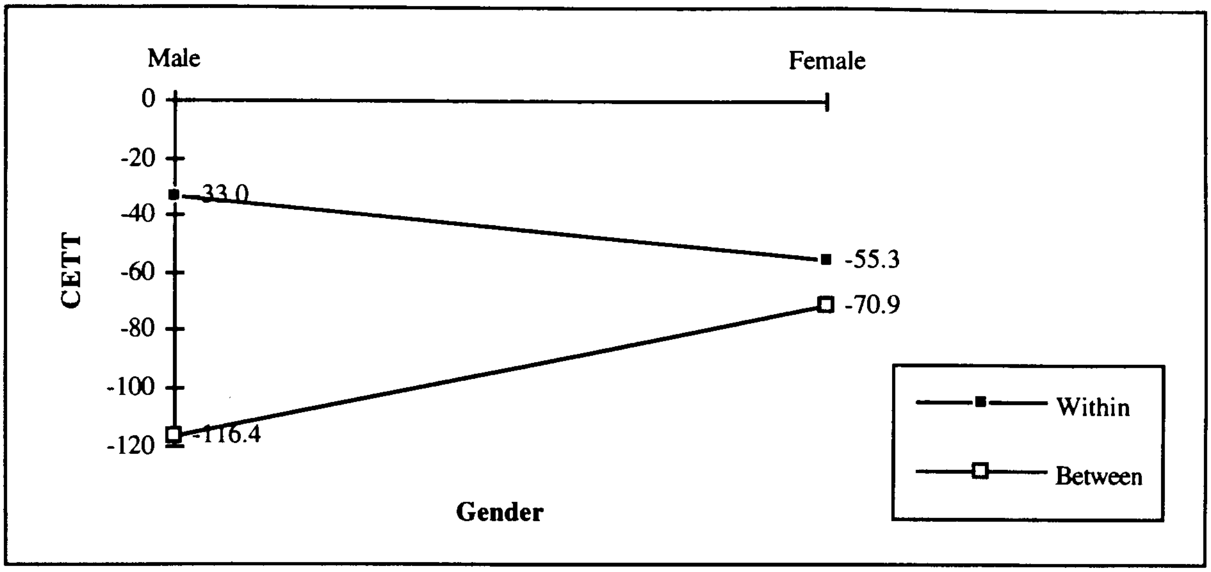
Configuration 4, F(1, 6) = 6.00, p = 0.0498. The significant differences found between Type of Movement for the CETT are confounded by the significant interaction of Configuration and Type of Movement. One type of movement did not perform better in each of the configurations.

Figure 11. Experiment 2 - Interaction between configuration and type of movement for the signed angular deviation to the target orientation (CETT).



There was also a significant Type of Movement by Gender interaction found for CETT, F(1, 24) = 6.17, p = 0.0203. As indicated in Figure 12, there is a smaller difference in performance between types of movements for females than for males.

Figure 12. Experiment 2 - Interaction between gender and type of movement for the signed angular deviation to the target orientation (CETT).



There was a significant difference amongst the Types of Movements on the signed angular deviation to the magnitude turned (CEMAG), $F(1, 24) = 12.58$, $p = 0.0016$, whereby within-pathway movements were more accurate when compared to between-pathway movements. A significant difference was also found for the between-subjects effect of Configurations, $F(3, 24) = 3.01$, $p = 0.0497$ (see Table 9). The most symmetric configuration was found to be the most accurate while the least symmetric was the least accurate. Post hoc comparisons did not reveal significant differences between the configurations. The variability of this measure was found to be significantly different, $F(1, 24) = 8.68$, $p = 0.0070$. Within-pathway movements were found to be less variable.

Table 9. Significant between-subject effects of configuration means◊

Variable	Config 1	Config 2	Config 3	Config 4	P-value
CEMAG	-1.4	4.4	-14.1	-14.5	0.0497‡
VEPER	0.111	0.239	0.162	0.152	0.0106‡

‡ Significant between-subjects effect for Configuration ($p \leq 0.05$)
◊ CEPER approached a significant difference ($p = 0.0561$)

A significant difference was found between the types of movements on the percentage error (CEPER), $F(1, 24) = 9.98$, $p = 0.0042$. Within-pathway movements were found to be closer to the target magnitude when differences in the magnitude of the movements were considered. In terms of the variability of this error (VEPER), significant differences were found, $F(1, 24) = 12.45$, $p = 0.0017$. Within-pathway movements were made more consistently. A significant between-subjects effect for Configuration, $F(3, 24) = 4.65$, $p = 0.0106$, was also present (see Table 9). The most symmetric of the pathways (Config 1) was found to be the least variable while the highest variability was found in one of the pathways with intermediate symmetry (Config 2). Post hoc comparisons revealed significant differences existed only between these configurations, $F(1, 24) = 13.04$, $p = 0.0014$.

In terms of the error measures of angular movement for Within- and Between-pathway movements, doubt is cast on the equiavailability principle. There was no evidence that differences in the symmetry of the configurations resulted in differences in judgements of angular movement. There was little evidence for the existence of significant interactions between symmetry and type of movement.

Table 10. Analysis of within-pathway (WPM) and between-pathway movements (BPM) means for measures of distance error

Variables	WPM	BPM	P-value
CEDIST	0.169	-0.108	0.3295
VEDIST	0.306	0.612	0.0077‡

‡ Significant main effect for Type of Movement ($p \leq 0.05$)

There was a significant difference in the variability of the signed distance deviation (VEDIST), $F(1, 24) = 8.45$, $p = 0.0077$. Within-pathway movements were found to be less variable than between-pathway movements.

Discussion

This experiment examined the equiavailability principle and its applicability to integrated cognitive maps constructed from ambulatory movements in medium-scale space. The importance of symmetry in integrated cognitive maps was also evaluated.

Simple Forward and Within-Shortcut movements

One of the purposes of this experiment was to attempt to replicate the findings of Levine et al. (1982) and Hanley and Levine (1983). Using an equivalent angular error measure, the present experiment replicated these findings. No differences were found between judgements of SF and WSC movements which suggests that the knowledge of the location of the target in either situation was equally available. In addition, the magnitudes of the SF and WSC movements were similar and both were found to be made equally close to the 120 degree criterion. Therefore, these results support the equiavailability principle.

Since subjects turned the appropriate magnitude, this indicates that they recognized that the points formed an equilateral triangle. However, some subjects turned in the incorrect direction when making a turn of the correct magnitude. As a minimum requirement, subjects were expected to recognize and remember the direction of the turn made in learning the particular numbered or lettered sequence. This seemingly contradictory situation suggests that the " . . . cognitive maps may have contained consistent spatial information, but spatially inconsistent information can be obtained from these representations due to retrieval or inference processes operating on the representations" (Moar & Bower, 1983, p. 112).

Therefore, there is one factor that has not been considered by the equiavailability principle and that is the direction turned to orient oneself to the target when the instruction is given to turn in the shortest possible angle. If the equiavailability principle suggests that information from learned and inferred routes is equally available, then it must also include equally available information on the direction that should be turned to comply with the constraint of movement in the shortest possible angle to a target.

When the angular error measure, which includes the direction turned is considered the equiavailability principle cannot be supported. Differences were found in CETT when comparing SF and WSC movements which implies that subjects were not able to locate the target position in an equivalent manner. From the negative mean values found for both types of movements, it is unclear whether the subsequent values were a result of subjects turning in the wrong direction, adding considerably to the error value or turning in the correct direction and making a judgement short of the target.

A closer look at the relationship of the CETT to the MAE and the percentage of times subjects turned in the incorrect direction revealed the mean value for the SF movements was probably due to subjects being short of the target once they had turned in the correct direction. Subjects turned in the incorrect direction only 7.8% of the time. On the other hand, in the WSC movements, the mean value was a result of subjects turning in the wrong direction a greater percentage of the time (25%).

Even though it may have only been implied in previous discussions of blind mobility, individuals are expected to try to become more efficient in addition to other essential requirements (Foulke, 1971). Therefore, these findings suggest that subjects were not equally efficient in locating a target in SF and WSC movements and this casts some doubt on the previous evidence for the equiavailability principle.

Levine et al. (1982) found in manipulatory tasks that the distance error for judgements made in the original or reverse direction of learning, in short cuts between points that had not been made previously or between learned points, were performed equally well. From pilot work, Levine et al. (1982) reported " . . . the angular error and the missed distance were highly correlated, [and] that both were not necessary" (p. 167) and subsequently, only angular error was measured in the ambulatory tasks. Thus Levine et al. (1982) produced no data with which to compare the errors in distance discussed below. It was implied in their paper that the correlation would have been highly *positive*.

The distance measures of accuracy and consistency were found to be different between SF and WSC movements. This is contrary to the predictions of the equiavailability principle in ambulatory distance judgements. Subjects were allowed to count the number of steps taken and as a result SF movements were more accurate and less variable since this type of movement required a replication of distances which were previously walked. On the other hand, WSC movements were most likely developed from a cognitive map which would have to include all of the distance and direction information between the three points in order to be successful and apparently this was not achieved. The use of a cognitive map was not as effective as the knowledge extracted from kinesthetic and vestibular information in producing identical distances.

Within-Pathway and Between-Pathway movements

A second purpose of this experiment was to determine the importance of symmetry as well as the applicability of the equiavailability principle to integrated cognitive maps constructed from ambulatory movements. In the between-and within-pathway judgements of orientation, there was only limited support for the applicability of the equiavailability principle to integrated cognitive maps. Except for one of the angular movement measurements, the variables indicated there were significant differences between within- and between-pathway movements. In Levine et al. (1982), when five-point paths were sequentially learned by ambulatory means, the inferred path judgements could be considered similar to the between-pathway movements in the present experiments and, therefore, similar survey knowledge should have been developed. The present findings do not support this statement.

When the influence of symmetry on the equiavailability principle is considered, there was some evidence to support the equiavailability principle if certain conditions were met. The significant interaction between configuration and the type of movement for CETT suggests that equal judgements of orienting to a target in the most efficient manner is possible if the configuration has particular properties. Unfortunately, these properties may not be a function of symmetry since equal performance on types of movements was not in the most symmetric of the configurations.

The gender by type of movement interaction for CETT indicated that there was a smaller difference between judgements of within- and between-pathway movements for females than for males. This may suggest that females were more likely to integrate the separate cognitive maps than were males.

In the analysis of the distance variables, the consistency of judgements was found to be different between the types of movements. Greater variability in the between-pathway movements suggests that subjects were less sure about these movements than they were about within-pathway movements. The signed deviation in producing the distance in the within- and between-pathway movements was found to be equivalent. Regardless of this finding, to say that the distance judgements were made equally well would be misleading and therefore total support for the equiavailability principle for distance was not found.

There was evidence to suggest that the total pathway system was not constructed well. First of all, subjects turned 45.3% of the time in the incorrect direction in attempting to produce the orientation to a between-pathway target. This is considerably more frequent than the 16.4% for the within-pathway movements. Further evidence that subjects did not construct an integrated cognitive map successfully was established by determining how frequently subjects were "guessing" based on the frequencies of individual error scores of greater than 90 degrees (Levine et al., 1982). Subjects were guessing only 8.6 % of the time in within-pathway movements and 43.8 % in between-pathway movements. The integrity of the composite cognitive map may be in doubt since subjects in the between-pathway judgements made movements in the wrong direction for almost half of the attempts and appeared to be guessing considerably more frequently than in judgements of within-pathway movements. Simply, if subjects were unable to perform the act of turning in the correct direction from a judgement point, the likelihood they had been able to form and use a useful representation of the environment is quite poor. Although Moar and Carleton (1982) have shown in slide presentations of two pathway systems that an integrated cognitive map can be created, evidence was not found in this experiment that two cognitive maps in medium-scale space could form a composite cognitive map in which judgements within- and between-pathways could be made equally well.

The importance of symmetry in the construction of the integrated cognitive maps was investigated. There was little evidence that this was a factor in determining judgements. There were no differences found between configurations on most of the variables measured. The only support for an effect of different degrees of symmetry was in the differences in the ability of subjects to produce the magnitude of the turn necessary to orient to the targets.

Chapter V

Experiment 3 - Is there a tendency toward symmetry?

Rationale

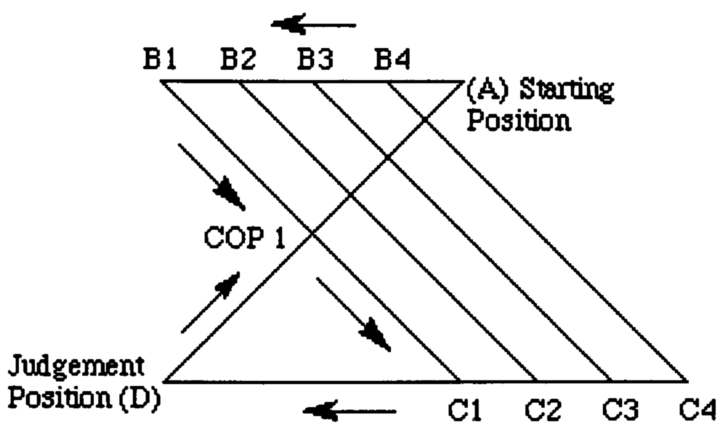
There have been suggestions by some researchers that distortions are inherent in the production of cognitive maps in large-scale space (Lloyd and Heivly, 1987; Tversky, 1981). The following experiment was designed to investigate the influence of the distorting properties of symmetry in developing cognitive maps of medium-scale space.

Attneave (1971) suggested, based on the Gestalt principle of Prägnanz, that " . . . one perceives the 'best' figure that is consistent with a given image. For most practical purposes 'best' may be taken to mean 'simplest' " (p. 67). A connection between symmetry and simplicity has been made previously by Rosen (1983). It is believed that in an attempt to make judgements of positions utilizing a cognitive map of a complex configuration, subjects will simplify the cognitive map. It is this propensity toward a preferred simpler arrangement of items in a balanced or symmetrical manner that will provide some evidence of the distorting nature of symmetry in imagery-based cognitive maps.

If symmetry is part of the simplification of the cognitive maps, it is expected to appear in a predictable manner. Thus "asymmetric" configurations are expected to be distorted toward a symmetric representation.

Each configuration used in Experiment 3 was developed from one "source" symmetric configuration which is labelled A-B1-C1-D in Figure 13. Each configuration created was bilaterally symmetric but they increased in the degree they were "removed" from the original. In a sense, they became more "asymmetric" relative to the original.

Figure 13. Experiment 3 - Family of configurations.



Scale: 1 centimetre = 1 metre

An example of one of the configurations used in this experiment is labelled A-B4-C4-D in Figure 13. Judgements of the orientation relationship between the judgement point (D) and the starting point (A) and judgement of the distance from D to the crossover point (COP) and from the COP to A were required. A distance variable, referred to as the Movement ratio, was defined as the ratio of the first distance walked (D to COP) to the second (COP to A). Two other ratios were used in this experiment. The True ratio is the actual ratio of the two distances in the experimental configuration. For example in the A-B4-C4-D configuration, the True ratio would be the first distance (4.95 metres) divided by the second distance (0.71). The resulting ratio would be 6.97. Lastly, the Symmetric ratio is the expected ratio when the length of the two segments in question is equivalent. The resulting ratio would always be one. This also is the value of the True ratio for the configuration A-B1-C1-D in Figure 13. The point labelled COP 1 represents the crossover point of this symmetric configuration.

Research Hypotheses

1) Configurations which differ in their pathway complexity, as determined by the degree of symmetry, affect judgements of angular movement between inferred points.

Statistical Test ANOVA

Statistical Hypothesis $H_o : \overline{error_{c1}} = \overline{error_{c2}} = \overline{error_{c3}} = \overline{error_{c4}}$

where c1 refers to the source symmetric configuration, and c2, c3, c4, refer to the degree to which the other configurations are "removed" from the source

2) If there is a distortion toward symmetry the D to COP and COP to A segment lengths in each of the configurations should become equal and thus the Movement ratios should be equivalent between the configurations.

Statistical Test ANOVA

Statistical Hypothesis $H_o : \overline{ratio_{c1}} = \overline{ratio_{c2}} = \overline{ratio_{c3}} = \overline{ratio_{c4}}$

3) If distortion of the segment lengths occurs as predicted by the influence of symmetry, then the comparison of Movement and Symmetric ratios in the individual configurations should show evidence of being equivalent.

Statistical Test One sample T-test for individual configurations

Statistical Hypothesis $H_o : \overline{ratio_{movement}} = \overline{ratio_{symmetric}}$

4) If distortion of the segment lengths occurs as predicted by the influence of symmetry, then the comparison of Movement and True ratios in the individual configurations should show evidence of being different.

Statistical Test One sample T-test for individual configurations

Statistical Hypothesis $H_0 : \overline{ratio}_{movement} = \overline{ratio}_{true}$

5) If distortion towards symmetry occurs, equating the segment lengths could be achieved by altering either the D to COP distance or the COP to A distance. A comparison of the errors from respective targets was made to determine in which of the segment lengths this equalizing is occurring. The first error measure involved the signed deviation from the target distance of D to COP (CEDIST1). The second error measure involved the signed deviation in distance from the particular target distance of COP to A (CEDIST2).

Statistical Test ANOVA

Statistical Hypothesis $H_0 : \overline{CEDIST1} = \overline{CEDIST2}$

Method

Subjects. The subjects who participated in Experiment 2 were also used in this experiment.

Design. Gender was not found to be a strong factor in the previous experiments and was not considered in this experiment. A one factor between-groups design was used. The factor was the pathway configuration which had four levels. Eight subjects were randomly assigned to each of the pathway configurations.

Stimuli. Four pathway configurations were used for this experiment (see Figure 13). All configurations were composed of four segments which totalled 19.32 metres in length. Path endpoints were labelled A, B, C, and D. The configurations overlapped in such a way so that the starting and stopping points corresponded to each other when marked on the gymnasium floor. The lengths of the segments are indicated in the Table 11. In each configuration, the total distance walked and the angle from point D to A were the same.

Table 11. Experiment 3 - Segment lengths in metres for configurations

	Distance from			
Configuration	A to B	B to C	C to D	D to A
1	4	5.66	4	5.66
2	3	5.66	5	5.66
3	2	5.66	6	5.66
4	1	5.66	7	5.66

Apparatus. Measuring devices included a steel measuring tape and the orientation device previously described.

Procedure. Detailed instructions for this experiment were also presented during the familiarization phase of Experiment 2 (See Appendix F for Experiment 3 instructions). After the completion of Experiment 2, subjects were given a two minute rest and remained blindfolded. Subjects were then brought to the start of the configuration for the training trials. Beginning at point A, the subjects were led to points B, C, and D while negotiating two 135 degree direction changes in the process. The labelled points along the pathway were announced when the subjects were stationary at these points prior to turning. At point D, the subjects were told to think about where the starting point of the pathway was relative to their present position. After approximately five seconds, subjects were seated in the wheelchair and led to the start of the pathway again, at which time the training trials were repeated an additional four times. During the experiment, an assistant moved the wheelchair to an appropriate position each time a subject was walking along a path.

Once the training trials were completed, subjects walked through the pathway as usual. At point D however, they were required to perform an orientation task that involved turning their entire body in the direction of the starting point (point A) in the smallest possible angle. The experimenter mapped out the pathway that the subjects judged to lead to the starting position and prepared to lead the subjects along this path. While the angle turned was being measured and the intended line of travel mapped out, the experimenter informed the subjects that the return path to the starting point would cross one of the already traversed paths. Subjects were then asked if they had noticed this before the experimenter had mentioned this fact and answered either "yes" or "no". The experimenter then instructed the subjects to walk to the point at which they believed these paths intersected (COP). A distance measurement was taken. From this point, the subjects were instructed to continue in the direction of the starting point and to cease walking at the position they believed the starting point occurred. Each time after finishing this walk, the subjects were seated in a wheelchair and led to the start of the pathway again, and the test trial procedure was repeated two additional times.

During the experiment, no feedback was given to the subjects with regard to the error in degrees and distance to the target. Once all of the testing trials had been performed in Experiment 3, subjects were then asked the following question in terms of the two experiments conducted: "Was there any particular strategy you used in making your judgements?" The time taken to complete Experiment 3 was approximately twenty minutes.

Results

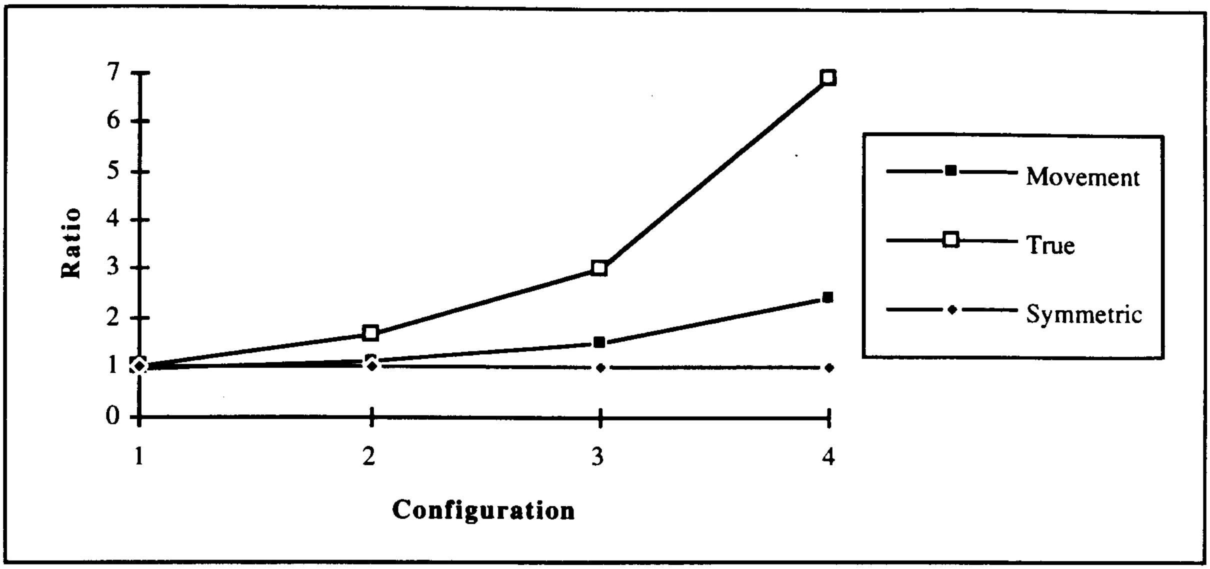
All reported F values are given with their associated significance levels. A significance level of $p \leq 0.05$ was used in determining the rejection of the null hypotheses. When post hoc analyses were appropriate, the Bonferoni method of correction for familywise error was used to determine significant differences.

Table 12. Analysis of configuration means for measures of angular movement

Variable	Config1	Config2	Config3	Config4	P-value
MAE	20.6	23.2	20.8	28.3	0.7603
CETT	-35.3	-13.2	-8.4	-22.7	0.7758
VETT	35.5	26.0	26.0	30.6	0.9765
MAG	130.2	148.2	137.8	125.2	0.2095
CEMAG	-4.8	13.2	2.8	-9.7	0.2095
VEMAG	15.3	7.7	10.2	12.5	0.3331

None of the variables of angular movement errors indicated a significant main effect for Configuration. For this experiment, examples of the statistical output from which the tabular data were derived are in Appendix G.

Figure 14. Experiment 3 - Ratio of the (D to COP) distance divided by the (COP to A) distance.



Overall, there was a significant difference between the Movement ratios of the configurations, F(3, 28) = 3.43, p = 0.0304. The mean ratio values are presented in Table 12. Post hoc analysis indicated statistical differences between the first and last configuration (p = 0.0064).

Table 13. Experiment 3 - Comparisons of movement and symmetric ratio for each configuration

Configuration	Movement ratio‡	Symmetric ratio	P-value
1	0.96	1.00	n/a
2	1.15	1.00	0.0869
3	1.51	1.00	0.0792
4	2.44	1.00	0.0644

‡ Significant between-subjects main effect for Configuration ($p \leq 0.05$)

In each of the configurations, the comparison of the Movement ratio to the Symmetric ratio produced no statistically significant differences, and therefore all deviations were in the direction of symmetry.

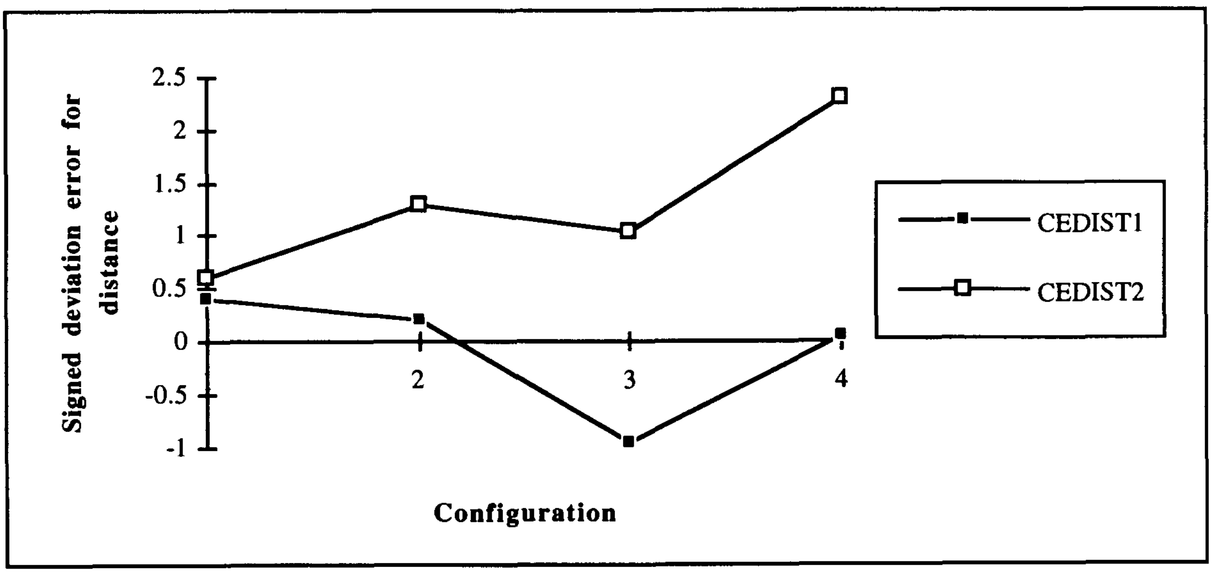
Table 14. Experiment 3 - Comparison of movement and true ratio for each configuration

Configuration	Movement ratio	True ratio	P-value
1	0.96	1.00	n/a
2	1.15	1.67	0.0002‡
3	1.51	3.01	0.0005‡
4	2.44	6.97	0.0002‡

‡ Significant One sample T-tests ($p \leq 0.05$)

When the Movement and True ratios were compared, significant differences were found in Configuration 2, $t(7) = 7.11$, $p = 0.0002$, and Configuration 3, $t(7) = 6.01$, $p = 0.0005$, and Configuration 4, $t(7) = 6.91$, $p = 0.0002$.

Figure 15. Experiment 3 - Signed deviation error of the distance walked from D to COP (CEDIST1) and from COP to A (CEDIST2).



The comparison of the average CEDIST1 and CEDIST2 values indicated a statistical difference, $F(1, 28) = 20.37$, $p = 0.0001$.

Based on the above results, there is evidence to support an argument that symmetrizing of judgements occurred and this was a result of augmenting the COP to A distance.

Discussion

Distortion is thought to be inherent in the production of cognitive maps of large-scale space (Lloyd & Heivly, 1987; Tversky, 1981). The purpose of this experiment was to see whether symmetry has a distortive effect on cognitive maps created in medium-scale space and whether the distortion created is predictable.

Subjects oriented themselves with the same degree of accuracy and consistency to the starting position in all configurations. The differences in pathway complexity did not have an effect on angular judgements between inferred points. Interestingly, the CETT indicated no differences between the configurations and this can be attributed to the low percentage of times that subjects turned in the incorrect direction (7.3 %). A closer look at the distance judgements to the COP and the starting position is required to determine whether distortions were occurring.

The ability to detect the crossing of paths appeared to be related to the degree to which a configuration departed from the source symmetric configuration in the "family". In the first two configurations, seven of eight subjects were able to detect that the return path to the starting position crossed another of the previously walked paths. Thus it was suspected that prior to being queried these subjects had successfully created a cognitive map which contained this property. In the third configuration, four of eight subjects were able to detect the crossing of paths and in the last configuration, only one of eight subjects indicated detecting this property. Even though some subjects did not realize the return path crossed a previously traversed path, experimental evidence suggests they were able to walk to their respective COP with a certain degree of accuracy.

Based on the ability of subjects to judge the position of their own COP, even if they had not detected the crossing of the paths initially, this locational information must have been "dormant" in the cognitive map created by some subjects and was not extracted until it was pointed out that it in fact existed (Downs, 1981). In support of the above statement, Kosslyn (1975) elaborated that all the properties of an image are not always available or can be activated simultaneously and thus some sort of "zooming in" has to occur in order to acknowledge their existence (e.g., in this case, the position of the COP).

Subjects did show evidence of using a cognitive map which deviated from the true representation and had been distorted toward a symmetric representation. This distortion varied, increasing with the departure of the configuration from the symmetrical source. The distortion toward symmetry was achieved through the augmenting of the COP to A distance.

The results indicate that the phenomenal shape of a symmetric representation had been achieved in a manner which suggests that it was transposed based on the length of the D to COP distance. The resultant map created was enlarged somewhat to accommodate the creation of the entire configuration but ultimately was limited by the structure of the "image space" (Kosslyn, 1975).

In summary, the Movement ratios were found to be different which suggests that the influence of the distortion toward symmetry was not maximized in each of the configurations. The comparison of the ratios for each configuration indicated a tendency for the representations to be distorted toward a symmetric representation away from the true representation. The equalizing of the distances walked appeared to be due to the augmentation of the COP to A distance and thus the symmetric representation created had been adjusted in size to achieve its phenomenal symmetric shape.

Chapter VI
Conclusion

Even without the benefit of vision, individuals comprehend the relationship of points in an environment by developing a cognitive map. From the introspective reports in this study, a variety of terms or phrases were used to suggest that the cognitive maps developed from experience with the experimental pathways were imagery-based (e. g., "mental images", "visualized pattern", "created a picture in my head", "spatial image", "mental pictures"). The present studies showed that imagery-based cognitive maps are subject to distortions which are influenced by the complexity of the pathway configurations and symmetry.

One of the ways in which the complexity of a configuration can be altered is by manipulating the angular relationships of the paths. In the first experiment, the effect of crossing paths was investigated. Research on cognitive maps has generally avoided the use of configurations in which paths crossed. It is presumed that judgements of orientation become particularly difficult due to an inability to detect this property.

Drawings indicated that the crossing of paths could be detected and therefore greater difficulty in judgements of orientation would not be expected. This was not found to be true. Kiara (1992) has suggested that there is greater difficulty in developing a proper "Gestalt" of an "X" shape and this may help to explain why large angular errors occurred when judgements of orientation were performed. An inability to detect the crossing of paths could account for the poorer performance as well as the greater frequency with which subjects turned in the incorrect direction when judging the target orientation.

When these findings are considered in the context of declarative and procedural knowledge (Magill, 1993), an additional or alternative explanation is possible for the reason that the detection of the crossing paths was not always achieved. When an environment is being learned, the focus is on "what to do" and thus individuals are able initially to describe the necessary actions required to perform a task (e.g., take X steps from point A to point B and then make a turn of Y degrees to orient to point C) but are unable to perform the task themselves. Declarative knowledge suggests that this information about the environment is stored as a list of descriptive statements. This list would not, for example, be expected to contain information with regard to whether the crossing of paths had occurred. Subjects would have to discover this property by other means.

On the other hand, as more practice is acquired, procedural knowledge would allow individuals to perform the task successfully without being able to describe how they accomplished the task. In this situation, the ability to judge the location of a target, which requires the acknowledgement of crossing paths in order to be successful, is made based on a cognitive map. It may be difficult to describe or verbalize what an individual must do when using a cognitive map of the environment to successfully achieve the goal.

In the configurations in which turns of ninety degrees were required for inferred judgements, this movement was made quite accurately. The ninety degree angle appears to be used as a benchmark for all angular movements and, as such, subjects are assumed to have an accurate representation of this particular angle. When the required angular judgements deviated from the 90 degree benchmark and obtuse angles were required, other compensatory factors still allowed for successful angular judgements of magnitude. In particular, when orientation tasks were performed in configurations resembling familiar geometric shapes, as in the case with the equilateral triangles in Experiment 2, successful judgements of other angle magnitudes could be made.

In order to move effectively through an environment, subjects must know where they are, where the goal is, and how to move between them. Subjects in the present experiments were instructed to turn in the direction which would require the smallest angle to orient to the target. The magnitude of the angles judged provided some evidence that subjects understood the relationship of the paths to each other. Subjects generally rotated the correct amount to orient to the target and therefore it appears that the information which is gathered from ambulatory exploration was processed appropriately. However, the execution was not always appropriate. Turns in the incorrect direction were made frequently and may be a result of subjects being unable to align the cognitive map with the experienced environment.

The findings of Levine et al. (1982) were supported when measures of orientation were used which did not consider the direction turned to the target. However, when both the accuracy of orientation to the target and the judgement of distances were considered, replication of the results of Levine et al. (1982) was not possible. This suggests that there are differences in the quality of the cognitive map created for learned as compared to inferred relationships. Judgements between learned points were more accurate since turns were made less often in the incorrect direction. In addition, subjects were able to walk with greater accuracy and less variability between learned points in terms of distance. These findings are contrary to what the equiavailability principle suggests would occur.

To extend the applicability of the equiavailability principle to judgements made between-pathways, integration of separately learned cognitive maps must be attempted. An example of the practicality of an integrated representation in a large-scale environment was suggested by Hanley and Levine (1983). "People may learn the spatial layout . . . . by selectively exploring separate regions of the space at different points in time" (p. 416). For example, separate areas of a city may be learned and later integrated by a main thoroughfare. Animals, on the other hand, frequently require the ability to integrate separately learned spaces for survival (Presson, DeLange, & Hazelrigg, 1989).

In the present experiments, two configurations in medium-scale space were only combined with limited success. Even though the "maximum" amount of orientation information was made available to the subjects for judgements of orientation and distance, this study suggests that integration of separately learned configurations was difficult. Therefore sequential learning of space may still remain the preferred strategy to use to learn environments, rather than the present method which would be described as sequential/integrative. One of the configurations showed evidence of equally good performance for between- and within-pathway movements. The reason for the superior performance in this configuration is uncertain.

In Experiment 2, configurations differed in terms of symmetry, but there were no differences in terms of orientation and distance judgements. Redundant information, in terms of equivalent angles and distances, was not used as expected. In fact, in building environments symmetry has been shown to be a problem for elderly visually impaired persons because of an inability to distinguish the specific cues of left and right (Kiara, 1992). Therefore, in some situations the redundancy of information provided by symmetry can be counter-productive when learning an environment, resulting in turns made in the incorrect direction.

Distortion in cognitive maps occurred in a manner which would suggest that the simplification of complex configurations is strongly influenced by symmetry. An imagery-based cognitive map would be expected to assume symmetry where symmetry is only approximate, and be affected by configurational properties. This was found to be true. As expected, the symmetrical configuration had the least amount of distortion. On the other hand, for the subjects who had experienced configurations which deviated from the symmetrical source, evidence supported the claim that distortion toward a more symmetric representation occurred.

In Experiment 3, subjects were able to make relatively accurate judgements of the position of the inferred crossing of paths, regardless of whether they had been able to detect this property in the first place. When the existence of the crossing paths was pointed out, subjects were able to "put" this property in the cognitive map. Balancing the distances before and after this point occurred by augmenting the distance from the crossing of paths to the starting position. Thus there was evidence for the simplification of the imagery-based cognitive map toward a preferred or stable symmetric state.

One of the measures of orientation used in these experiments attempted to determine the ability of subjects to orient to a point of interest when the signed angular deviation from the target is considered. It appears that the previous conclusions of Levine et al. (1982) and Hanley and Levine (1983) have been based on an artifact of the method of measurement since they could not be replicated when the efficiency of the orientation movement was considered. Based on this evidence, previous conclusions made with regard to the cognitive map need to be re-assessed.

Implications for blind mobility

Training methods used to teach the visually impaired or blind individual to learn his or her environment, may benefit from the findings of these experiments. For example, avoiding the use of pathway systems in which the crossing of paths occurs is beneficial to learning an environment. In addition, the use of familiar angles such as 90 degree turns should be encouraged as well as "familiar" geometric configurations. Simplification of cognitive maps to a more stable symmetric representation will occur due to the distortive properties of symmetry; thus near symmetric pathway systems should be avoided. Regardless of the complexity, physical experience of paths between points is more effective in learning the interpoint relationships than is making judgements based solely on inferred information.

Chapter VII

Factors to consider: Present and future

Present

In the present experiments an attempt was made to simulate the experience that visually impaired or blind individuals have when learning an environment. However, the implications of these findings, as they relate to the visually impaired and blind population, must be treated cautiously. Blind individuals normally do not learn environments in the same way as the subjects in the present experiments. In the most common situation, information is extracted from the environment through sequential haptic exploration. Blind individuals also use compensatory strategies such as the knowledge of environmental regularities and echolocation to learn space. Such opportunities were unavailable to the present subjects. In addition, physical objects are normally in the explored environment and act as landmarks from which judgements of other locations can be made. Such landmarks were not present in these experiments.

Two methods of establishing orientation were used in the series of experiments. In Experiment 1 and Experiment 3 subjects were allowed to walk through the particular series of paths (performed in the learning trials) and made the judgement of a target once an end point had been reached. In Experiment 2, due to the nature of the test movements, all of the orientation information had to be recalled from memory as subjects were told prior to making the necessary angular movement to the target where they were standing relative to another point in the configuration. This method of orientation required additional mental processing and thus the difficulty of performing the task was increased.

Once the orientation had been established, subjects were required to turn the angle necessary to orient to the target and follow that line without deviation. This method of measuring movement eliminated veering while separating the measures of orientation and distance. This method is somewhat unnatural in that it does not allow for normal adjustments that may be made enroute.

Future

The findings from the present series of experiments suggest that future research should be pursued in several areas. These areas include improving methods to integrate cognitive maps, determining the reasons for turns made in the incorrect direction when efficiency of orientation movement is considered, and the effect of the presentation of the COP on judgements of distance.

Levine et al. (1982) have suggested that regardless of the manner in which the environment is learned similar survey knowledge should be developed. In subsequent experiments survey knowledge was investigated either by an integration of individually learned portions or by sequential learning of the total system. Hanley and Levine (1983) also stated that survey knowledge was to be " . . . independent of the way the spatial layout is learned . . . .[however] separate acquisition and subsequent integration of the component regions affected the accuracy of the subjects' survey knowledge of the integrated layouts" (p. 421). It is possible, as has been suggested by Hanley and Levine (1983), when pathway information is well remembered, individual differences in cognitive skills may have " . . . overcome the effects of independently learning the paths" (p. 421). A sequentially learned five-point path configuration similar to Configuration 1 or Configuration 4 (in Experiment 2) could be used to compare performance to identical tasks performed in the integrated map condition. In this way, one would be able to see how detrimental the integration process was to the judgements made.

Better methods of integrating cognitive maps must be investigated. One way to rectify the lack of information available for successful integration of the cognitive maps is to have subjects walk between points which would integrate the two pathways in some way. This could have been accomplished by learning the relationship of two points between labelled pathways in one direction and testing them in the reverse direction. In fact, this information (or similar information) would be available during the learning sequence and would be much more beneficial to any future judgements being made between pathways (Moar & Carleton, 1982). Another way which could have improved the relationship of the separate pathways would be to have a segment, instead of a point, which corresponded to both component configurations. This is very similar to the experimental procedure employed by Moar and Carleton (1982) in which segments in a large-scale environment were the same in two sets of slides of a neighbourhood.

The integrative process may have been easier for females as indicated by a smaller difference between the movement types when the signed deviation from the target orientation was measured in Experiment 2. Further research is required to establish the nature of the gender differences.

Previous experiments have not attempted to explain why subjects turn in an inappropriate direction when asked to orient to a target. Subjects were expected to remember the direction of turns made when learning the configurations and repeat these turns when orientation information was given. Even when test movements of the simplest nature were attempted, some subjects turned in the incorrect direction while making a turn of the correct magnitude. This was evident in the SF movements made in Experiment 2 in which subjects turned in the incorrect direction 7.8% of the time. When inferred movements were required subjects were expected to determine the correct direction to turn by accessing their cognitive map of the environment. In this regard, when subjects were performing WSC movements (an inferred judgement) they turned in the incorrect direction 25% of the time. Pathway complexity also appears to influence the tendency to turn in the wrong direction. Subjects turned in the incorrect direction only 7.3 % of the time in Experiment 3, while in Experiment 1 with paths crossing during the learning of the configuration, subjects turned in the incorrect direction 29.6% of the time. Thus there appears to be evidence that regardless of whether the nature of the test movement requires a learned or inferred movement a certain percentage of the turns will be in the incorrect direction, and this occurs more frequently with complex configurations.

Turning in the incorrect direction may be a result of an inability to determine one's present position relative to the cognitive map created. Therefore when inappropriate judgements of orientation are made they may be a result of guessing. On the other hand, incorrect turns may also be a result of forgetting. Distinguishing the contribution of guessing and forgetting to the frequency of turns made in the incorrect direction is important when the efficiency of the movements to a target are considered. The specific contribution of guessing or forgetting to turning in the wrong direction to the target must be established so that appropriate strategies can be used which will compensate for these factors.

Lastly, subjects were required to acknowledge the existence of a crossing of paths which had been referred to as a crossover point (COP). Initially, the COP did not exist in all of the subjects' representations of the configurations. Its detection appeared to be related to how close the COP was to the starting position. Thus future research should investigate how the presentation of this information (the existence of the COP) affects judgements of the starting position and whether any improvement in locating the COP occurs once subjects are aware of their existence.

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Appendix A

Information for the subjects in Experiment 1

In this experiment you will be required to walk three series of pathways while blindfolded. Each series will contain changes of direction. You will be required to learn the relationship of each point to all other points on the path and the total relationship of the paths to each other. The experimenter will lead you, while blindfolded, through the pathways during the entire experiment using a method for leading the visually impaired described in Hill and Ponder (1976) (See attached sheet).

The experiment will begin by leading you along a reference path. The knowledge of the length of the reference path will be required later during the testing trials when you will be required to draw the relationship of the learned paths to each other with the correct orientation and proportion to a scale that will be on a piece of paper. You then will be placed in a wheelchair, disoriented within the room and then brought to the beginning of the first series of paths.

On the first series of paths you will begin the **training trials** at point A. You will be brought to this point via a wheelchair. From this point you will continue to be led to points B, C, and D. At each point at which a change of direction will occur, an announcement of that point will be made by the experimenter. At point D, you will then be told to think about the relationship of the start of the path to point D and the relationship of all of the other paths and points to each other.

Following this, you will be seated in a wheelchair, spun around and then pushed around the experimental area for approximately 10 seconds. You will then be brought to the beginning of the reference path and led through an additional time. Once this has been completed, you will be disoriented and then brought to the the beginning of the previous A-B-C-D pathway and led through four additional times. These are considered the training trials.

On the testing trials, you will be led through the same pathway as you have just been trained on. This time once you have reached point D, you will be asked to make a judgement to the position of the start (Point A). This will be done by first shuffling your feet in the same spot to the orientation that you feel that the starting point occurred. You will be instructed to turn in the direction of the smaller angle to the goal. A measurement of the direction that you have chosen will be noted. Once this has been done, the experimenter will lead you along a path in this direction and require you to stop at the point that you feel Point A occurred. After this, you will be brought to the start of the reference path and led along this path.

After you have completed the reference path, you will be brought to a desk at which time you will be asked to draw the relationship of the paths (the distance and direction) to each other based on the knowledge that the length of the line on the paper marked J and K represents the length of the reference path that you have previously walked. You will do this task with the aid of vision. The experimenter will ask you to draw the relationship from point A, B, C, D and then back to A based on this knowledge. Label and connect these points to each other making sure that the angles between the points are correct and the distances of the paths between the points are in the correct proportion to the scale that is represented by the reference path and the J - K distance. For example (only as an illustrational tool), if the length of the path represented a distance of 20 metres, a distance of 4 metres would be one fifth of the distance. Remember the distance on the page represents the distance that you walked on the reference path and that all judgements of the drawings should be based on this knowledge. Please only use the long edge of the straightedge provided. You will have approximately 90 seconds to complete this drawing.

The second drawing involves the use of a different scale length (L - M) but with the same knowledge that this distance now represents the distance of the reference path that you have used before. Based on this, you are expected to draw the length of the total distance walked from A to B to C to D back to A in a **straight** line. Mark the straight line with the appropriate letters at which you believe they occur. When you are finshed you should have a straight line with five points marked on it. Again, make sure that the lengths between each of the points are correct based on the knowledge of the ratio of the reference path length to the length of the path L - M. You will have approximately 90 seconds to complete this drawing. Once you have finished this, you will be brought to the same testing path as before and will go through the same procedure two additional times without walking through the reference path. During the training and testing of the other series of paths you will be asked prior to and after the first training trial of a configuration and immediately following the five training trials whether you wish to walk the reference path an additional time. If you make this request, an additional "walk" will be granted.

Once you have been tested on the first series of paths, this entire procedure of training and testing will be done on a new series of paths. Remember there are three series of paths in total.

Summary of tasks

1) The subject will be led along a reference path.
2) The subject will be led through the first series of paths once.
3) The subject will be led along a reference path.
4) The subject will be led through the first series of paths four additional times.
5) On the testing trials the subject will be led through the first series of paths and then be required to make a physical judgement of the starting position from Point D.
6) The subject will be led along the reference path.
7) The subject will be brought to a desk at which time they will be required to draw the relationship of the points with the correct angles between the points and another drawing with the relationship of the points in a straight line. These judgements will be based on two different scales.
8) Steps 5 and 7 will be done three times in total on the first series of pathways.
9) Steps will be repeated with two other series of pathways. You will be prompted when the opportunity to complete the reference path is made available for additional trials.

Remember, you may withdraw your participation from this experiment at any time.

Appendix B

The following instructions are from Hill and Ponder (1976) on the proper method of guiding blind pedestrians and also in proper seating technique.
From pages 12 to 13:

A. Basic Sighted Guide

PURPOSE:
To enable the student to utilize a sighted guide safely and efficiently
To provide the student with a basis for subsequent guiding skills

1. BASIC METHOD

1.1 Procedure

1.1.1 With the back of his hand the guide contacts the student's arm.

1.1.2 The student moves his hand up the guide's arm into position just above the elbow.

1.1.3 The student's thumb is positioned just above the elbow on the lateral side of the guide's arm with the remaining four fingers on the medial side, in a grip that is secure, yet comfortable for the guide.

1.1.4 The student's upper arm is positioned parallel and close to the side of his body.

1.1.5 The student's upper and lower arm form an angle of approximately 90 degrees with the forearm pointing forward.

1.1.6 The shoulder of the student's grip arm is directly behind the shoulder of the guide's gripped arm.

1.1.7 The student remains approximately one half step behind the guide.

1.1.8 The guide outwardly rotates his arm, simultaneously turning toward the student, and the student releases his grip.

From pages 23 to 24:

H. Seating

PURPOSE:

To enable the student to locate and examine seat and independently seat himself

1. BASIC METHOD (General Seating)

1.1 Procedure

1.1.1 The guide brings the student within close proximity of a seat.

1.1.2 The guide verbalizes the seat's position relative to the student.

1.1.3 The student releases his grip on the guide.

1.1.4 The student moves his foot in the direction of the seat until contact with the seat is made.

1.1.5 The student faces the seat, assuming a modified hand and forearm vertically or horizontally in front of his face and forehead.

1.1.6 The student bends at the waist, and with his free arm contacts the seat at the point where it contacts his leg.

1.1.7 With the backs of the fingers, the student lightly clears the area on which he will sit by using: a) horizontal and vertical; or b) circular movement.

1.1.8 With the back of his legs, the student squares off the front of the seat and is seated.

1.1.9 To exit, the guide reestablishes contact with the student.

1.1.10 Simultaneously with rising, the student trails his hand up the guide's arm to the approximate grip position and assumes the proper grip and position.

Appendix C

Formula for the calculation of the proportion of success

$$Z = \frac{\hat{p} - p}{\sqrt{\frac{p * q}{n}}}$$

where $\hat{p}$ is the sample proportion

p is the proportion expected in the population

q is the equal to 1-p

Calculation of the proportion of success for the first research hypothesis

where $\hat{p} = 13/36 = 0.361$

$p = 0.125$

$n = 36$

$$Z = \frac{0.361 - 0.125}{\sqrt{\frac{0.125 * 0.875}{36}}}$$

$Z = 4.28$

Calculation of the proportion of success for the second research hypothesis

where $\hat{p} = 26/36 = 0.72$

$p = 0.125$

$n = 36$

$$Z = \frac{0.72 - 0.125}{\sqrt{\frac{0.125 * 0.875}{36}}}$$

$Z = 10.79$

For Table 1. Contrast of treatment means for segments in angled drawings

Constrast of Treatment means (Treatment 1 vs. Treatment 2) for CE of the first segment

Parameter	Estimate	T for HO: Parameter=0	Pr>|T|	Standard Error of Estimate
Treat 1 Vs. 2	0.23003472	1.21	0.2295	0.18965052

For Table 4. Summary ANOVA Table for the variable MAE

Source	DF	SS	MS	F	Pr>F
Gender	1	78.37037	78.37037	0.05	0.8327*
Sequence	5	1394.41573	278.88315	0.17	0.9733*
Sequence*Gender	5	10915.98764	2183.19753	1.27	0.3089*
Subject(Seq*Gen)	24	41243.33332	1718.47222	1.37	0.1584
Period	2	4225.02677	2112.51338	1.68	0.1936
Treatment	2	12066.35769	6033.17884	4.81	0.0112
Residual	2	2605.66718	1302.83359	1.04	0.3598
Error	66	82826.37796	1254.94512		

*Error term for Gender, Sequence, and (Sequence * Gender) is Subject (Sequence*Gender) MSE

Appendix D

Information for the subjects in Experiment 2

In this experiment you will be required to walk two series of pathways while blindfolded. Each series will contain changes of direction. You will be required to learn the relationship of all of the points on the pathway as well as the total relationship of the paths to each other. The experimenter will lead you, while blindfolded, through the pathways during the entire experiment using a method for leading the visually impaired described in Hill and Ponder (1976) (See attached sheet).

In the training trials, the procedure to be followed in each series of pathways will be the same. You will begin the training trials of each series of pathways at either point A or point 1. You will be brought to this point via a wheelchair. From point A or 1 you will be led to additional points at which changes in direction will occur. An announcement of that point will be made by the experimenter. You will then be told to think about where the points of the pathway are relative to your present position and the other relationships within the paths. After approximately five seconds, you will then be seated into a wheelchair, spun around and then pushed through the experimental area for approximately 10 seconds. This process will be repeated a total of three times for each pathway.

In the test trials, you will be brought to a position on one of the pathways by a wheelchair and asked to stand. For each test movement, there is a minimal amount of information that must be given to you so that a successful replication of the correct orientation and distance to the target chosen may be made. First, you will be told what point lies behind you. Then, the experimenter will announce two points from the two pathways that are to be considered the integration point. A slightly different procedure will be used for particular judgements.

Once you confirm that you are familiar with the orientation, you will be required to judge the distance and direction to a point as announced by the experimenter. You will **rotate** your body in the direction you feel the point requested by the experimenter is situated in the smallest possible angle. During the measurement of this orientation, I want you to continue to concentrate on that point. Once this measurement has been made, you will be asked to walk to that point. You will be led along the direction that you have chosen and the experimenter will ask you to stop walking when you feel you have reached the point.

After finishing each walk, you will be seated in a wheelchair, spun around and then pushed through the experimental area. After this has been done for approximately 10 seconds, you will be led to the next test position of the pathway and the procedure will be repeated for another movement. Six test movements will be made.

Remember, you may withdraw your participation from this experiment at any time.

Appendix E

For Table 6. Summary table for contrast variables for the variable MAE where "Type" represents a SF or WSC movement.

Source	DF	SS	MS	F	Pr>F
Type	1	4704.5	4704.5	2.58	0.1214
Type*Gender	1	1725.78	1725.78	0.95	0.3404
Type*Config	3	1518.44	506.15	0.28	0.8411
Type*Config*Gender	3	2885.28	961.76	0.53	0.6678
Error	24	43778.00	1824.08		

For Table 8. Summary table for between-subject effects on the analysis of WPM and BPM means for the variable MAE.

Source	DF	SS	MS	F	Pr>F
Gender	1	3813.06	3813.06	3.83	0.0622
Config	3	2794.36	931.45	0.93	0.4393
Config*Gender	3	1423.76	474.59	0.48	0.7018
Error	24	23920.97	996.71		

For Table 8. Summary table for univariate tests of within-subject effects for the variable MAE where "Type" represents a WPM or BPM.

Source	DF	SS	MS	F	Pr>F
Type	1	37369.72	37369.72	39.01	0.0001
Type*Gender	1	3052.56	3052.56	3.19	0.0869
Type*Config	3	3786.27	1262.09	1.32	0.2918
Type*Config*Gender	3	2950.04	983.35	1.03	0.3984
Error	24	22990.28	957.93		

Appendix F

Information for the subjects in Experiment 3

In this experiment you will be required to walk a series of pathways while blindfolded. The series will contain changes of direction. You will be required to learn the relationship of all of the points on the pathway as well as the total relationship of the paths to each other. The experimenter will lead you, while blindfolded, through the pathways during the entire experiment using a method for leading the visually impaired described in Hill and Ponder (1976) (See attached sheet).

In the **training trials**, you will be brought to point A of the pathway (via a wheelchair) and then led to points B, C, and D. Once each point is reached, the experimenter will announced that point to you. Once you reach point D, you will be told to think about the relationship between the points announced and the pathways that connected them. After approximately five seconds, you will be seated in a wheelchair, spun around and also pushed through the experimental area. After this has been done for approximately 10 seconds, you will be led to the start of the pathway again, and then this procedure will be repeated an additional four times.

During the **training trials** you will be led through the pathway as usual, however, at point D you will be required to perform an orientation task that will involve **turning** your body in the direction of the starting point (point A) in the smallest possible angle. While a measurement of the angle that you have moved is being made, continue to concentrate on the position that you feel the point occurs. The experimenter will then map out the direction that you judged to be the orientation of the starting position. Once the measurement of this orientation is made, you will be led along this path and asked to stop once you feel you have reached the position of A. Each time after finishing this walk, you will be seated in a wheelchair, spun around and pushed through the experimental area. After this has been done for approximately 10 seconds, you will be led to the start of the pathway again, and then the test trial procedure will be repeated two additional times.

Remember, you may withdraw your participation from this experiment at any time.

Appendix G

For Table 11. Summary ANOVA Table for the variable MAE

Source	DF	SS	MS	F	Pr>F
Config	3	350.75	116.92	0.39	0.7603
Error	28	8369.19	298.90		

For Table 12. Summary ANOVA Table for the Movement Ratio

Source	DF	SS	MS	F	Pr>F
Config	3	10.38799976	3.46266659	3.43	0.0304
Error	28	28.24879708	1.00888561		

For Figure 16. Summary ANOVA Table for between-subject effects for Configuration.

Source	DF	SS	MS	F	Pr>F
Config	3	10.78581429	3.59527143	2.76	0.0610
Error	28	36.53282580	1.30474378		

For Figure 16. Summary ANOVA Table for univariate tests of within-subject effects for DIST (CEDIST1 and CEDIST2).

Source	DF	SS	MS	F	Pr>F
DIST	1	31.07597942	31.07597942	20.37	0.0001
Config	3	10.41910055	3.47303352	2.28	0.1015
Error	28	42.71425919	1.52550926		

Glossary of terms

Adventitiously blind

Blind individuals who have had some visual experience (early or late blind).

BPM (between-pathway movement)

A movement made between two differently labelled cognitive maps after the integration of these maps has occurred.

CEDIST

Distance error based on the signed deviation from the target distance.

CEMAG

Signed angular deviation to the magnitude turned based on the signed difference between the target magnitude and the magnitude turned.

CEPER

An angular movement error based on the CEMAG value divided by the target magnitude to be turned. Also referred to as the percentage error.

CETT

Error turned to the target as the signed angular deviation from the target orientation.

Cognitive map

A " . . . mental representation of our milieu . . . " (Gärling et al., 1984, p. 5) which is necessary for successful navigation of an area.

Congenitally blind

Individuals that have been blind since birth.

Equiavailability principle

Suggests that judgements of distance and direction between learned and inferred points can be made equally well.

Euclidean judgements

Judgements of the straight line relationship between points in the environment.

Homing vector model

An internal representation of space that allows for shortcuts to the origin of locomotion without a memorial record of the traversed pathway.

Imagery-based cognitive map

A survey representation of space which corresponds to a map-like image of the environment.

MAE

The minimum absolute turning error is the minimum number of degrees by which a subject erred in orientation to the target orientation regardless of the direction turned.

MAG

Magnitude of the turn made.

Mobility

The " . . . ability to walk from one place to another in complete safety, and to walk as quickly and smoothly as possible without undue psychological stress" (Shingledecker & Foulke, 1978, p. 281).

Movement Ratio

A ratio used in Experiment 3. It was calculated by dividing the distance walked in the first test segment (D to COP) by the distance walked in the second test segment (COP to A)

Orientation & Mobility

Study of the perceptual guidance of locomotion.

Ratio-scale drawings

A method of determining lengths of segments in the testing environment based on a distance learned at the same scale as the testing environment and another which is present on a piece of paper.

Reference path

A path which is experienced by ambulatory or manipulatory means necessary for ratio-scale drawing tasks.

Reflective symmetry

Symmetry determined by the transformation of a figure on to itself by its reflection upon a symmetry plane.

Rotational symmetry

Symmetry determined by the rotation of the figure about a line, a symmetry axis, which causes the figure to map onto itself more than once.

Route knowledge

Knowledge of space which is limited to the particular order in which the environment has been learned when judgements of distance and direction are required.

SF (simple forward movement)

A movement made between points whose relationship has been learned previously. These movements occur in a similarly labelled cognitive map and is one of the within-pathway movements (WPM).

Survey knowledge

Knowledge of space which is not limited to the particular order in which the environment is learned and thus allows for judgements of distance and direction between points that must be inferred.

Symmetric Ratio

A ratio used in Experiment 3. A one to one ratio.

Translational symmetry

Movement of a group of points in a figure an equal distance along a straight line such that those points map onto themselves on another portion of the figure.

Trigonometric-computation model

A survey representation of space which allows for the angular and distance relationships between learned and inferred points to be determined by trigonometric computations.

True Ratio

A ratio used in Experiment 3. It was calculated by dividing the actual segment length of the first test segment (D to COP) by the second test segment (COP to A)

VEDIST

Variability of the CEDIST values.

VEMAG

Variability of the CEMAG values.

VEPER

Variability of the CEPER values.

VETT

Variability of the CETT values.

Wayfinding

A " . . . person's abilities, both cognitive and behavioral, to reach destinations in the everyday environment" (Passini & Proulx, 1988, p. 228).

WPM (within-pathway movements)

Movements made within a similarly labelled pathway system (e.g., SF and WSC).

WSC (within-shortcut movement)

A movement made between points whose relationship must be inferred. These movements occur in a similarly labelled cognitive map and is one of the within-pathway movements (WPM).