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The Role of Planning and Memory in the Navigational Ability

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***Abstract*—**Navigational ability requires spatial representation, planning, and memory. It covers three interdependent domains, i.e. cognitive and perceptual factors, neural information processing, and variability in brain microstructure. Many attempts have been made to see the role of spatial representation in the navigational ability, and the individual differences have been identified in the neural substrate. But, there is also a need to address the influence of planning, memory on navigational ability. The present study aims to evaluate relations of aforementioned factors in the navigational ability. Total 30 participants volunteered in the study of a virtual shopping complex and subsequently were classified into good and bad navigators based on their performances. The result showed that planning ability was the most correlated factor for the navigational ability and also the discriminating factor between the good and bad navigators. There was also found the correlations between spatial memory recall and navigational ability. However, non-verbal episodic memory and spatial memory recall were also found to be correlated with the learning variable. This study attempts to identify differences between people with more and less navigational ability on the basis of planning and memory.

***Keywords*—**Memory, planning navigational ability, virtual reality.

I. Introduction

SPATIAL navigation is the fundamental behaviour that is shared by each living being of the earth. It is required by living beings from basic needs like survival to a high complex representation of environment like wayfinding. Navigation and memory are so entangled that if one navigates in a familiar territory, then his/her effort to travel become less challenging. One might not able to remember the path travelled by oneself for familiar region because all of his/her motor movements synchronise with the brain autonomously (unconsciously). In the other words, one has developed cognitive map for that location by repetitive movements. Spatial knowledge acquisition is supported by the stage/sequential model in which representation of environment is gained through stages, i.e. (i) landmarks knowledge, (ii) route knowledge, and (iii) survey knowledge which helps in making cognitive map for a particular territory [1] Besides these, it also differs in strategies that can either be landmark-based or direction-based. Path integration is one of the defined strategies which depend on velocity and directions of navigator [2]. Complex representation encompasses both metric like information and path integration for successful way findings. Spatial navigation hence involves activation of multiple brain regions and mechanisms. For example, grid cells and head directional cells located in the entorhinal cortex (MEC) fire when there is a change in velocity and direction integrated over time to allow a constant representation of space [3]. Unlike to grid cells, place cells located in the dorsal hippocampus strongly fire for landmarks only [4]. It indicates that multiple but distinct brain regions are involved in both kinds of strategies, i.e. landmark and path integration. Although a lot of studies were conducted on monkeys and rats [5], [6], recent imaging techniques showed importance of virtual reality in studying navigation for human beings [7]-[9]. One of these studies [9] showed how the brain deals with the changing demands on spatial processing related purely to landmarks. Results indicated that humans were able to flexibly encode location information based on expected spatial cues during retrieval. Result gave cues to associate memory with the locations (landmarks) that can be defined as one of the strategies in the navigation and hence showed that there are some shared brain regions for memory and navigation. In one such study, Buzsaki and Moser [10] pointed out that memory and planning have evolved from mechanisms of navigation, and underlying cortical areas would be in the entorhinal cortex and hippocampus. Extending further, animal studies showed that any lesions in hippocampus, MEC, and Posterior parietal cortex (PPC) can impair navigation [11].

The overall evidence thus implies an essential role for planning and memory in navigation as confirmed by various neuroscience studies. But, none of them so far, have explored the influence of planning and memory on navigational ability. The objective of the study is to identify influence of planning and memory on navigation through designed experiment in virtual environment. Virtual environment has the ability to replicate real life situation in a controlled lab settings and therefore provides an opportunity to control variables.

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II. Methodology

A. Participants and Procedures

30 male participants volunteered in this study (mean age 20). Participants had no history of brain trauma, cardiovascular disorder, recent psychoactive substance abuse, and impaired cognitive functioning. All of them were recruited from Netaji Subash Institute of Technology (NSIT). They gave signed consent form prior to the study.

Participants completed half an hour standard psychological test for planning and memory. Following it, they underwent in a navigation task designed in the virtual reality for the assessment of their navigation skills.

B. Measures

1. Cognitive Test Variables

To measure planning, ecological subtasks derived from the Behavioural Assessment of the Dysexecutive Syndrome test battery [12] were used: the ‘‘Zoo Map Test" and "Modified Six Elements Test". To measure Visuospatial memory, the Brief Visuospatial Memory Test-Revised (BVMT-R) [13] was used.

Zoo Map test: It is a valid indicator of planning ability. In this task, an ability to identify and organise steps and elements that are required to achieve a goal is measured. Participants were given a map of zoo and a set of instructions relating to visit some places in the zoo. Also, they were instructed to follow some rules like 'shaded path can be traced multiple times', 'end journey at the picnic spot', and so on. This was consisted of two versions; in the version 1, participant planned their route as per the instruction and then drew the path from different colours of pen to visit designated places (six out of twelve places). In version 2, everything was similar except sequence of visiting places were provided in an order. Therefore, version 2 had requirements of low resources of planning. This test provides comparison between two versions in the evaluation of participants on the basis of available structure (Formulation Condition versus Execution Condition). Scoring variables included sequencing scores, the total number of errors, and the times taken to plan (thinking time) and execute (drawing time) the routes. In the sequencing scores, sequence points were earned if participants visited places in the correct order, while errors included: paths used more than once, deviations from the paths, failure to make a continuous line, inappropriate places visited.

Modified six elements test (MSET): It examines higher levels of executive function with regard to prospective memory and organisation of behaviour. It consisted of total six subtasks that were required to be completed in 10 minutes. It included two sets of dictation tasks, two sets of pictures that had to be named, and two sets of arithmetic tasks. It should be completed by following one rule in which two parts of same task could not be attained consecutively. Scoring variables included the total number of the subtasks partially attempted in ten minutes, errors (rule was broken or not), and time taken to attempt subtasks.

BVMT-R: It is an assessment tool to measure visuospatial learning and non-verbal episodic memory. It consisted of three learning trials in which six geometric shapes were shown to participant for 10 seconds each. Following each trial, participant was asked to reproduce all figures simultaneously from memory. Each shape was given two points, one point for correct form and one point for correct location. 20-minute break was given to participants in between and after that they were asked to draw all six figures. Scoring variables included learning, total recall, delay recall, percentage retained, and recognition discrimination index. In this study, only 'form 1' was used as stimuli.

2. Virtual Reality Based Navigation Task

This task was designed in the unity 5. This consisted of a two storeys shopping building in which total 10 shops were displayed. Participants were shown the map of the building and were asked to navigate in each shop with the minimum possible time (Fig. 1). Following this, the participant navigated using arrow keys and mouse in the virtual environment displayed in the oculus rift. This phase was termed as 'navigation' phase. In this phase, performance was measured: completion time and number of errors (omission of any shop and double visit of a shop). The performance matrix was further evaluated and divided participants into the good and bad navigators. After completion of the movement, participants were instructed to draw the map as they would have travelled in the virtual environment. This phase was termed as Recall phase. The scoring was done on the basis of four variables; namely, number of shops drawn, alignment of the vertices, presence of stairs, and locations of the shops, accurate representation of spatial relations among locations.

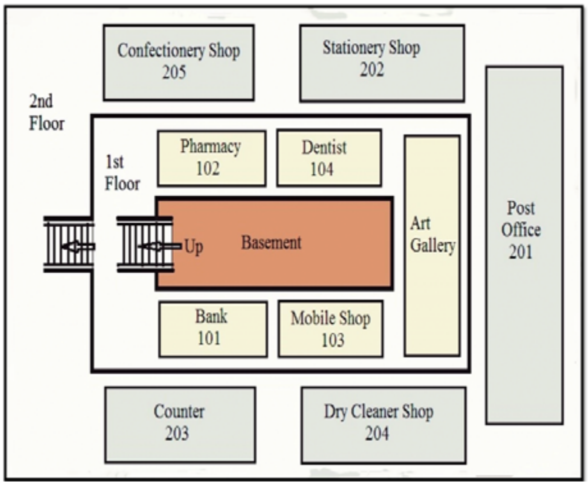

Fig. 1 Map shown to participants before navigation in a virtual environment

III. Result

Statistical analysis of cognitive test variables and virtual reality based navigation task was performed on the R 3.1. Independent sample t-test was applied to find out differences between good and bad navigators for aforementioned measures. There were reported significant differences in zoo map test (Fig. 2), $t(28)=2.93$, $p<0.05$, total recall of BVMT (Figs. 3 and 4), $t(28)=1.98$,$p<0.05$. Pearson correlation was calculated between variables of navigation task and cognitive test measures. Zoo map test and performance matrix of navigation task was found to be highly correlated, $r=0.39$, $p=0.039$. Learning variable of BVMT was found to be highly correlated with the recall score of navigation task, $r=0.482$, $p=0.013$. Recall score was calculated on the basis of points made in the sketch of map (Recall phase). Fig. 5 showed some of the snapshots of the sketches drawn by participants, and Fig. 6 showed distribution of the recall score between good and bad navigators. Bad navigators had more recall scores, Percentage retains (BVMT), and profile scores (MSET).

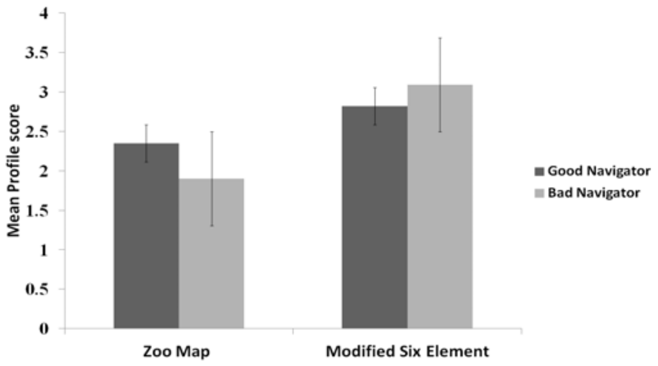

Fig. 2 Mean profile scores for the Zoo Map test and Modified six element test (MSET)

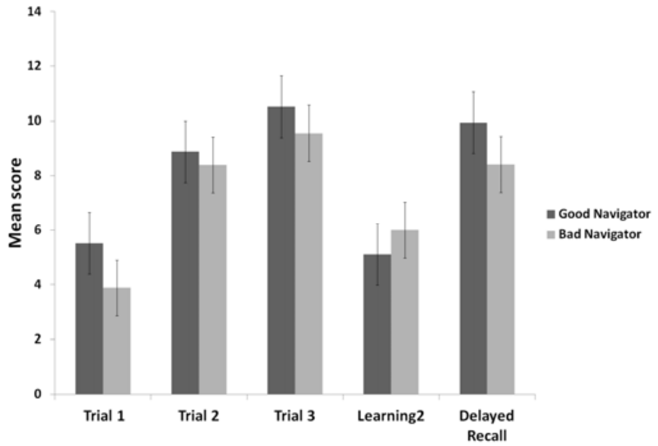

Fig. 3 Scores obtained for BVMT

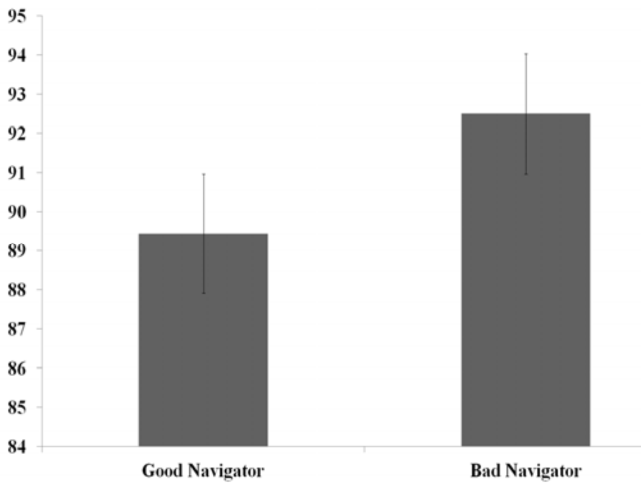

Fig. 4 Percentage retained scores (BVMT) for good and bad navigators

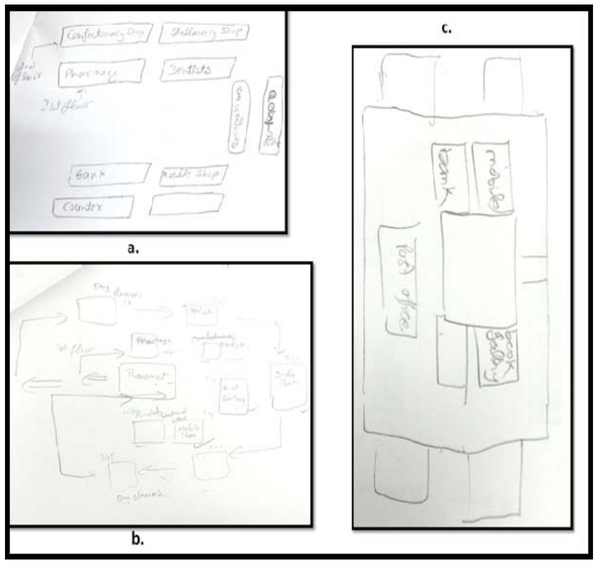

Fig. 5 Sketches of the map as drawn by the participants

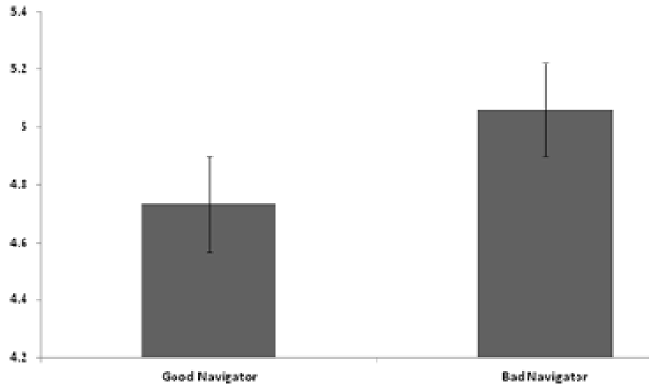

Fig. 6 Recall scores for good and bad navigators

IV. Discussion

Navigation in unknown or familiar terrain is highly influenced by planning and memory. These factors are so much intertwined with the navigation that researchers cannot segregate underlying neural dynamics. Although a lot of studies have focused on identifying the role of spatial skills in navigation [14]-[17], but none of them have segregated the differences. Recent advancement of technology in the field of medical imaging and signal processing in one hand and computer graphics on the other hand unravel the mystery of neuroscience study. For example, under such combination, there has been a feasibility of developing an experiment for the navigation on the platform of virtual reality which would be difficult to carry out in the real environment. The purpose of the study is to explore the influence of memory and planning ability on navigation ability using virtual reality platform. In the other words, if a person is a good navigator then would he/she be having good memory or how planning and memory are correlated with the navigation ability. Results showed that planning ability is highly correlated with the navigation performance (success for reaching goal), while the memory is highly correlated with learning ability (visuospatial learning). However, this study highlighted the individual differences in the mental representation of an environment by dividing groups into good and bad navigators based on the performance matrix of virtual navigation task. It also supported the notion of past researches that were against the stage/sequential models of the adult's constructions of environment representation [14], [15]. In our case, recall scores of bad navigators were found to be higher, which might indicate that successful means of navigation could not predict through accurate representation of an environment. It should be noted that the presented virtual navigation task had a less degree of freedom in rules and goal, which was found to be highly correlated with the classification of the navigators. In the other words, participants were provided with the minimum challenges for completing the task. There could be a situation when there would be a demand of decision making in choosing the shortest path if multiple paths would lead to a single destination. This might reflect the occurrence of more recall scores for bad navigators as challenges were minimum. Our result had shown that zoo map test is highly correlated with the navigation performance, which indicated that Zoo map test is a valid indicator of planning ability. It also showed that bad navigators had lesser capacity to mentally represent complex plans, which showed their poor performance in the virtual navigation task. In contrast, recall score was highly correlated with the learning ability of the BVMT-R. It showed the significant link between learning and mental representation of the environment. It has been mentioned in the previous study that individual differences in visual spatial abilities predict the types of representation made by participants [14]. Participant who drew survey like sketches had a higher visual-spatial ability. While in this study, participant who performed well in navigation task had less 'percentage retained' and 'prospective memory' as indicated by lower scores in BVMT and MSET. It suggested that mental representation did not rely on the navigation performance but to the ability to memorise the location. Therefore, bad navigators had more scores for 'percentage retained'. It provides accurate information about ability to successfully retain learned visuospatial information over a time delay. However, bad navigators who showed more scores in MSET showed their ability to wider executive ability.

In summary, this study points out that to assess navigation ability through a virtual navigation task can become a valuable asset to measure navigation ability. Altogether considering the other cognitive abilities like planning and memory also has common shared neural networks which can influence navigation ability. This study identified planning ability as an influential variable for navigation ability especially, through zoo map test. Non-verbal memory showed influence on the learning variables; therefore, participants who were classified in the bad navigators, had shown better percentage retained and prospective memory (MSET scores). Learning was found to be correlated with the recall score (ability to mentally represent the environment) which also found to be higher in the bad navigator. It shed lights on the restatement of the problem about how cognitive processes for memory and navigation can be segregated through carefully designed study.

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