Chapter 4
Empirical Investigation of Human Navigation

"One day Alice came to a fork in the road and saw a Cheshire cat in a tree. "Which road do I take?" she asked. "Where do you want to go?" was his response. "I don't know," Alice answered. "Then," said the cat, "it doesn't matter."

Lewis Carroll, *Alice in Wonderland*

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4.1 Introduction

In Chapter 3, cBDI, the extended BDI agent was introduced. A major feature of cBDI agent is the human centric strategy library-the domain specific knowledge of human strategies. While cBDI agent is a step towards being collaborative with a particular emphasis on navigation task for this thesis, the basic ingredients for such behavior is the knowledge of human strategies to getting from *one location* to *other location*. This chapter is about the empirical investigation of human strategy of wayfinding. The knowledge of strategy form the part of the human centric strategy library of the cBDI agent- makes the agent to know wayfinding– the cognitive component of navigation.

This chapter first focus on the significance of empirical investigation. Thereafter attention is on the wayfinding experimentation and on research hypotheses.

4.2 The significance of empirical investigation

> *To what extent can the view-based approach be extended to.., for use in tasks like navigation?*
>
> Wallis and Bülthoff [195]

The above question was first made by Wallis and Bülthoff [195] and is relevant even today. So far, very little work has been attributed to the role of *view-based approach* in navigation. Individual work of Kosslyn *et al.* [196] and Mallot *et al.* [197] mention that human navigation knowledge is represented and processed in *visuospatial principles.*

The empirical investigation reported here intended to address two aspects in which view based navigation is possible: a. *under transitive transformation of views (i.e. under view translation and rotation)*; and b. navigation *under changed complexity of spatial layout.*

4.2.1 Context: Human centric wayfinding strategy

As discuss in section 2.4, the human as wayfinder are well equipped with an array of flexible wayfinding. The experimentation on maze solving provides an opportunity to assess how wayfinding strategy gets influenced under transitive changes of view information.

4.2.2 Context: Human as a navigation system user

Let us now discuss significance of the experimentation in context of human as a user of an "intelligent wheelchair". As the system is *intelligent*, we find it rational to conceive that wheelchair provides allocentric view–map based information of environment to the user. Allocentric view (exocentric view) of the space presents information about the origin, goal location and orientation. While moving through the environment, the perceivable view for the user is of egocentric view. So, that while navigating with such IW, a user has egocentric as well as an additional exocentric view of the environment. We find it quite reasonable to visualize one of the possible situations, where exocentric representation of space is oriented differently than user's current egocentric view. Under such situation to make decisions, user needs a kind of mental transformation to coordinate two different views (egocentric and exocentric) into alignment. In literature, it is known that mental transformation involves mental imagery and rotation [198].

While navigating with such IW, apart from bringing some sort of mental transformation, we can envisage that, the user switches between two views of the environment. We define the change of views of environment as transitive transformation of views. To be successful in wayfinding, synchronization between the views is needed for the user to make decision about actions and maintain orientation. This demands the user to simultaneously manage the *cognitive tasks* [199] of understanding the views, spatial layout of the environment, along with the position of target location. We envisage navigation with IW in context where the user needs to find his way to goal under transitive transformation of views and changed complexity of the environment. The experimentation that is reported in this chapter is an effort to replicate this context. We explore maze solving experimentation and investigate effects of "transitive view information" vis-*à*-vis participants' wayfinding strategies.

It is worth mentioning that, the empirical investigation need to be part of designing wayfinding assistive devices. The thesis is an effort towards such a design. The following quote of Daniel R. Montello and C. Sas [145] is relevant:

> *While theoretical work strives to improve our understanding of wayfinding, tools and applications that have been developed attempt not only to support wayfinding behavior but also to train spatial skills (VEs are promising in the latter respect). Applications are limited mainly because they are insufficiently connected with the body of literature on theories of wayfinding and attend almost exclusively to its technological aspects.*
>
> Montello and Sas. [145, Page 2008]

Why maze: Computational property of maze

The focus on mazes is motivated by their functional importance in spatial reasoning study. They are viewed as tour puzzle which must be solved and the solver must find and follow a path between start to goal location. Solving of maze would be wayfinding as solvers only consideration is to reaching the destination. Maze structure can generalize to indoor space connected by networks of rooms and paths.

4.3 Research Hypotheses

The experiment is based on two global hypotheses and a set of research questions. The following are the two global hypotheses:

> H^0_A: Wayfinding is not influenced by prior exocentric preview under change in viewing angle and orientation of target.
>
> H^0_B: Wayfinder does not switch between different strategies of wayfinding even under transitive change on transformation of views and spatial lay-out for wayfinding

Consequently, two main research questions are as follows:

> Question Q_A: Whether wayfinding is influenced by prior exocentric preview even after visual overloaded view[1] of environment?
>
> Question Q_B: Do visual overload resulting out of change in viewing angle and orientation of target lead to switching between different strategies of wayfinding?

In order to perform a more detailed analysis of the global hypotheses, five more fine–grained hypotheses are investigated. The remainder of this section contain detailed discussion of about these hypotheses. Section 4.6 relates the outcomes of the study of these hypotheses.

To analyze the research question, we have conducted an experimentation where two different mazes were solved with following set of experimental manipulations:

* View information of maze changes from a complete cognitive map to partial views (i.e. change of viewing angle),
* Secondly, when target location of originally explored maze change and given a mirrored maze (i.e. change position of target) and
* When maze of different complexity are solved (i.e. change of complexity).

[1] Visual overloaded view refers to way-finders representation of environment (accumulation of visual information) under change of *visuospatial information* resulting out of change in viewing angle and orientation of target

Cognitive aspect of theses manipulation are given in Table 4.1. These three experimental manipulation and two main research questions entail following sub-questions:

Experimental manipulations	Cognitive aspects
Change of viewing angle	Solving of mazes under change of viewing angle involve solving under different content of visual information.
Array-rotated view	This experimental manipulation evolves mental rotation to imagine how target location would be after mirroring. We assume that wayfinding experience of exocentric as well as egocentric view of maze influence wayfinder while finding his . way on mirrored view of originally explored maze
Change in complexity	The process of wayfinding involves spatial inference. We assume that prior experience on complex spatial layout of maze influences wayfinder while wayfinding in simpler spatial layout.

Table 4.1: Cognitive aspects of experimental manipulations

* If view information of the maze changes from a complete cognitive map to partial views, whether it influence wayfinding?
* Whether rotation of originally explored maze influences wayfinding?
* Whether prior exocentric experience of complex spatial layout influence wayfinder while planning in simpler mazes?

The first sub-questions is related to wayfinding task under view translation. The expected outcome can be formulated through following null hypothesis:

H_1^0: Wayfinding is not influenced by prior exocentric environment information.

H_2^0: Wayfinding does not differ with change in viewing angle of prior viewed environment.

The second sub-questions is related to wayfinding task under rotation i.e solving a mirrored view maze. The expected outcome can be formulated through following null hypothesis:

H_3^0: If multiple views [2]of an environment is experienced, wayfinding in mirrored view of environment do not bring any difference.

H_4^0: Way-finder's view-specific effect [3]of an environment does not decrease with increased exposure to the environment.

The third sub-questions is related to wayfinding under change of complexity. The expected outcome is formulated through following null hypothesis:

H_5^0: Prior experience on complex spatial layout does not influence while wayfinding in simpler plan.

It is important to mention here that a large number of experimentation has been conducted to study spatial plan and its complexity for wayfinding. An increase in spatial plan complexity leads to a decrease in wayfinding performance has been shown by O'Neill [164]. O'Neill also found that as familiarity increases complexity of an environment impacts less on wayfinding. In general, most of the work investigated architectural aspects and its influence on human wayfinding. There is enough work in the literature on wayfinding and factors influencing wayfinding in built environments [167, 200–203]. Despite the importance of spatial layout to our understanding of wayfinding, to the best of our knowledge none of these studies have directly examined the fact that whether previous experience of complex spatial layout influence wayfinder while planning in simpler spatial layout?

Apart from the above, it was Scholkopf and Mallot's [204] work, where it was mentioned that view based navigation bears some resemblance to view based object recognition. If so, it is quite reasonable to raise the question whether wayfinding influence upon rotation of originally explored spatial layout. So, through our experimentation of maze, we covers all these aspects of wayfinding, that has not been addressed in previous works.

4.4 Experimental Exploration

For experimentation, a virtual environment is used. Virtual environment offers the opportunity of studying fairly realistic navigation traits [205–207]. Results obtained with virtual maze environment are able to portray a conclusion that can be approved to human wayfinding [170, 176, 208].

[2]The term *multiple views* refers to solving experience of exocentric as well as egocentric view of same mazes.

[3]Here the term *view specific effect* refers to the appearance of environment (maze) under specific viewing (angle) condition.

4.4.1 Materials and Methods

Subjects: The experiment was conducted on 23 subjects. Four participants give up after playing the first game. 19 subjects (Mean Age = 25.32, S.D = 3.23) completed all eight games. Participants were naive to the purpose of the experiment and none of them was suffering from any perceptual, spatial or motor deficiency.
Maze Design: We constructed eight practice maze and two experimental maze-like topographies. For these ten topographies, ten different virtual mazes were designed. Virtual mazes [4] were constructed with variable arrays of structural elements. Details of the two experimental mazes are given in Table 4.2; including a list of geometrical structures that are used to generate our experimental mazes. The mazes incorporated 3-D characteristics to give the sense of a real maze. Both experimental mazes were constructed in such a way that when the participant maneuver through the mazes, participants encounter many route intersections which required taking a decision of route selection (i.e., decision points as defined in [167]). The two mazes were different in arrays of structural elements, while keeping position of start and target locations constant. Participants have to solve the mazes from up start location to down direction of the target. Maze2 was comparatively simpler than Maze1 (Plan complexity is according to [167]). Within the mazes, there were no landmark cues. First, we varied each maze in two changed conditions of viewing angle. In change of viewing conditions, for exocentric view, maze was presented at zero degree view point, whereas in the egocentric view condition, maze was presented with elevated view point of 30 degree. Views of the mazes are as given in Figure 4-1 and Figure 4-2. Next we simply flipped starting and target location of the mazes by 90 degree (array rotated mazes). Participants completed four different instances for each of the possible combinations of conditions (2 viewing angle X 2 different starting and target location pair = 4). Eight possible combinations of mazes (2 viewing angle X 2 different target location X 2 maze) has to be solved. The mazes were administered on a HP computer equipped with 1GB of RAM and an 18.5-inch monitor. Participants were seated

Table 4.2: Structural details of Maze1 and Maze2

Maze	Number of decision points in maze	Geometrical structures (Within the mazes)
Maze1	14	Dead end, Straight
Maze2	7	L-shaped, Cross intersection T-intersection

[4]Pritom Rajkhowa,Computer Centre, Tezpur University provided the 3-D maze models used in the experiment

in a normal chair in a comfortable position at a distance about 50 centimeter in front of the display screen. The center of the computer screen located 15 to 20 degrees below horizontal eye level. Manoeuvre through mazes was controlled by the subjects using arrow keys on standard 101 computer key board. Each movement through the maze was recorded by screen casting CamStudio open source software. Experiments were conducted under normal indoor lighting condition.

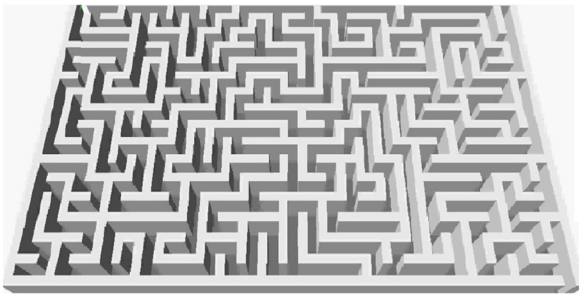

Figure 4-1: Exocentric view of Maze1

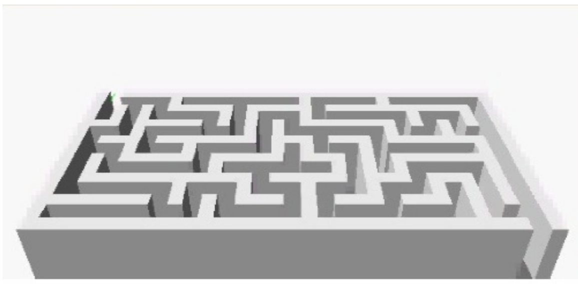

Figure 4-2: Egocentric view of Maze2

Experimental Protocol and Overview

The experimental protocol is sequence of four different tasks with inter task periods ranging between 30 seconds to 120 seconds. Figure 4-3 shows the experimental protocol with timing diagram.

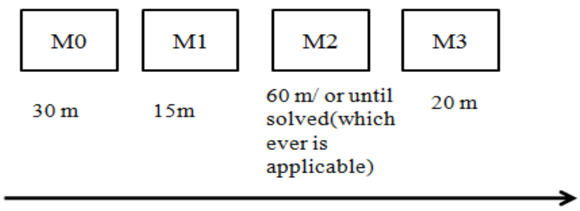

Figure 4-3: Experimental protocol with timing diagram

M0:Training: In M0, participants were provided with instructions which explained the experimental modalities and highlighted the task they had to perform. Subjects were familiarized with arrow keys to maneuver through the maze. The participant carried out practices with 5-7 mazes from the practice pool. Each participant was required to respond to the practice session correctly before beginning the next sequence of task. Subjects were given enough training time to practice.
M1: Relax: In M1, Subjects were asked to relax. During this phase computer screen remained blank and experimenter recorded participant age, gender and familiarity with computer game. Table 4.3 provides more detail.

Table 4.3: Questionnaire to be filled during M1

Question Q_0: Fill up and make a choice:
• Subjects age
• Subjects Gender
• Familiarity with computer game
a. I have never played computer games.
b. I play computer game every day.
c. I play computer game once a week.
d. I play computer game very rarely.

M2: Maze Solving Phase: An audio cue marked the start of maze solving Phase (M2). Each solving phases were started by asking the participant if he was ready to perform the task. There were eight solving phases and we named them as Phase11 to Phase14 for Maze1 and Phase21 to Phase24 for Maze2. Detailed description of Maze solving phase are given below:
Figure 4-4 illustrated the solving phases in M2.
Phase11 (respectively Phase21): In Phase11 (respectively Phase21) [5]

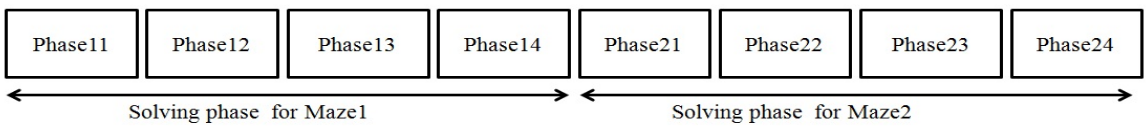

Figure 4-4: Illustration of solving phases in M2

exocentric view of Maze1 (respectively Maze2) [6] was presented to participant as maze solving task. In these phases, participants were asked to imagine themselves as standing above the maze from where he could physically view the entire maze. With this we biased participants towards an exocentric interaction with the

[5] read as both in Phase 11 and Phase21
[6] read as both in Maze 1 and Maze2

environment to find a solution.

Phase12 (respectively Phase22): In Phase12 (respectively Phase22) [7] egocentric view of Maze1 (respectively Maze2) was presented to participant as maze solving task. Here participants were asked to imagine[8] themselves to be physically on the maze. We biased participants towards an egocentric interaction with the environment.

Phase13 (respectively Phase23): In Phase13 (respectively Phase23) [9] exocentric view of array rotated Maze1 (respectively array rotated Maze2) was presented to participant as maze solving task.

Phase14 (respectively Phase24): In Phase14 (respectively Phase24) [10] exocentric view of array rotated Maze1 (respectively array rotated Maze2) was presented to participant as maze solving task.

M3: Participant Feedback.: After the experiments, in M3, participants were instructed to fill up a questionnaire of four questions. Table 4.4 provides more detail.

Table 4.4: Questionnaire to be filled during M3

Question Q_1: Rate the maze in terms of solving difficulties • 1-easy • 2-medium • 3-hard
Question Q_2: What are the tasks you find easy/difficult to perform?
Question Q_3: How you find your way around mazes and what are the factors that you have taken into account when you solve maze?
Question Q_4: How will you instruct someone to solve the maze?

4.4.2 Overview of Experimental design

Wayfinding in Phase11 (as well as Phase21) take place in an unfamiliar environment (with only knowledge of the relative position to the target). Both experimental phases were designed to acquire exocentric views of mazes. In Phase21, maze environment was comparatively simpler than in Phase11. Phase12 (respectively

[7] read as both in Phase 12 and Phase22

[8] When mazes were presented to participants, they were asked to describe view of the environment. Few of the participants spontaneously described view of the environment. These imaginations were checked through participant mention of situation in their linguistic report; how they themselves related to presented environment view.

[9] read as both in Phase 13 and Phase23

[10] read as both in Phase 14 and Phase24

Phase22) quantified how well viewing angle effect prior knowledge of exocentric view of Maze1 (respectively Maze2). Presented mazes in experiment Phase13 (respectively Phase23) were mirrored configuration of starting and target location of Maze1 (respectively Maze2) in Phase11 (respectively Phase21). We named these configurations as rotated array mazes. These experimental phases were designed to address impact of mirroring on wayfinding performance. Experiment Phase14 (respectively Phase24) were designed for investigating subjects' view specific effect of environment on wayfinding performance.

4.4.3 Metrics of Interest

The metrics that are consider to evaluate wayfinding is split in to two main groups: qualitative metrics and participant's subjective evaluation.

The first group of metrics are based on the those proposed by Roy [179]– participant performance is categorized in three levels.

Level-1: Wayfinding performance Level: Participants' wayfinding performance was based on navigation time: Measure how fast participant is able to reach the target.

Level-2: Wayfinding Behavior Level: Wayfinding behavior was based on response time: participant spent time before traversing a maze. As, Maze1 was comparatively complex plan than Maze2, response times of first trial of both mazes i.e. in Phase11 and 21 was considered specially important.

Level-3: Rationale Level: Our focus was on rational (behavioral and task performance) aspects of wayfinding, and were based on metrics derived out of the written report. Participant's strategic focus was accessed through their written linguistic pattern. To identify used strategies, we limited ourselves to four wayfinding strategies: a. *Least angle strategy* [165] - Participants choose routes which are most in line to target location; b. *Central point strategy* [209] - When participant walk back to well known part of maze; c. *Trajectory based strategy* [210] - Conceptualize a route by positioning at a particular part of the maze, in order to avoid detours from trajectory; and d. *Summary scanning strategy* [211] - Participants find a way to target by conceptualizing the whole maze. We created a list of *lexical choice set* from the literature that serve as indicator of strategies [169, 209–211]. The lexical choice set is listed in Table 4.5.

The second group of metrics is based on subjective evaluation according to the questionnaire responses. As shown in Table 4.3, Participant have to choose one of the options ranging from "I have never played computer games" to "I play computer game every day". The questions, as in Table 4.4, were intended to determine each participant's solving difficulty as well as his or her strategies of solving the maze. Participants responded to the questions using a 3-point Likert scale ranging from easy to difficult for the first question and elaboration of maze solving for the third to fourth questionnaire.

Table 4.5: Strategies and corresponding lexical choice set

Strategy	Lexical choice set
Least angle strategy	With direction and projective terms: Heading in right direction, facing in right direction, move towards [169]. *Example:...facing in the right direction and then start straight.*
Central point strategy	Verbs indicate orientation process such as : orient towards something, look out for, search something or uncertainty markers, concrete spatial elements as defined in [209]. *Example*: *try to set a point at the junction*
Trajectory based strategy	Verbs reflect route attributes such as loops, estimate , short, obstacles, stuck, dead end [210]. *Example*:*...opted for no dead-end path*
Summary scanning strategy	Verbs that mark perception process such as look at the view, whole view, imagine, see, look [211] *Example*:*..memorized the view*

4.5 Experimental Result

Spearman's rank order correlation was run to determine the relationship between familiarity with computer games (Question Q_0) and participants self-rating on solving difficulties of mazes (Question Q_1). Spearman's correlation coefficient is 0.159 (p= 0.516), which is statistically insignificant. Participant's familiarity with computer games did not signify that better they performed in the experimental mazes.

4.5.1 Analysis of Behavioral data

Table 4.6 provides descriptive statistics for the measured values of participant navigation time and response time in term of seconds. The table is categorized by the solving phases.

Table 4.6: Mean (± Standard deviations) of participant navigation time and response time in seconds

	Time in seconds	Phase 11	Phase12	Phase13	Phase14
Maze1	navigation time	578.64 (464.10)	465.5 (239.06)	510.6 (423.73)	304.42 (242.57)
	response time	72.5 (68.00)	27 (26.51)	98 (93.34)	27.55 (45.13)
		Phase 21	Phase22	Phase23	Phase24
Maze2	navigation time	172.21 (91.08)	125.42 (55.48)	142.89 (97.48)	110.57 (51.70)
	response time	31.92 (48.01)	18.31 (21.93)	37.92 (72.60)	14.42 (20.92)

Null Hypothesis (H_1^0): Wayfinding is not influenced by prior exocentric information of environment.
Alternative Hypothesis (H_1^a): Wayfinding is influenced by prior exocentric information of environment.

To analyze the influence of environment information, participant navigation time in exocentric and partially egocentric phase of Maze 1 (respectively of Maze2) were recorded. A paired sample t-test[11] was used to analyze the statistical significance in navigation time between Phase11 vs. 12 (respectively Phase 21 vs. 22). The paired sample t-test results are reported in Table 4.7. For Maze1, navigation time between solving phases: Phase11 to 12 (t(18)=2.345, p= 0.033) and for Maze2, between solving phases: Phase21 to 22 (t(18)=2.2217, p= 0.039) were statistically significant at p=0.05 level. Thus, null hypothesis was (H_1^0) rejected. Alternative hypothesis (H_1^a) was accepted. With this finding we can conclude that prior exocentric environment information influences wayfinding on performance level.

Table 4.7: Paired sample t-test results for H_1^0

Maze	Solving Phases	t	df	Level of of significance
Maze1	11 vs. 12	2.34	18	0.033
Maze2	21 vs. 22	2.21	18	0.039

[11]Paired t- test was used rather than 2x2 ANOVA since we were interested to know whether these different structure influence way-finding and how much; not the interaction of these two mazes' influence on wayfinding.

Null Hypothesis (H_2^0): Wayfinding does not differ with change in viewing angle of prior viewed environment.
Alternative Hypothesis (H_2^a): Wayfinding differed with change in viewing angle of prior viewed environment.

Wayfinding was judged in terms of response time. Paired t-test was conducted to examine null hypothesis. The t-test revealed that the change in viewing angle between phases were significant at the p=.05 level (as reported in Table 4.8). Thus the null hypothesis (H_2^0) was rejected and therefore, alternative hypothesis (H_2^a) was accepted. In examining t-test results of Table 4.8, we note a differing result. The result could be due to the fact that once the environment views are learned, change in viewing angle of prior viewed environment no longer influence wayfinding. This might be explained by the assumption that after wayfinding is experienced through the array rotational view of Maze1, the learned experience of this kind of environment view serve as retrieval cue to solve the array rotational view of Maze2. Consequently, solving Phase 23 and 24 is not statistically significant.

Table 4.8: Paired sample t-test results for H_2^0

Maze	Solving Phases	t	df	Level of of significance
Maze1	11 vs. 12	2.551	18	0.020
	13 vs. 14	2.183	18	0.042
Maze2	21 vs. 22	2.30	18	0.033
	23 vs. 24	1.589	18	0.129

Null Hypothesis (H_3^0): If multiple views of an environment is experienced, wayfinding in mirrored view of environment do not bring any difference.
Alternative Hypothesis (H_3^a): Experience of multiple views of an environment, leads to better wayfinding in mirrored view of the environment.

Wayfinding performance was analyzed in terms of navigation time. We computed mean navigation time of Phase11 and 12 (henceforth Phase112) (respectively Phase21 and 22; henceforth Phase212). We compared it with Phase13 (respectively Phase23), which was simply the exocentric view of rotated array of Maze1 (respectively Maze2). A paired sample t-test was conducted. It was found that difference was not statistically significant: for Maze1 between Phase112 and 13 ($t(18)= -1.268$, $p= .228$), and Maze2, Phase212 and 23 ($t(18)= 0.376$, $p= 0.711$) (as reported in Table 4.9). Thus, null hypothesis (H_3^0) was accepted.

Comparison of the t-test value between Maze1 and Maze2, gives us an impres-

Table 4.9: Paired sample t-test results for H_3^0

Maze	Solving Phases	t	df	Level of of significance
Maze1	112 vs.13	-1.26	18	0.22
Maze2	212 vs.23	0.376	18	0.711

sion that there exists a performance difference with the two different mazes. One possibility of this result is that although mirrored view of an environment do not bring any difference to wayfinding performance, but performance shows strong association to spatial plan of the mazes and correspondingly to the environment. This assumption is based on the fact that Maze 2 was comparatively simpler in structure than Maze1.

Null Hypothesis (H_4^0): Way-finder's view-specific effect of an environment does not decrease with increased exposure to the environment.

Alternative Hypothesis (H_4^a): Way-finder's view-specific effect of an environment decreases with increases exposure to the environment.

Here wayfinding was reviewed through navigation time between Phase 11 and 14 of Maze1 (respectively Phase 21 and 24 of Maze2). In solving Phase 11 and 21 participants do not have previously experienced knowledge of the environment; whereas Phase 14 (respectively Phase 24) was performed after extensive experience of Maze1 (respectively Maze2). Table 4.10 summarize the paired t-test results. Thus, the null hypothesis (H_4^0) was rejected. Alternative hypothesis (H_4^a) was accepted. Thus we can conclude way-finder's view-specific effect of an environment decreases with increases exposure to the environment.

Table 4.10: Paired sample t-test results for H_4^0

Maze	Solving Phases	t	df	Level of of significance
Maze1	11 vs. 14	3.395	18	0.004
Maze2	21 vs. 24	3.29	18	0.004

Null Hypothesis (H_5^0): Prior experience on complex spatial layout does not influence while wayfinding in simpler plan.

Alternative Hypothesis (H_5^a): Prior experience on complex spatial layout influence while wayfinding in simpler plan.

Wayfinding was analyzed in terms response time in solving Phase 11 and 21.

The strength of association between the solving Phase 11 and 21 was analyzed by Pearson correlation test. It was found that after traversing a complex plan in Phase11, when comparatively simpler exocentric information was presented in Phase 21, response time exhibited strong positive correlation with response time of presented complex exocentric environment information, which was statistically significant (Pearson correlation, r(19)=0.559, p=0.012, df = 17). Thus null hypothesis (H_5^0) was rejected. Alternative hypothesis (H_5^a) was accepted.

This hypothesis testing is an attempt to explore influence prior experience of complex spatial layout on wayfinding at behavioral level. From the result we can conclude that irrespective of spatial plan, possibility of a wayfinder spent time before traversing a plan (i.e. response time) remains same. We argue that this has happened because subjects could not ignore impression they carried from previous maze when they first saw the exocentric view of next maze. Carried impression of previous maze effect way-finders' "state of mind" [212] and therefore, their wayfinding behaviour.

As a whole, to decide prior exocentric preview influence on wayfinding, we have the following hypothesis:

Null Hypothesis (H_A^0): Wayfinding is not influenced by prior exocentric preview under change in viewing angle and orientation of target.

Alternative Hypothesis (H_A^a): Wayfinding is influenced by prior exocentric preview under change in viewing angle and orientation of target.

F-statistic [213] was evaluated to decide prior exocentric preview's influence within composite conditions of wayfinding. The result is shown in Table 4.11, the critical value at the 5% significance level for F(4, 89) is 2.47. The F-statistic evaluated $F_{Calculated} > F_{critical}$. With F-statistic result on the set of hypotheses, our hypothesis that wayfinding is influenced by prior exocentric preview in change in viewing angle and orientation of target was met.

Table 4.11: F-statistic of joint hypothesis test for H_A^0

Number of Restrictions Imposed	Number of Independent Variables	Sample size	Degree of Freedom	$F_{critical}$	$F_{Calculated}$
4	5	95	89	$F_{.05}(4,89)$ =2.47	30.50

4.5.2 Analysis of Linguistic data

Linguistic data analysis started with the central aim of exploring description of wayfinding activity and showing underlying wayfinding strategies through set of linguistic markers. Question Q_3 intended to highlight what a particular person would do to find his way around the maze. Question Q_4 intended to focus on how a person accessed his current wayfinding experience to develop a hypothetical user perspective. Linguistically, participant answers to the Question Q_3 as well as Q_4 reflect two different conceptual (individual) perspectives. Participant answers to Question Q_3 was usually expressed in first person form, *I*.

Examples: 1. *I make a virtual way to reach the target in my mind.*
2. *When I got stuck, I retrace my path .....*

Answer to question Q_4 was represented in second person form, *you*, referred to a hypothetical user navigating through and perceiving the maze.

Examples: 3. *First you see which the options in hand to take turn are*
4. *... where there is more than one path take your decision carefully*

It was also clear from these examples that the perspective they impose on the hypothetical user was egocentric. Interestingly, in question Q_4, participant conceptualized a hypothetical user on the basis of current experienced knowledge of the maze. It was typically a survey perspective experienced in which hypothetical user is supposed to have exocentric information of the environment.

Examples: 5. *Before starting, solve it once in* ***your mind***
6. *If you can't find way then try to find the possible path* ***visually***

Our analysis of linguistic reports provided the evidence that each form of environment information can be used in wayfinding and how participant related themselves to that environment view. With participant's conceptualization of hypothetical user with exocentric representation of maze, we can draw a conclusion that exocentric information aid to improved wayfinding.

Strategic description

For strategic description analysis, we limit ourselves to four wayfinding strategies. In our experimental scenario, we can imagine the following scenario: A way-finder walks through an unfamiliar environment and tries to navigate towards the target - a salient landmark. At intersection, way-finder can perceive the outgoing routes and the salient landmark. Under such scenario, if we assume that movement pattern would show a tendency to minimize the travel distance by choosing route which was least deviated from direction of the target - the least angle strategy should result. The participant who used this strategy relied strongly on their movement in direction to target - the refection of this concept is given by the

following example:
Example: 8. *... direction that lead towards destination.*
This example explicitly reflected least angle strategy as speaker referred to direction to the reach the target. In our experimental scenario, we can also imagine the following situation: to find a way to the destination, you start to orient towards particular part of the maze or route, and try to find a way to the destination from there. Such type of movement pattern where someone plan a route to a particular access point and then plan the next part of the plan there- the central point strategy should result. The reflection of this concept can be understood by the following example:
Example: 9. *Try to set a point at junction ...*
Here the participant described about how he mark place at a certain place of the maze and gradually explored the maze from there. Other than these strategies, we also include strategy where participant mentally visualized the trajectory as part of a inspection process, as following example:
Example: 10. *... opted for no dead-end path.*
There were indications in the data that some of participant conceptualized the maze as a whole, as in following:
Example: 11. *... memorized the view.*
The above example can be interpreted as part of summary scanning strategy that the participant gradually developed.

Given the description of the four strategies with example, it is important to analyze participants retrospective written report to get to each strategy. We create a list of lexical choice set from the literature. The lexical choice set serve as basis for participant representation of underlying strategies. We were look at written report in relation to spatial strategies. Strategic description is derived from retrospective reports through the following steps:

Step 1 : Identify *bag of words* in relation to *strategies.* Construct wayfinding propositions.

Step 2 : Re-write each report in propositional format.

Step 3 : Select information items i.e., proposition that were either relevant to wayfinding related consideration or to action during wayfinding.

Step 4 : Select process propositions: Minimum set of proposition that reflect the concept of wayfinding [214]; as shown in Table 4.12.

Step 5 : Reconstruction: Reconstructed each report with process proposition.

Table 4.12: Process propositions

Label	Process proposition	Examples of information unit	Label	Process proposition	Examples of information unit
a	Avoid detour	check dead end	b	Estimate path length	Shortest path to target
c	Follow path		d	Solve in mind	Recall way
e	Visualizing the whole view	Remember turn	f	Backtrack to point	Retrace path to start
g	Move along the border		h	Possible movement from a point	Choose a check point at diversion
i	Path leads towards the goal	Follow direction towards the goal			

Table 4.13: Processes description (PD)

label	group	label	group	label	group	label	group
a,b	route status	i	direction	f,h	mark	d,e	retention

Step 6 : Process descriptions: Process proposition categorized into four groups; as listed in Table 4.13.

Step 7 : Proposition mapping: Process descriptions mapped to strategies; as shown in Figure 4-5.

Step 8: Review participant's reconstructed report with proposition mapping to find out participant strategic description.

Based on the steps as mentioned above, the reconstructed reports were categorized into four groups of strategies. Reconstructed reports on each group was used to test the following hypothesis.

Null Hypothesis (H_B^0): Wayfinder does not switch between different strategies of wayfinding even under transitive change on transformation of views and spatial lay-out for wayfinding

Alternative Hypothesis (H_B^a): Wayfinder switches between different strategies of wayfinding even under transitive change on transformation of views and spatial lay-out for wayfinding

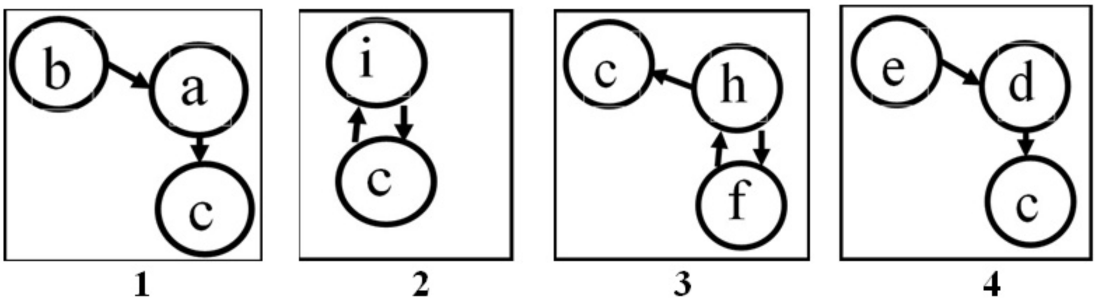

Figure 4-5: Proposition mapping: 1- PD to trajectory based strategy ; 2- PD to least angle strategy; 3-PD to central point strategy; 4-PD to summary scanning strategy

We found that only 26.31% (5 out of 19) participant's reconstructed report produced single strategic description; while 73.68 % (14 out of 19) reports revealed combination of strategies and was statistically significant (Mann-Whitney U test $U = 7.50, z = -2.973, p = .001$). Thus, there was sufficient evidence to reject the null hypothesis (H_B^0). Alternate hypothesis was accepted. Figure 4-6 shows the

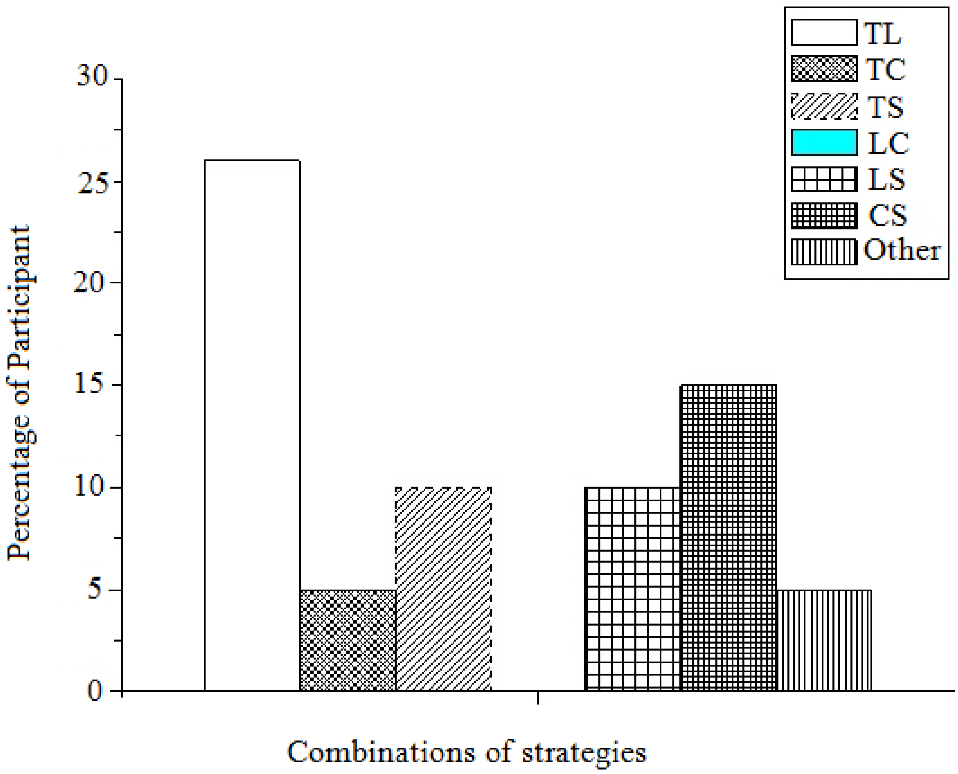

Figure 4-6: Combination of strategies vs. Percentage of participants; T stands for trajectory based strategy; L stands for least angle strategy; C stands for central point strategy; S stands for summary scanning strategy.

participant percentage who used combination of strategies. Majority of participant lexical choice reflect the combination of trajectory based strategy and least angle strategy (5 out of 14); whereas 2 out of 14 combined trajectory based strategy and central point based strategy. As observed, least angle is combined with summary scanning by 2 out of 14 participants; central point strategy is combined with summary scanning strategy by 3 out of 14.

4.6 General Discussion

The experimentation described here is based on behavioral data along with linguistic data. Table 4.14 showed the summary of hypothesis testing. It is pertinent

Table 4.14: Summary of hypothesis testing-I

Testing of hypotheses	Hypotheses considered
Hypothesis H_1^0	H_1^a is accepted
Hypothesis H_2^0	H_2^a is partially accepted
Hypothesis H_3^0	H_3^0 is accepted
Hypothesis H_4^0	H_4^a is accepted
Hypothesis H_5^0	H_5^a is accepted
Hypothesis H_A^0	H_A^a is accepted
Hypothesis H_B^0	H_B^a is accepted

to mention that, in their review Cheng and Newcombe [215], focused on two categories of cues to spatial orientation: geometric and featured cues. Geometric cues are provided by environmental surfaces (for example, shapes formed by walls of a room). Non-geometrical properties such as colors and textures which cannot be expressed in geometric terms solely are categorized as featured cues. Our experimental mazes contained components such as T-junctions that can be categorized as geometrical cue. Even though our experimental mazes are without any landmarks, environmental shapes may be interpreted as cues. Under such a context our experiments can be generalized to scenarios where landmarks would be available.

> Q_A: Whether wayfinding is influenced by prior exocentric preview even after visually overloaded view of environment?

To analyze the research question, we have conducted experimentation where two different mazes were solved with set of experimental manipulations: change of viewing angle, under array–rotated view, change of complexity. It is hypothesized that visual overload would distort the exocentric preview of environment and thereby does not influence wayfinding in consecutive solving phases of mazes (H_A^0).

The research question (Q_A) leads to three sub-questions with five hypotheses. We discuss those first. H_1^0 states that wayfinding would not be influenced by prior exocentric environment information. Testing of H_1^0 hypothesis revealed that prior exocentric environment information influences wayfinding on performance level. Interestingly, it seems to confirm that change in viewing angle of prior viewed environment positively affect wayfinding on the behavior level (based on hypothesis testing of H_2^0). For wayfinding under rotation of spatial layout, Hypothesis H_3^0 claims that if exocentric as well as egocentric view of an environment is experienced, wayfinding in array rotated view of environment do not bring any difference. Testing of H_3^0 hypothesis give no evidence that this is false. The finding hints that wayfinding performance on mirrored view might be dependent on complexity of spatial plan. This is in accordance to findings of the mental rotation literature that orientation task produce different level of performance depending on the complexity of arrays of a map or physical display [216]. Hypothesis H_4^0 posits that view specific effect of wayfinder would decrease with increased exposures to the environments. Testing of H_4^0 hypothesis revealed that once the structure of maze under different viewing angle and orientation are learned, "view specific effect" is no longer influential in wayfinding. This result bears a strong resemblance to findings in object recognition literature, where [195] showed that transformation invariant representations of objects are learned through experience. It hints that that change in viewing angle of prior viewed environment positively affect wayfinding on the behavior level. Interestingly, under change of complexity of spatial layout, result indicated wayfinder behavioral dependence on prior experience on complex spatial layout (based on hypothesis testing of H_5^0).

The hypothesis H_A^0 states that visual overload resulting out of the experimental manipulations would distort the exocentric preview of environment. As (in context of H_A^0) exocentric preview influence is not possible to address through test of a single hypothesis because of involvement of composite conditions (i.e. change in viewing angle and orientation of the target); we need to have statistical test that could determine prior exocentric preview influence on wayfinding under composite conditions. More precisely it demands a joint significance test of multiple hypotheses [217]. Accordingly with F-statics result (hypothesis testing H_A^0), it is shown that wayfinding is influenced by prior exocentric preview with change in viewing angle and orientation of target. From the result, we confirmed the long-established finding that wayfinding performance is influenced by prior exocentric environment information. This work extended those finding and have been able to show that change in viewing angle and orientation of target within that representative environment would not distort the exocentric preview of environment information.

Q_B: Do visual overload resulting out of change in viewing angle and orientation of target lead to switching between different strategies of wayfinding?

On rationale level, we started with the aim of investigating switching between different wayfinding strategies via set of lexical choice. We analyzed retrospective written report for participant's strategic description. Although participants describe variety of individual experience of wayfinding process in the mazes, we limit ourselves to four wayfinding strategies. Inference here is based on linguistic data. To derive metric out of linguistic data, we initially identify bag of words in relation to four strategies and construct wayfinding propositions. After that we rewrote each report in propositional format and select information items that were either relevant to wayfinding related consideration or to action during wayfinding. Following that we select minimum set of proposition that reflect the concept of wayfinding and reconstructed each report with process proposition. Process proposition were categorized into four different groups. We then mapped process descriptions to strategies and in the final step participant's reconstructed report were reviewed with proposition mapping to find out participant strategy description. Statistical analysis (testing of hypothesis H^0_B) of metric derived out of participant reconstructed reports revealed participant's mixed use of wayfinding strategies. The existing literature on wayfinding [169, 218] also support mixed use of wayfinding strategies. The result extends those findings, showing even under transitive transformation of views and spatial lay-out, wayfinder switch between different strategies.

4.7 Final comments

In the above discussion/experimentation, the number of maze solving phases, the number of wayfinding strategies and the number of participants, which we have selected for answering the research questions to formulate a set of strategies for navigation, are rather limited. It is very significant that growing number of maze solving phases has close connection with increasing complexity of exocentric information and number of participants. In the behavioral data analysis, we have quantified wayfinding only in terms of finish time and response time. It would be interesting to consider other range of qualitative metrics to quantify close connections between increasing number of solving phases and complexity of exocentric information. It is also expected that increasing number of participants will give clearer picture of association of solving phases and complexity of spatial layout.

The linguistic data analysis demonstrated here is a pilot experiment and validated the general usefulness in description of wayfinding activity and systematic statistical analysis in derivation of wayfinding strategies. We see greater opportunity to further investigate the very rich data provided by retrospective written report, in particular to derivation of wayfinding strategies. Current analysis is discussed under the assumption that the participants used only four types of wayfinding strategies. It seems to be a strong assumption and almost unrealistic. We wish to extend the analysis by collecting data for more wayfinding strategies. The four wayfinding strategies are considered most frequently during wayfinding. That is why we argued that results can be generalized for answering the second research question.

4.8 Chapter Summary

This chapter is about wayfinding in the maze environment. We find out how participants find their way to reach the goal in maze under transitivity of transformation of views as well as changed complexity of mazes. We collected behavioral data as well as linguistic data. Our goal was to gain an understanding by pinpointing two general questions of wayfinding a. Whether wayfinding is influenced by prior exocentric preview even after visual overload view of environment resulting out of change in viewing angle and orientation of target? b. Do overload view of environment lead to switching between different strategies of wayfinding? We evaluate wayfinding under three levels: performance, behavior and rationale level. Through this experimentation, we demonstrated the long-established finding that wayfinding performance is influenced by prior exocentric environment information. We extended this finding and have been able to show that visual overload resulting out of change in viewing angle and orientation of mazes would not distort the exocentric preview of environment information. Apart from this, based on linguistic data analysis, demonstrated that even under transitive transformation of views and spatial lay-out, wayfinder switch between different strategies.