Learning A Complex Urban Route Without Sight: Comparing Naturalistic versus Laboratory Measures

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Abstract
In this paper we report some of the results from a study of how people with severe visual impairments learn a complex route through an urban environment. Ten totally blind, ten partially sighted and ten sighted people learned a route 1600 meters long through a suburb of Belfast over four trials. On the first trial respondents were guided around the route. On the second, third and fourth trials respondents led the way around the route, pointing to the start, end, and three locations enroute from these locations. On completion of each trial respondents built a model of the route using magnetic pieces. Analyses of these tasks found no significance differences in pointing or model building between groups. Visually impaired and blind people did however make more errors when retracing the route although by the fourth trial the majority could retrace without error. The results, in combination, reveal that people with severe visual impairments can learn complex routes through a geographic environment both quickly and efficiently. The combined use of laboratory and naturalistic tasks indicated that levels of spatial knowledge do not necessarily predict the ability to use those knowledges effectively in everyday spatial behaviour. As such, the navigation problems facing visually impaired and blind people lie in learning new environments independently and in articulating their knowledges in wayfinding practice. These results led to the adoption of the *difference theory* of spatial cognition. This suggests that the cognitive map knowledge of adventitiously blind individuals are different from the sighted rather than underdeveloped or used inefficiently.

1 Introduction

Vision is often quoted as the spatial sense par excellence (Foulke 1983). This is because, as Brambring (1982) notes, sight is vital to locomotion as it allows the immediate perception of objects and the opportunity to easily orientate oneself. In particular, vision allows a person to perceptually differentiate perspective and scale, to recognize the invariant structure of an environment (Sholl 1996), and makes available distal information about the location of objects not just in relation to the perceiver but also relative to one another (Morrongiello *et al*. 1995). As such, vision provides an external frame of reference for coding spatial information. People with no or limited vision have to rely on sequential learning using tactile, proprioceptive and auditory senses to construct spatial relationships (Bigelow 1996) and intuitive logic dictates that limited vision (perception) leads to limited spatial knowledge (in absolute, if not relative, terms).

As a consequence of restricted vision it is widely contended that people with severe visual impairment or blindness experience a world different from those who are sighted (see Spencer *et al*. 1989). This has led researchers such as Golledge (1993) to argue that beyond communicating by reading and writing the inability to travel independently and to interact with the wider world is the most significant problem produced by visual impairment or blindness. Indeed, Clark-Carter *et al*. (1986) reported that at least 30% of people with visual impairment or blindness make no independent journeys outside their homes and most of those venturing outside their home independently, adhere to known routes, as exploration can lead to disorientation and chaos, accompanied by the fear, stress and panic associated with being lost (Golledge 1993; Hill *et al*. 1993). Like a sighted individual, a person who is vision impaired or blind must be able to traverse space at a reasonable pace (Golledge 1993) and undertake such mobility with grace, comfort and safety (Foulke, 1983). However, our understanding of the spatial world experienced by people with severe visual impairments remains relatively sparse.

In this paper, we examine how people with severe visual impairments learn a new route and compare the findings from a 'naturalistic' measure with two 'laboratory' measures. This is part of a wider study addressing issues of spatial cognition. The wider study compares the spatial behaviour of people in the United Kingdom and in the United States with little or no vision, investigating such issues as the effect of differences in mobility training, and the design of street layouts. The study reported here will be replicated in Santa Barbara, California. Learning environments consists of linking and integrating spatial knowledges at different scales into a coherent knowledge system. Over time we integrate knowledges of different routes experienced, with knowledges of vistas along those routes, with information gathered through a variety of secondary mediums such as maps and social mediation, to build a spatial understanding (see Kitchin, in press). People with severe visual impairments have limited access to vistas and most secondary mediums and, at present, we are unsure of how contemporary theories concerning the form and structure of sighted people's cognitive map knowledge, or how they learn and process spatial information, relates to them. We are unsure for two principle reasons. First, there have been relatively few studies of how people with severe visual impairments understand space, and secondly, those studies that have been undertaken generally relate to knowledge learnt through one particular medium (e.g. tactile maps, see Golledge 1991; Jacobson 1992; Ungar *et al*. 1994) and scale, rather than comparing across media (although see Jacobson, in press, and Espinosa *et al*, in press) and scales.

Compounding the problems of making insights about how people with severe visual impairments learn and behave in complex, real world environments is the fact that the vast majority of what research has been undertaken has tended to concentrate upon the conceptualization of small scale spaces such as a room (e.g. Tellevik 1992; Haber *et al*. 1993; Hill *et al*. 1993) or a building (e.g. Passini and Proulx 1988; Bigelow 1996) and hypothetical spaces such as a purpose built maze in a room (e.g. Passini *et al*. 1990; Klatzky *et al*. 1990). Little research has focused upon large scale geographic spaces such as an urban park or a residential area (although see Byrne and Salter 1983; Rieser *et al*. 1992; Espinosa *et al*. in press). A few researchers have tested blind people's wayfinding performance in real environments, but most have only asked individuals to walk a short route with one or two choice points (e.g. Leonard and Newman 1967; Dodds *et al*. 1982; Herman *et al*. 1983) rather than long and complex routes that often have to be traversed in everyday behaviour. As such, in this study we focused upon how people with visual impairments learn complex routes at the geographic scale. These large scale spaces need to be studied because they form the everyday space, the real world environment of blind people.

To test the visually impaired individual's ability to learn a complex route through an urban environment, a battery of naturalistic and laboratory measures were used. In this paper, we report and compare the results from three of these measures. The naturalistic measure consisted of a wayfinding error measured as the number of times respondents made mistakes while walking the route. The two laboratory measures consisted of pointing to locations and model building. In combination, the three measures provide an insight into how people with visual impairments learn new routes while providing an opportunity to test convergent validity. Convergent validity is the examination of the similarity of the results from different experiments which supposedly test the same hypothesis (Campbell and Fiske 1959; Russ and Schenkman 1980). If the results from the experiments deviate, then convergent validity is said to be weak, as alternative conclusions can be drawn from each experiments. Either one of the tests is producing true results and the others are suspect or they are all suspect methodologies. As we have argued in a previous paper (Kitchin and Jacobson 1997), the convergent validity of cognitive mapping tests in relation to people with severe visual impairments is generally unknown.

2 Methodology

2.1 Respondents

The participants in the study consisted of 10 people who were totally blind (no vision), 10 people who were visually impaired (legally blind but with some residual or peripheral vision) and 10 sighted individuals. All respondents either lived in the Belfast Urban Area or within 15 miles of Belfast city centre. The 10 sighted participants were all family members of blind or visually impaired respondents and were matched for educational background and age. The totally blind respondents consisted of 3 females and 7 males, were aged between 29 and 65 (mean 42.0), and had been blind between 2 and 38 years (mean = 23.5). All were adventitiously blind, 5 of the totally blind respondents were long cane users and 5 were guide dog users. The partially sighted respondents consisted of 5 females and 5 males, were aged between 29 and 59 (mean 42.5), and had been partially sighted between 1 and 42 years (mean = 27.8). All of the partially sighted respondents used residual vision to navigate, 3 used improvised mobility aids such as umbrellas and sticks. The sighted respondents consisted of 5 females and 5 males, were aged between 25 and 55 (mean 37.6). The orientation and mobility training of the blind and partially sighted respondents varied considerably. Three congenitally, partially sighted individuals had received none. The majority of participants had received orientation and mobility training shortly after going blind, involving rehabilitation, guide dog or cane training and the learning of routes to places of relevance in their daily lives. All the data was collected between 12 May and 28 Oct 1997. Respondents were paid £10 ($16) for completing part one of the project (tracing a known route) and £65 ($104) for completing part two of the project (learning a new route). Seven people completed part one without progressing to part two. In this paper, we only present results from part two of the project.

2.2 The Route

The route chosen was in a quiet, 'leafy' suburb of Belfast in the Stanmillis area. Its choice was based upon four main concerns. First, it provided a spatial layout that was reasonably complex and differentiated. Second, it was an area that was largely unfamiliar to all the respondents. Third, the area although flanked by a main road is generally quiet with light traffic allowing respondents to learn the route in a generally relaxed atmosphere. Last, Stranmillis is a relatively neutral, middle-class part of Belfast that all our respondents were happy to walk through and explore. This is particularly important given the nature of political territoriality in Northern Ireland and the propensity for members of the two communities to restrict their spatial behaviour to areas of their own community.

The route itself was 1600 metres long and included 16 choice points, with 8 left turns, 3 right turns, 3 intersections plus the start and end points (see Figure 1). The route was generally level although there were slight inclines and declines on certain sections. In general there were no auditory landmarks, although occasionally a police surveillance helicopter would hover over West Belfast for 2 to 3 hours at a time. None of our respondents indicated in de-briefing interviews that the helicopter provided them with clues concerning orientation. To avoid the sound of the schoolchildren playing most of the data was collected during the summer break. Of the remaining respondents their trips around the route were carefully regulated so that coincided with lessons and the school was quiet.

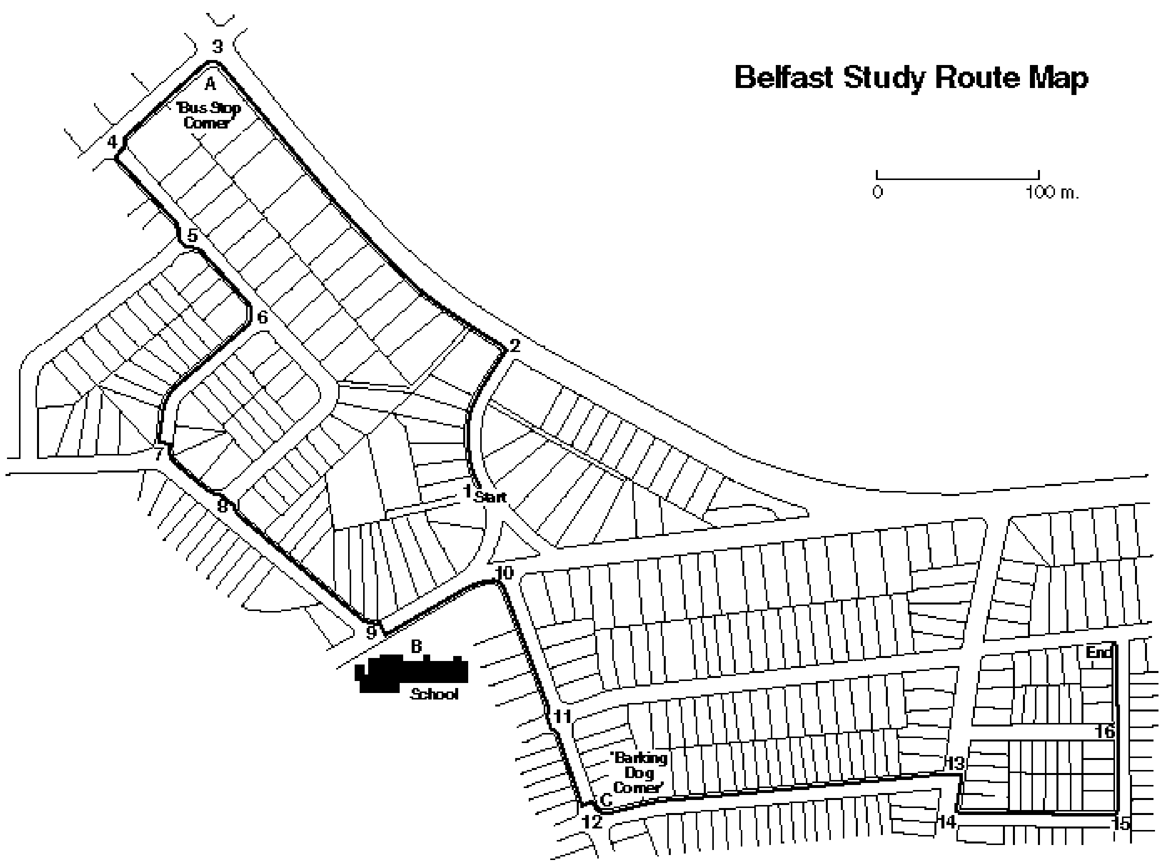


Figure 1

2.3 The Learning Procedure and Data Collection

All respondents were briefed on the learning procedure and the tasks they would be asked to complete before walking the route for the first time. Respondents were informed that they would be walking the route four consecutive times during the course of the day, on the later three of which they would be completing a set of tasks:

1. Pointing to and from three locations along the route plus the start and end points.
2. Verbally describing how to travel the route.
3. Estimating all distances, using a ratio scaling technique, between three locations along the route plus the start and end points.
4. Constructing a model of the route using black magnetic pieces against a white board.

At the end of the four trips they would also be completing a supplementary task (estimating which distances are further between paired locations) and a debriefing interview. If for any reason, such as rain, the respondent wanted to stop the process they were informed that they needed to do so after the first trip. If they wanted to stop after this point then they would be unable to complete the project at a later date. Only two respondents postponed the data collection after one trip, both because of poor weather. Both individuals were rescheduled and completed the project after a two week period. All the participants were tested individually. Two researchers (named authors) were present when totally blind and partially sighted respondents were undertaking the project and one for sighted participants.

The first phase of the learning procedure was to guide each respondent around the route. (Applying the findings by Allen (1982) that route learners tended to 'chunk' sections of a route).Respondents were informed that the route had been divided into four sections (see Figure 1). The first part of the route was from the Start (point S) to Bus Stop Corner (point A: bus stop was actually across the road, not on the corner). Respondents were told to make their own way there, with the researchers providing orientation guidance. The researchers did not physically lead respondents over any part of the route nor did they give any directions (e.g. left/right). Instead directional guidance was given by 'you need to turn to face my voice', 'or you need to cross the road you have just been walking down'. In this way, respondents had to code directions through their own actions. Once the respondent had reached the first destination they were informed that they had reached their interim destination. They were then allowed to explore the destination and were informed that on subsequent trips that they would have to point from this location to the start, end and the other two section points. Using the same procedure, respondents then learnt the other three sections (Bus Stop Corner to the School (point B) – actual landmark; the School to Barking Dog Corner (point C) - a barking dog was intermittently present; and Barking Dog Corner to the End (point E)). At all times these locations were referred to by their full title. All respondents learnt the same path, crossing roads at the same points (see Figure 1).

Upon completion of the first route respondents were driven back to the start. Sighted respondents were blindfolded for this trip. After each subsequent trip the journey from the end to the start took an alternative route. At the start respondents were asked to point to the three section points (A, B, C) and the end. Each pointing response was measured with a compass. They were then asked to walk to the first section point, Bus Stop Corner (A), informing the researchers when they thought they had reached there. They were informed that the researchers would follow just a little way behind and that they would be warned of hazards such as low branches. Further, if they deviated from the route by more than 5 metres then they were told that they would be stopped and led back to where they left the route. Rather than being pointed in the right direction respondents were encouraged to discuss where they thought they should have headed before being allowed to continue the route. Respondents were also told they would be video-taped at choice points to record their spatial behaviour. Upon reaching and identifying Bus Stop Corner respondents completed the pointing task before repeating the whole procedure for section 2. The same procedure was repeated for sections 3 and 4.

At the end of trips 2, 3, and 4 respondents were required to estimate distances between locations and to build a model of the route. For the purposes of this paper only the model procedure is detailed. Respondents were asked to construct an accurate model of the route using black magnetic pieces upon a white metal board (46 cm by 31 cm). Respondents were instructed that the model should include enough detail for another person in a similar position to themselves (e.g. totally blind, partially-sighted, sighted) to be able to retrace the route using their model. Before starting to build the model respondents were 'shown' the full range of available magnetic pieces. There were 10 types of magnetic pieces ranging from squares to rectangles, triangles, circles and semi-circles plus a selection of piping pieces. Respondents were then given the magnetic board and asked to orientate it as they saw fit (e.g. landscape or portrait). Once happy, they were given a small square to denote the start and then asked to complete the model. Whilst constructing the model the respondents were free to adjust and change magnetic pieces. Throughout the model construction respondents used a talk-aloud protocol to describe what they were doing and what the pieces they were laying represented. This protocol was recorded using a video camera (audio and visual) and once completed, the model was photographed.

2.4 Data Analyses

2.2.1 Route Walk Analyses

The video log of participants' spatial behaviour at choice points was used to construct a coding scheme for the number and nature of their errors. At each choice point respondents' actions were recorded as one of four classes:

1. successful navigation;
2. deviation from route, self correction then successful navigation;
3. deviation from route, required guidance, then able to give correct direction;
4. deviation from route, required guidance, then unsure or 'lost'.

This data was then analyzed using a mixed factorial analysis of variance (ANOVA) Within-subjects factors were trials (3) and choice points (16) and between-subjects factor the groups (3) (sighted, blind and visually impaired). In addition, the data was used to create a junction error score (JES) for comparison of actions at individual choice points. This score was calculated by applying a simple formula to the actions across a group at each junction using the four classes of actions as ordinal scores (OS) (e.g. class 1 equals a score of 1, class 4 equals a score of 4):

$$JES = \frac{\sum_{i=1}^{n} OS}{n}$$

where n = number of respondents.

2.2.2 Model Analyses

Each model was analysed using three different measures. First, the topological structure of the route was calculated. Second, a subjective classification of the orientation, shape and completeness of the route was administered. Third, a quantified calculation of absolute and relative error was undertaken using bidimensional regression. In this paper we only report on the first two of these measures.

Topological Structure

Figure 1 displays a topologically correct map of the route and figures 2-4 display each individual's models for each trial grouped according to vision status. Each of the models is labeled with the start (S), bus stop corner (A), the school (B), barking dog corner (C), and the end

(E). For the purpose of this study, the topology of the route refers to the correct sequencing of nodes and route segments (junctions right, left, and straight-on along the length of the route). A 'topologically correct' route would be a route whose sequence of nodes and route segments matches that of the actual route. This measure can be operationalised by calculating the sequence of rights, lefts, and straight-ons from the start to the end of the route. Clearly when assessing topological correctness of the models, however, account has to be made of omissions and errors. Otherwise an omission on the model will lead to cumulative "out-of sequence" errors. Consequently, the remaining junctions may be represented correctly, but are miscoded as the sequence of junctions is misplaced by the omission. To avoid this problem the sequence of route segments were anchored about the landmarks. That is, a right or left turn was allocated to a preceding or following landmark when an error or omission occurred. This allocation was cross-checked against the video model talk-aloud protocol to confirm the participants intended junction placement. Each junction (16 choice points) was then coded as: (1) correct; (2) incorrect; or (3) missing.

Subjective Classification

It is clear, through visual comparison between the map of the route (Figure 1) and the models (Figures 2-4), that some maps are clearly "better" than others. This difference was not quantified by topological analysis or bidimensional regression so a further subjective classification was undertaken. Three measures of accuracy were judged: completeness, shape and orientation. Completeness was scored using the following error codes (1) complete including side roads; (2) complete without side roads; (3) partially complete; (4) incomplete. Shape was scored using following error codes: (1) a "c" or "u" shape; (2) step-like shape; (3) circle or spiral; (4) linear. Orientation scores were based on the bearing of the end from the start. The correct bearing is approximately southeast, this was scored as 1. Moving away from the south east in either direction for 45 degrees was scored as 2. The 90 degrees segments to the north east and the south west were scored as 3. The 90 degree segment at the north west (180 degrees opposite the correct orientation) was scored as 4. These data were then analyzed using a 3(groups) by 3(trials) by 3(class: completeness, shape and orientation) ANOVA.

2.2.3 Pointing Analysis

The direction estimates were compared to their objective counterparts using accuracy scores. Two accuracy scores were constructed, one reflecting the absolute accuracy of direction estimates and the other the relative accuracy. The absolute accuracy score (AAS) represents the average percentage difference between the objective direction values (ODV) and the cognitive direction estimates (CDE) (Figure 5a).

$$AAS = \left(\frac{\sum_{i=1}^{n} \left(\frac{ODV^{i} - CDE^{i}}{180} \right) * 100}{n} \right)$$

where n = number of direction estimates.
Note: final answer is made positive (i.e.unsigned).

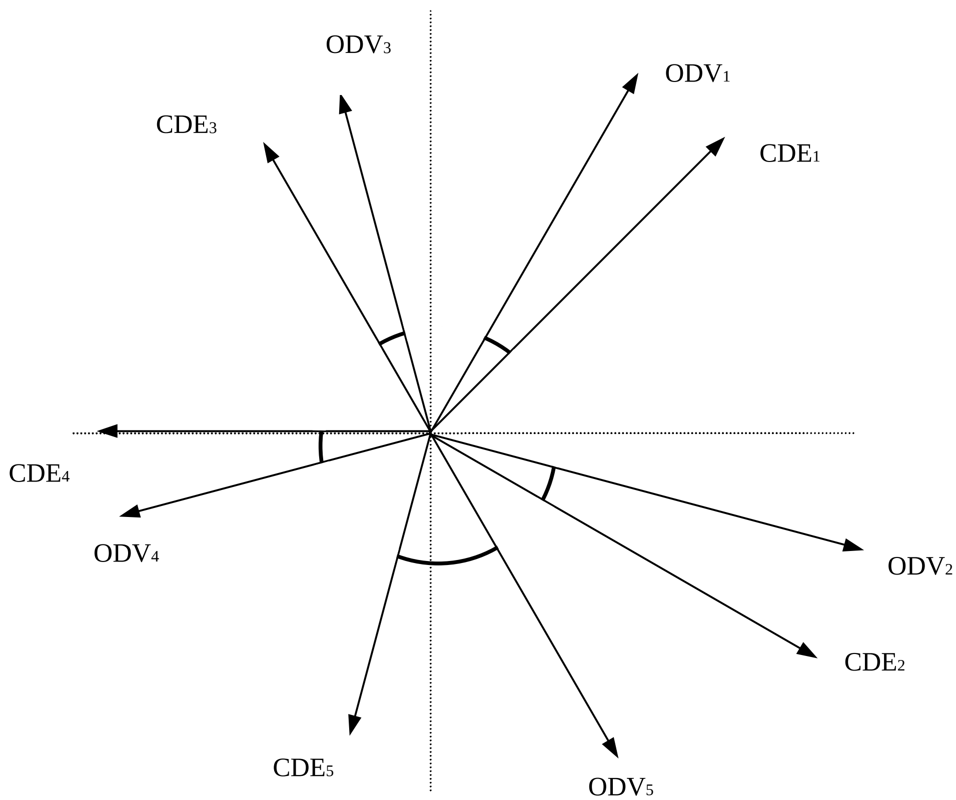
The relative accuracy score (RAS) represents the average percentage difference between objective angle segments (OASs) and cognitive angle segments (CASs) (Figure 5b). Once again, care must be taken in both cases to convert difference over 180 degrees to lesser values.

$$RAS = \left(\frac{\sum_{i=1}^{n} \left(\frac{OAS^{i} - CAS^{i}}{180} \right) * 100}{n} \right)$$

where n = number of angle segments.
Note: final answer is made positive (i.e.unsigned).

In addition, the absolute error scores were aggregated for each individual by calculating the mean of the pointing estimates for a trial. The aggregated absolute scores were analysed using two-sample t-tests to compare the results between groups for each trial, and within a group across trials to test for a learning effect.

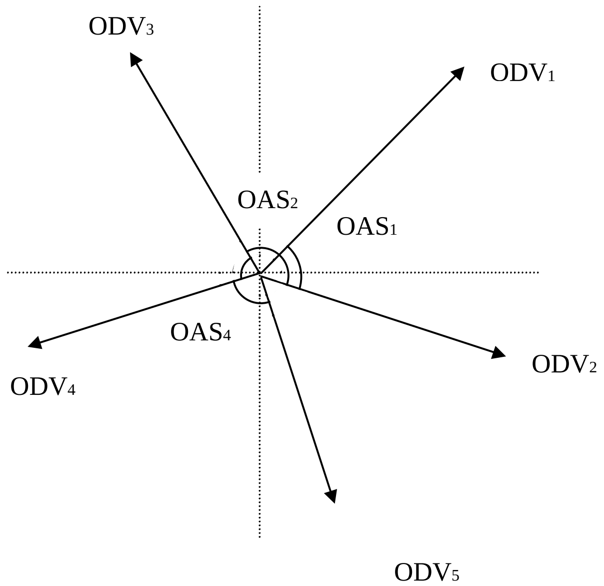
Figure 5a Absolute accuracy score

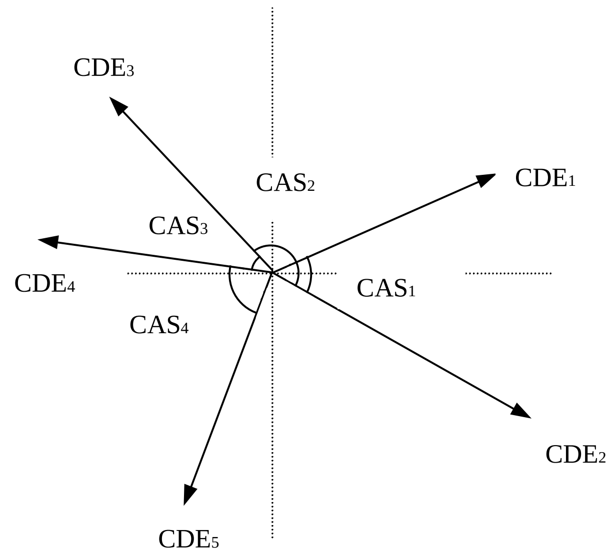


ODV - Objective direction value
CDE – Cognitive direction estimate

Angles marked are the unsigned absolute error

Cognitive angle segments





Calculating relative objective angles

Calculating relative cognitive angles

ODV – Objective direction value
OAS – Objective angle segment

CDE – Cognitive direction estimate
CAS – Cognitive angle segments

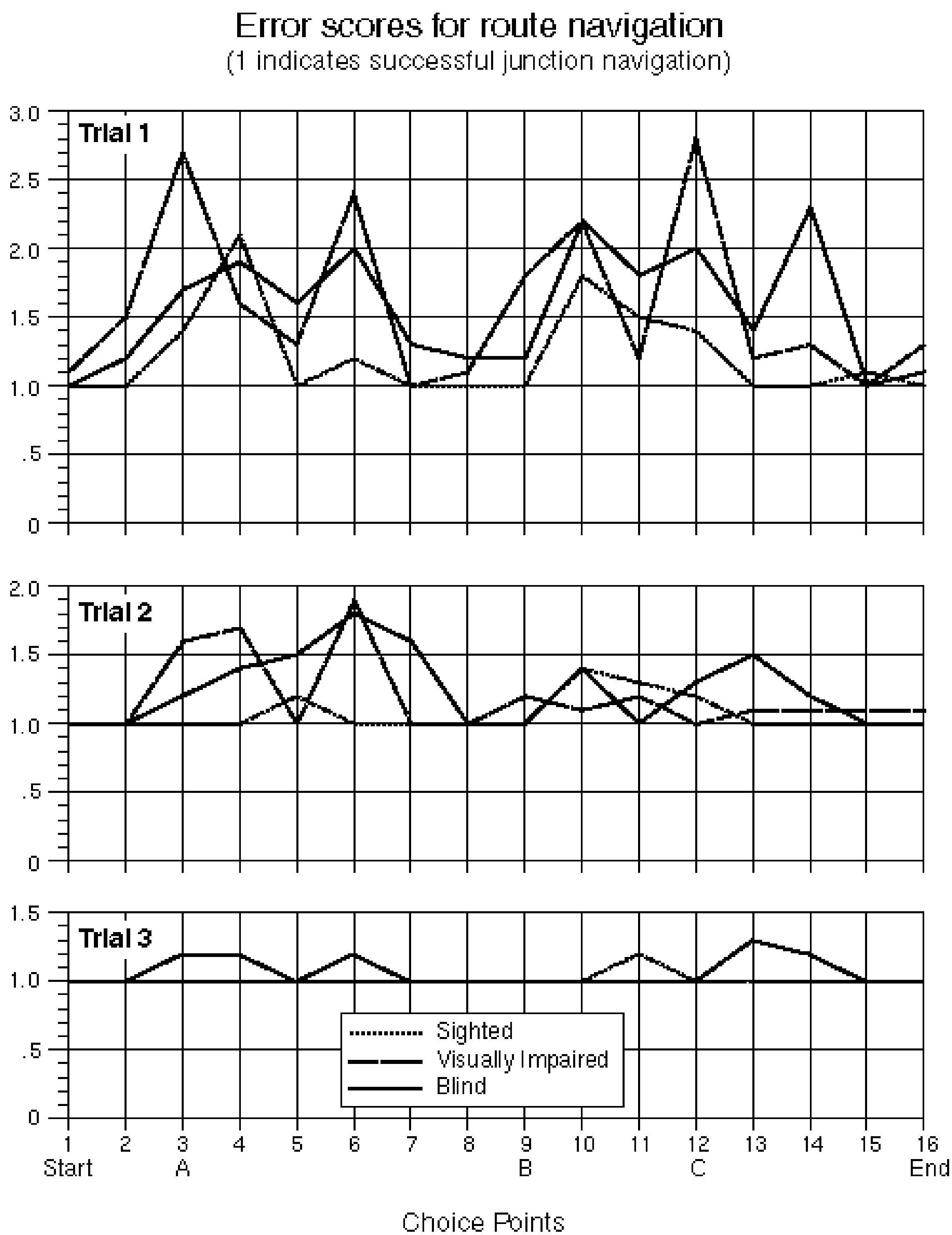
The raw (unaggregated) absolute error score for each pointing was analyzed using a mixed factorial analysis of variance (ANOVA). Within-subjects factors were the trials (3) and the directions to point (20), and the between-subjects factor the groups(3) (sighted blind and visually impaired). Although absolute error is the best index of "accuracy" (Spray, 1986) the data was further broken down into variable and constant errors, as absolute error can confound constant and variable error (Schutz and Roy, 1973). Variable error being the difference between each response and the mean response within that condition, and therefore reflects disagreement across responses. That is, the spread of pointing directions to a certain place. Constant error is the difference between the mean response to a pointing direction and the true direction, therefore representing a consistent bias across responses. For example, for a certain location and direction individuals consistently pointed to the left of the true direction. The mean response was calculated with circular statistics (Batschelet, 1981).

3 Results

3.1 Route walk

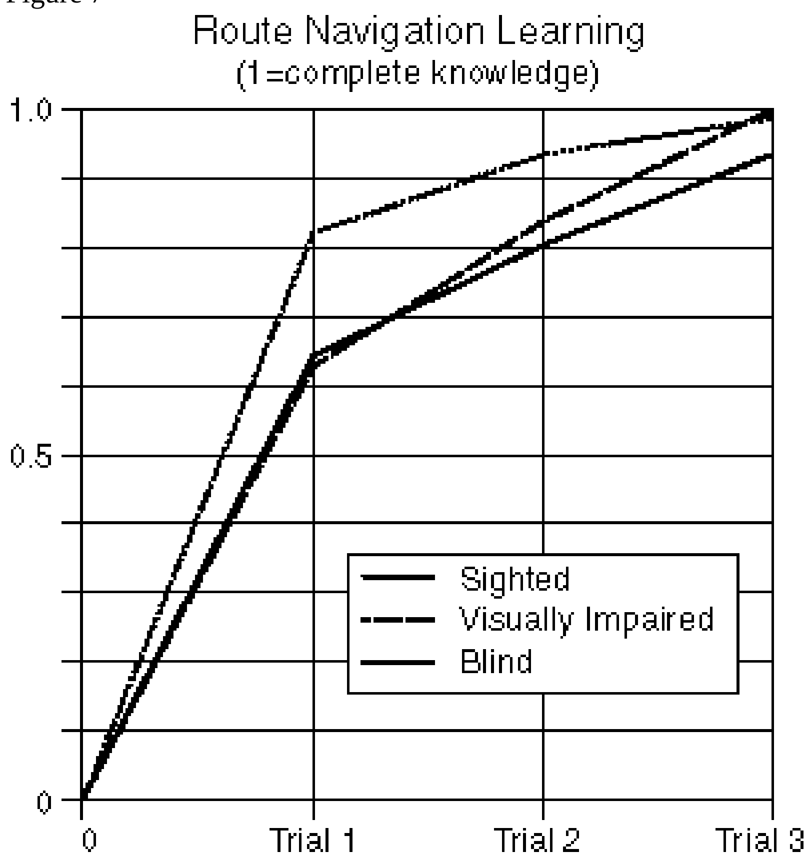
As expected the effect of the number of trials upon the ability to successfully retrace the route was highly significant ($F(2,54) = 49.152$, $p<0.0001$). From field observations participants clearly demonstrated an ability to learn the route, and for members of all three groups the number of errors diminished with each subsequent trial. As might also be expected, individual errors were highly related to specific junctions ($F(15,405) = 6.451$, $p<0.0001$), with participants making more navigational errors at certain choice points along the route. There was also a small group effect in relation to specific junctions, with some intersections significantly more prone to errors by a particular group ($F(30,405) = 1.776$, $p<0.1$). For example, one junction had very low kerbs, making it almost undetectable to totally blind cane users who would miss the junction, continuing straight on. The differences in route navigation abilities for each group are visualised in Figures 6 and 7. Figure 6 displays the JES for each of the groups (sighted, visually impaired and blind) at each of the choice points along the route for each trial. Figure 8 displays the learning curve for each group against trial. From these diagrams is apparent that the sighted learned the route faster, making fewer errors on the first and second trials, and could complete the route almost without error by the third trial. The visually impaired and blind groups learned at slower rate, making more errors on the first trial and second trials but by the third trial they too had learned the route almost to perfection. The mean JES for the third trial being, sighted 1.0125, visually impaired 1.0 and blind 1.0687 where a mean score of 1 indicates that all junctions were successfully navigated (the higher the score the greater the error).

Figure 6



Error scores for route navigation
(1 indicates successful junction navigation)
Trial 1
Trial 2
Trial 3
3.0
2.5
2.0
1.5
1.0
.5
0
Sighted
Visually Impaired
Blind
1
Start
2
3
A
4
5
6
7
8
9
B
10
11
12
C
13
14
15
16
End
Choice Points

Figure 7



3.2 Model

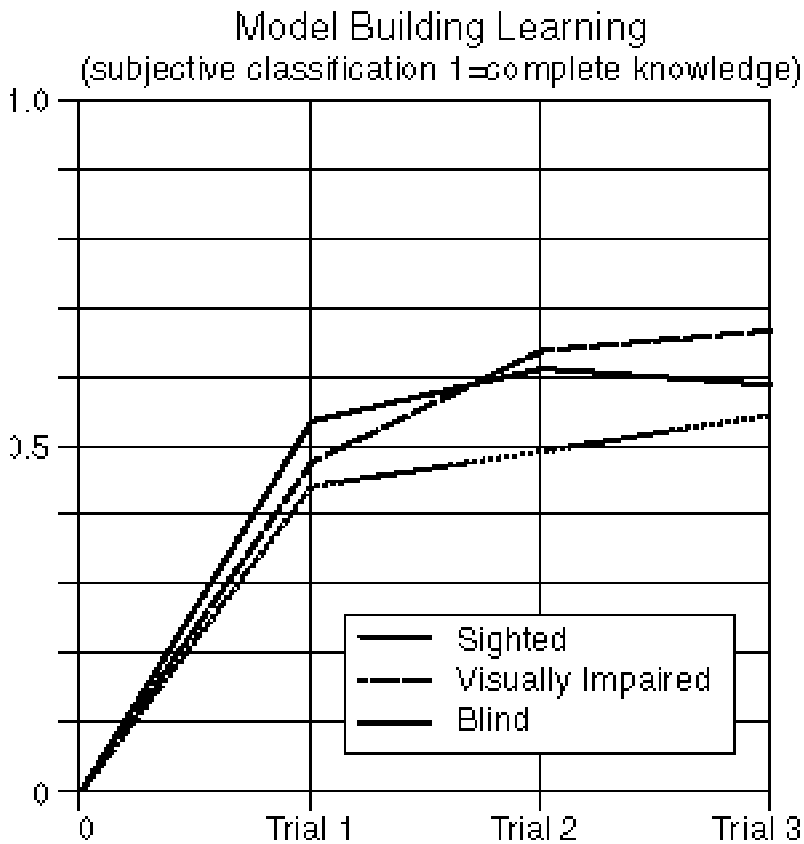
Topological Structure of the Route

The effect of the trials upon topological structure was highly significant (F(2,54) = 11.859 p<0.0001) (the mean error score across groups decreasing from 1.6958 for trial 1 to 1.4521 for trial 3). Individual junctions were represented very differently and had a disproportionate effect upon topological scores (F(15,405) = 40.563, p<0.0001). The effect of level of sight was found to be not significant (F(2,27) = 0.338, p = 0.717). In other words, there were no significant differences in the topological structure of the routes for members of blind, visually impaired and sighted groups. Similarly, there were no differences across trials and between groups (F(4,54) = 0.734, p<0.5), suggesting that each group learned at a similar rate.

Subjective Classification

Again there was significant effect of trials (F(2,54) =7.665 p<0.001). There was a strong effect of each individual measure (F(2,54) = 17.762, p<0.0001) and small effect of the measure by group (F(2,54) = 2.319, p<0.1) with each group scores varying across the measures. When the measures were combined, there was no overall effect of group (F(2,27) = 1.737, p<0.2). However, if each measure is taken independently, and t-tests used for each pairing of group, significant measure and trial effects were found between sighted and the visually impaired for the orientation measure (t= 2.132, p<0.05). The visually impaired group performed better than the sighted group (Figure 8).

Figure 8



3.3 Pointing

Figure 10 displays the pointing results, illustrating constant and variable error. The mean direction for each group across all trials pointing to a specific place, is shown by a line radiating from the place of pointing. The specific place they are pointing to is labeled at the end of this line. The circular standard deviation for that mean is represented graphically by an arc on the end of the mean observation line. The greater the size of the arc the greater the variable error. Constant error is shown by the difference between the mean line and the true direction.

A series of paired two-sample t-tests of the absolute (Table 1) and relative (Table 2) error scores for individuals, averaged across the whole route, showed no significant difference between the groups (sighted, visually impaired and blind), and no learning effect across the trials (Table 3). When analysed at a disaggregate level with ANOVA there were similarly no significant effect for the group ($F(2,27) = 1.061$, $p<0.36$), although the blind performed marginally worse than the sighted and vision impaired (blind mean = 22.8º, sighted mean 18.5º, visually impaired mean 18.7º). An absolute error of 90º represents a chance response. These errors are generally low and it is particularly salient that there is no significant difference between the group with sight and the groups with impaired or no sight. There was a significant effect for trial $F(2,54) = 8.467$ $p<0.001$, across the groups. That is, over the course of the trials mean absolute error reduced (m1=22.5º degrees, m2 = 18.9º, m3=18.7º) ((pairwise comparison, m1-m2, and m1-m3 $p<0.05$)).

Table 1: Two-sample t-test results comparing overall absolute error in pointing estimates across groups

	Trial 1		Trial 2		Trial 3	
	t	p	t	p	t	p
SI vs VI	-0.36	0.72	0.65	0.53	0.81	0.43
SI vs BL	-1.41	0.18	-0.38	0.71	-0.72	0.48
VI vs BL	-1.14	0.27	-1.31	0.21	-1.89	0.077

Table 2: Two-sample t-test results comparing overall relative error in pointing estimates across groups

	Trial 1		Trial 2		Trial 3	
	t	p	t	p	t	p
SI vs VI	0.99	0.34	0.56	0.58	1.34	0.20
SI vs BL	0.12	0.90	-0.15	0.88	-0.22	0.83
VI vs BL	-0.97	0.34	-0.69	0.50	-1.70	0.11

Table 3: Two-sample t-test results comparing overall absolute and relative error in pointing estimates across trials

	Absolute error		Relative error	
	t	p	t	p
SI1 vs SI2	0.22	0.83	0.67	0.51
SI2 vs SI3	0.08	0.93	0.56	0.58
SI1 vs SI3	0.31	0.76	1.07	0.30
VI1 vs VI2	1.52	0.15	-0.15	0.96
VI2 vs VI3	0.34	0.73	1.75	0.10
VI1 vs VI3	1.96	0.067	1.28	0.22
BL1 vs BL2	1.32	0.20	0.47	0.65
BL2 vs BL3	-0.36	0.72	0.47	0.65
BL1 vs BL3	0.86	0.40	0.88	0.39

Variable error (the standard deviation of estimates) is a useful measure of discontinuity in a group, how homogeneous are the sighted at pointing to a certain location? When measures of variable error are taken overall, across the route, the means are sighted 43.4º, visually impaired 45.1º, blind 57.6º. Overall there was no significant difference across the groups or trials for the variable errors. From the means it can be seen that overall the blind appear to have a higher variable error. Figure 10 clearly shows that in certain locations, pointing in certain directions produces differences between the variable errors, and this lack of statistical significance of an overall difference of variable error can be attributed to noise within the data set. In order to make a comparison of the variable errors between groups at certain locations a homescedasticity ratio test of variance was undertaken. This compares the variance of two samples to see if the assumptions of equal variance hold. Comparisons were made for each of the pointing directions

(20), between each group (3) for each trial (3), giving a total of 180 paired ratios. There were only 31 situations where significant differences occurred: 11 where the sighted had greater variable error than the visually impaired; 8 where the sighted group had greater variable error than the blind; The remainder were differences between the visually impaired and blind groups. This means that overall variable error was fairly similar across the groups for the whole of the route, with the blind having a slightly higher average of variable error. However, in certain situations, pointing to certain locations on the route the sighted had a greater variable error than the other two groups. In comparisons of variable error that were different to a statistically significant level, the sighted had the greater variance 95% of the time. It appears from this that the variable error made by the blind and visually impaired were more structured, a 'constant' distribution of points around a mean. The variable error of the sighted was far more place specific, and more 'random' at the places where they pointed poorly. A simple explanation suggests that the best of the sighted group point better than the best of the blind group, while the worst of the sighted group are worse at estimating directions than the poorest blind and visually impaired performers. These results differ slightly from those reported by Loomis et al., (1993) where the best of both blind and (blindfolded) sighted were equivalent, but where the worst of the vision impaired wee worse than the worst of the (blindfolded) sighted.

Constant error results are still undergoing analysis in an effort to look at the ongoing inter-relationships between the ability to point to places on the route and to navigate the route. There appear to be place and group specific constant biases visible in Figure 10. Possible reasons to explain these biases include environmental cues and the nature of the environment (Sadalla and Montello, 1989), such as alignment with features close to the place of pointing, or the inability of blind pedestrians to sense a shallow curve (several of the route segments contained shallow curves). Various egocentric "spatial framework" models, suggest people are biased to certain orthogonal axes to their own body (Franklin *et al*., 1995). This may indicate that when a participant is facing north, and the true direction of the landmark they wish to point to is at 80º. They may bias their response to a pointing direction of 90º, a right angle to their orientation. These biases are similar those reported in 9add ref to a work on generalising angles to 90, 180, 270,360. (Franklin *et al*., 1995).

4 Discussion

The results in combination reveal that people with severe visual impairments can learn complex routes through a geographic environment both quickly and efficiently. As such the results providing supporting evidence for the *difference theory* (as opposed to the deficiency or inefficiency theories - see Golledge, 1993 or Kitchin et al., 1997 for full discussion) of the spatial cognition of blind or vision impaired people This theory suggests that cognitive map knowledge and abilities are different rather than underdeveloped or used inefficiently. It is contended that visually impaired individuals possess the same abilities to process and understand spatial concepts, and that any differences, either in quantitative or qualitative terms, can be explained by intervening variables such as access to information, experience or stress. (The deficiency theory holds that spatial concepts are impossible in people who have been blind from birth. This theory is largely discredited today. The inefficiency theory suggests that people who are blind from birth develop concepts and representations of space that are functionally inferior to those of the sighted. (i.e. they are inefficient). The difference theory proposes that the visually impaired and blind may build up a set of spatial relations, which are functionally equivalent to those of the sighted, but that they do so by different means more slowly). This seems to be the case in our study where it is clear that people with severe visual impairments could successfully navigate a route, point to locations along a route and make a model of the route. Any slight differences in knowledge could be attributed to the lack of sight rather than mental processing capabilities.

While the laboratory tasks support the difference theory, it could be argued that on the naturalistic task (i.e. learning and navigating a complex urban route) performance on the early trials the visually impaired and blind individuals were *inefficient* when compared to the sighted, for the groups with partial or no sight made more errors in those early trials. However, by the third trial, the level of wayfinding ability in all the groups was similar (see Figures 7 and 8). Ongoing analysis of verbal descriptions of the route suggest that sighted people could successfully repeat the route at an earlier trial because they could spatially 'chunk' the route into less units (see Allen,1982). The groups without sight refer to many more discrete units or 'chunks' of geographic space in their descriptions (such as driveways and street furniture between the major choice points of the route. Haptic, tactile, and proprioceptive senses work within the bodyspace of the individual, while audition and sight work with more distal information. What is noteworthy is that in spite of a greater number of smaller, sometimes disparate "chunks" of spatial information the groups without sight were still able to synthesise this information, within a short time frame into a synoptic and coherent whole of similar content, complexity, and accuracy, to that of sighted people. The difference is an artifact of the learning of trials and the effectiveness of strategies used.

It is hypothesised that visual strategies of spatial thought are central to this accelerated learning and synthesis. The majority of the sample of visually impaired and blind people had at one time been sighted. Previous studies with individuals who have never seen suggest that the spatial abilities of the congenitally blind are inferior to those of the adventitiously blind and the sighted (for example Casey, 1978). It is hoped that current parallel testing, phase 2 of this study (being conducted in Santa Barbara) with congenitally blind individuals will expose further insights into the effects of having sight earlier in life.

The results reveal that naturalistic and laboratory tests measure related but different facets of knowledge and ability. The route retrace task measures the ability of an individual to use acquired spatial knowledge. Model and pointing tasks measure the levels and use of spatial knowledge. The tests indicate that people with severe visual impairments do possess the same abilities to process and construct spatial knowledge but their lack of vision interferes with initially putting knowledge into action, but not eventually. It is therefore suggested that a combination of laboratory and naturalistic tasks be used in order to expose the different facets of spatial learning and subsequent spatial behaviour based upon such learning.
It should be noted that, during de-briefing sessions and follow up interviews, many of the blind and visually impaired participants expressed a strong preference for the way in which they learnt the route. They suggested that tasks such as the pointing and the model building forced them to explore and reconstruct their spatial knowledge, to "actively learn and think about the route, and how it all went together". The value of active over passive learning is widely held in psychology. The methodology of the study may then have 'elevated' the spatial cognition of the individuals with partial or no sight. This illustrates that with suitable training, structured presentation of, and access to the geographic environment, the spatial abilities of the blind and visually impaired are comparable to those of the sighted.

5. Conclusion

Cognitive mapping research is of vital importance to blind and visually impaired people. It has the potential to provide clues as to how to enhance these wayfinding and orientation skills. By directly influencing orientation, mobility and rehabilitation training, a more complete understanding of their environment can be achieved, thus ultimately impacting on independence and quality of life. Secondly, there have been an increasing number of assistance devices developed for blind and visually impaired people. It is essential that into their conception and design goes a baseline awareness of how visually impaired and blind people navigate without these aids. Cognitive mapping research can provide this baseline, suggesting what information is needed by a blind navigator and how this information needs to be presented to the traveller (Kitchin *et al.*, 1997). Thirdly, the insights and understanding obtained through cognitive mapping research could be used to facilitate the planning of environments that are easier to remember and more pleasurable to use. Fourthly, by studying the acquisition of spatial cognition by people who have a degree of sensory deprivation, valuable information is obtained concerning the role of sensory experience in cognitive mapping in general. This leads to theoretical insights in the nature of human thought and could have implications for other projects relating to wayfinding, such as robotics and artificial intelligence (for example, Kuipers, 1997).

The study reported in this paper has demonstrated that, contrary to popular and scientific opinion, people with severe visual impairments are capable of learning a complex route through an urban environment both quickly and efficiently, and that their levels of spatial knowledge and their abilities to process such knowledge become equivalent to those of sighted individuals. Admittedly the learning process is slower but not by very much. Whereas a sighted person had generally learned to retrace the route without mistakes by the second trial, visually impaired and blind respondents could do the same by the fourth trial. The navigation problems facing visually impaired and blind people lie then in learning new environments independently and in articulating their knowledges in wayfinding practice. Providing the opportunity for independent living should be the goal of orientation and mobility training, and navigation systems designed for non-sighted people should aim at providing such opportunity. In particular, the process of 'active' learning, where routes are learnt through independent travel reinforced through distance evaluation, directional pointing, and the recreation of an environment via model-making all seem to be of critical importance to achieving such a goal.

In addition, the study highlighted the fact that to obtain a more valid and complete picture of the spatial cognition of people with visual impairments, or people in general, it is important to use a variety of measures. Any one assessment only offers specific access to a particular facet of spatial knowledge, subject to the ecological validity of the method. In this study the laboratory tests provided insights different from those obtained from the naturalistic task, highlighting the fact that the level of spatial knowledge does not necessarily compute to an ability to use that knowledge effectively in everyday spatial behaviour. (i.e the naturalisttic task showed a delayed equivalence between the groups, when compared to the laboratory tasks**.** The links between spatial cognition and spatial thought are multi-faceted, dynamic and highly complex.

6. References

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