Virtual Reality in Cognitive Rehabilitation

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Abstract*—The studies of topographic disorientation from brain injury focus on describing impairments, specifying neuroanatomical correlates of topographic disorientation, and categorizing types of topographic disorientation. Models of environmental cognition have been applied in some studies of topographic disorientation. The study is done here to develop a system that analyses the spatial behaviour of the individual and train the ones with poor spatial visualization and navigation skills in an optimal way so that they can maintain orientation during navigation. Virtual Reality provides the best tool for the rehabilitation and assessment of topographical disorientation. Therefore, using virtual reality technique, a virtual environment has been created as the part of study and the subjects have been exposed to it in order to treat the spatial impairment. For creating the virtual environment, Unity Game engine is used.*

Keywords — *Virtual Reality, Topographic disorientation, cognition, virtual environment*

I. INTRODUCTION

Spatial orientation impairment is a very common consequence of brain damage. It reduces the quality and anatomy in daily life of neurological patients. With the help of Virtual Reality technique, simulated virtual environment has been created, in which egocentric disorientation or allocentric disorientation can be assessed more precisely. VR offers a simulating realistic spatial navigation under controlled experimental conditions in comparison to the traditional assessment methods for example paper and pencil measures. In the present study, a VR based verbally guided navigation program and visually guided navigation programs are designed. In the first program the individual is been exposed to the audio which guides him through the infrastructure of the virtual environment. The second program of visually guided navigation shows the map of virtual environment to the individual, with the help of which he needs to navigate in the virtual environment.

II. MOTIVATION AND GOAL

Virtual reality (VR) is a computer-simulated environment that can simulate physical presence in places in the real world or imagined worlds. Virtual reality can re-create sensory experiences, including virtual taste, sight, smell, sound, touch, etc. Most current virtual reality environments are primarily visual experiences, displayed either on a computer screen or through special stereoscopic displays, but some simulations include additional sensory information, such as sound through speakers or headphones. The simulated environment can be similar to the real world in order to create a lifelike experience—for example, in simulations for pilot or combat training—or it can differ significantly from reality, such as in VR games. In practice, it is currently very difficult to create a high-fidelity virtual reality experience, because of technical limitations on processing power, image resolution, and communication bandwidth. However, the technology's proponents hope that such limitations will be overcome as processor, imaging, and data communication technologies become more powerful and cost-effective over time.

To characterize the cognitive processes engaged during dynamic way-finding in large-scale space a virtual environment *'Square Plaza'* is made to analyse and enhance cognitive skills of the individual. In the virtual environment the subject will come across with various tasks which are to be accomplished in the minimum time. As far as verbal and visuo-spatial learning is concerned, a different task is assigned for it. Visuo-Spatial or Spatial memory is the part of memory responsible for recording information about one's environment and its spatial orientation. For example, a person's spatial memory is required in order to navigate around a familiar city.

The ability to familiarize oneself within the environment is essential in our everyday life. The aim of this study is to develop a system that uses specific physiological test, a virtual environment and electrophysiological computing to analyse the spatial behaviour of the individual and train the ones with poor spatial visualization and navigation skills in an optimal way so that they can maintain orientation during navigation.

III. BACKGROUND THEORY

A severe and persistent impairment of spatial orientation and navigation is Topographical disorientation (TD). It is also a common consequence of brain damage and can happen in familiar as well as new environments. [2]

Topographical orientation in humans is a very complex brain function. It basically relies on different approaches used by individuals to move in the environment and on the familiarity with the different features of the environment. Such a complex and multi componential skill involves the combination of various different cognitive abilities and, accordingly, does involve several neural systems. Thus, brain injured regions that influence various different cognitive functions involved in

orientation can product in several topographical orientation disorders that are very disabling in everyday life. The individuals affected by topographical disorientation are not capable to orient themselves in the environment or to recognize, illustrate or discover pathways, even in familiar surroundings. [3]

A. *Classification of Topographical Disorientation*

Topographical Disorientation can be classified into five:

- ***Developmental Topographical Disorientation (DTD)***
  DTD is a cognitive disorder, which is characterized by the incapability to isolate landmarks for deriving navigational information from it or producing cognitive maps. The individuals with DTD get lost in very well-known surroundings, such as their own house.
- ***Egocentric Disorientation***
  It is characterized as the lack of ability to represent the object's location with respect to the self. The individual finds no intricacy in recognizing the objects or names of the people but they are unable to state the relationship between two objects for example left, right, above or below.
- ***Heading Disorientation***
  It is characterized as the lack of ability to represent the direction of orientation with respect to the external environment. Individuals, with the help of landmarks are able to decide their location but are not capable in determining which direction to carry on from those landmarks so as to reach their destined location. They are also weak in map drawing task.
- ***Landmark Agnosia***
  It is characterized as the lack of ability to recognize significant environmental stimuli for example – landmarks. Individuals can differentiate between different types of buildings for example – house or mall, but they are not capable to identify particular buildings for example their house or some famous landmark. Individuals are able to draw detailed maps easily.
- ***Anterograde Disorientation***
  It is characterized as the lack of ability to orient in new environments.

B. Virtual Reality

Virtual reality, integrates real-time computer graphics, body tracking devices, visual displays and other sensory input devices to immerse patients in a computer generated virtual environment [1].

Virtual Reality originally explains experiments in the simulation of artificial generated elements that could be used to fool human perception. In 1968 Ivan Sutherland created the first virtual reality and augmented reality (AR) head-mounted display (HMD) system with the help of his student Bob Sproull. Ivan Sutherland also founded the first virtual world in the same year which was popularized later in 1980s by Lanier. [9]

The cost of virtual world was very high in the beginning which eventually degraded with the rapid growth of the technology and the virtual world became affordable to many users.

The technology development will grow with the time and thus will result in lower cost and more application in different fields.

The different categories of VR are *Artificial Reality, Augmented Reality, Fish tank* and *Simulated Reality*.

Artificial Reality: Artificial reality was the term used by **Myron W. Krueger** to describe his interactive immersive environments which was based on video recognition techniques that place the user in full, imaginative contact with the digital world. *"An artificial reality perceives human events in terms of the relationship of the body to a simulated world. Then it generates sounds, sights and other sensations that create the illusion of participating in that world convincing."*

Myron Krueger established an artificial reality 2 dimensional Video place medium from the years 1974 to 1985, and used it as an interface to both 3 dimensional and 2 dimensional applications [4].

There are no real world applications based on this category of virtual reality yet.

Augmented reality: It is a system that combines computer generated data and the real world. Here the user experiences an environment with both virtual reality and real world elements [5]. AR basically complements reality rather than completely replacing it.

Augmented Reality as systems have following three characteristics [5]:

- Interactive in real time
- Registered in 3 dimension
- Combines real and virtual

Fish Tank VR: It is basically used to describe desktop systems that display stereo image of a 3D scene, which is viewed on the monitor using perspective projection coupled to the head position of the observer. In the Fish Tank VR user can see the entire volume on screen and can even rotate it to view from different perspectives. The performance can be measured by response time and accuracy.

Simulated Reality: It is an approach that combines scientific or technical simulation and optimization techniques with modern visualization and interaction methods [6].

Simulated Reality is the reality that could be simulated to a degree that the computer simulated world could not be distinguished with the real world. Where Virtual Reality can be easily distinguished from the experience of *"true"* reality, the Simulated Reality would be hard or in fact impossible to distinguish from *"true"* reality.

IV. LITERATURE REVIEW

The project is aimed at utilizing virtual reality as a non-invasive intervention for the research on "Cognitive Enhancement". The study is done to examine the physiological responses and spatial visualization which are collected during the route learning and navigation task in the virtual environment. The subject is first been exposed to the map of the whole virtual environment, in this case Square Plaza. The subject is then asked to navigate the whole Plaza and every shop in it. Various tasks are then given in the virtual environment which the subject needs to accomplish while his physiological responses are been collected. Such cognitive training can be used to provide a route learning scenario and test the subject's route knowledge with the help of navigation task. Also, various tasks given in the environment is used to test the planning skills of the subject.

This project would not only benefit the training regimen for defence personnel as it would enhance their reasoning, attention, planning, decision making, memory and sensory input processing abilities, but would also contribute to the treatment of Navigating persistent mental illness i.e. topographical memory deficit, profound verbal and visual memory deficit in individuals.

The non-invasive interventions used in the project are psychological tests, music and virtual reality technology. And the electrophysiological computing can be done through EEG.

A. A Brief Review

- **Brain**

The brain controls and co-ordinates everything we do. Its main purpose is to receive messages, process those messages and respond to them. The responses generated by the brain allow us to think, move, and breath, speak, show emotion and regulate all of our other bodily functions.

The brain forms a part of our central nervous system. It is a soft jelly-like substance weighing about three pounds on an average and sits inside the skull, cushioned by a liquid known as cerebrospinal fluid. Although the brain only accounts for two percent of body weight, it uses twenty percent of the body's oxygen supply and blood flow [14].

Our brain is made up of billions of brain cells. Some cells, known as neurons are responsible for carrying messages to and from the brain. Other cells, known as glia provide the support structure for the neuron.

Neurons require oxygen to function, and begin to die within 3 to 5 minutes without it. The neurons themselves are quite fragile and need extensive protection from being crushed, infected or other harm. The long fibrous parts of the neurons, called axons are prone to tearing when the brain is injured by sudden movements such as those occurred during car accident. This can result in injury known as diffuse axonal injury [14].

Despite being protected by the thick boned of the skull, suspended in cerebrospinal fluid, and isolated from the bloodstream by the blood-brain barrier, the human brain is susceptible to damage and disease. The human brain is also susceptible to degenerative disorders. A number of psychiatric conditions are also associated with brain dysfunctions.

The memory of our Brain is processed in stages:

Encoding
(Transforming sensory information into meaningful memory)

↓

Storage
(Creating a biological trace of the encoded information in memory, which is either consolidated or lost)

↓

Retrieval
(Using the stored information)

- **Cognition**

"How Brain transform Brain Information into action."

The word cognition means a process of knowing, including aspects such as awareness, perception, reasoning and judgment. It is also the mental act or process by which knowledge is acquired, including perception, intuition, and reasoning the knowledge that results from such an act or process.

Cognitive Science examines the mental functions that give rise to information processing, termed cognition. These include attention, memory, producing and understanding language, learning, reasoning, problem solving and decision making. Cognition science seeks to understand thinking in terms of representational structures in the mind and computational procedures that operate on those structures.

Cognitive skills are any mental skills that are used in the process of acquiring knowledge; these skills include intuition, reasoning and perception. Humans generally have a capacity for cognitive function once born, so almost every person is capable of learning or remembering. "Reading and writing rely on a specific set of cognitive skills such as attention, memory, symbolic thinking, and self-regulation. Deliberate attention is required to differentiate between letters, even if they look alike, and to isolate specific portions of a word for encoding or decoding it.

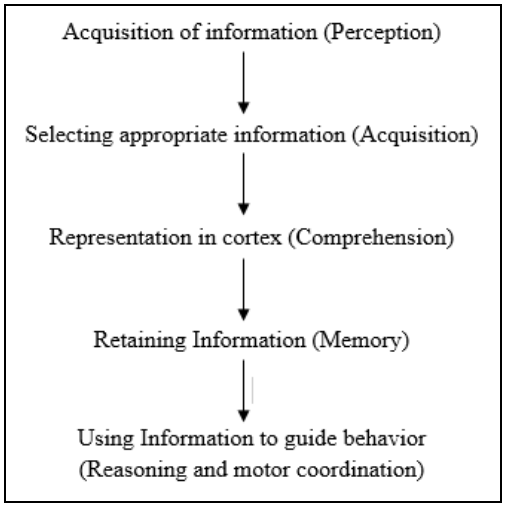

Fig. 1 Cognitive Processing

- **Spatial Navigation**

Spatial Navigation is simply the ability to navigate in the environment with the help of visual information about spatial relations between objects or their parts and, perform mental spatial transformations and manipulations. The ability to familiarize oneself within the environment is essential in our everyday life. Maintaining and memorizing the track of landmarks and directions during navigation requires the uptake and integration of polymodal sensory information, additional processing of spatial information within different frames of reference, and computation of a spatial representation of the environment traversed.

For this research topic, the roles of working memory for both people with poor sense-of-direction and people with good sense-of-direction are examined, and the differences between the two groups are discussed. Furthermore, basing on the results of the above research, the influence of spatial strategies and processes biases on spatial learning are examined and deeper understanding is achieved in human's spatial behaviours.

The research focuses on examining the dissociation between the two types of spatial imagery transformations: allocentric spatial transformations, which involve an object-to-object representational system and encode information about the location of one object or its parts with respect to other objects, versus egocentric perspective transformations that involve a self-to-object representational system.

The study examines, individual differences in egocentric (imagining taking a different perspective in space) and allocentric (mentally manipulating objects from a stationary point of view) spatial abilities, and develop assessments of these abilities .The research also seeks to discover the relation of these two types of spatial ability to locomotion and spatial navigation.

- **Virtual Reality**

The fully immersive technologically mediated dream worlds, rendered mind spaces where you literally inhabit another world. Terence McKenna says, these technologies (oculus rift) will allow us to share our dreams with one another. Everybody will have essentially a cosmos of the imagination where they can build cathedrals of the mind.

In order to capture the true dynamism of real navigation while maintaining some degree of stimulus control, a fully immersive computer simulated virtual environment has been used to study navigation. Navigation is performed on the basis of visual information. The virtual environment used in the study has been named “Square Plaza”. This mall consists of a basement and two floors, each having five shops.

V. METHODOLOGY

The relevant information on the Topographical Disorientation subject was gathered from internet sites, articles, and research papers. From all the collected material, the information necessary to facilitate the design of virtual environment for the treatment of TD was extracted. Neurological patients with focal lesions showed deficit in spatial orientation [2]. The main elements included in virtual environment, which can help in treating the subject are: Planning done for navigating the environment, route finding when a task is given to the subject and finally before exiting the environment the subject should relocate the starting position. The subject will learn and recall different routes for navigation in the virtual mall. General spatial abilities were assessed with standardized neuropsychological tests, before and after VR assessment and training.

To realize this virtual environment, few stages have to be gone through. The stages of method are:
In the first stage the requirements are analysed. In the second stage an analysis is constructed. The functionality of the proposed system is also included here. In the third stage, specifications are met. A global design is drawn up. In fourth stage, implementation is done. Finally, the system is evaluated. Evaluation is actually done during the whole process. The final evaluation is an experiment of the prototype.

The objective of the evaluation of system is to test whether it meets the requirements and specifications and whether the virtual environment can serve as a useful prototype for future research projects.

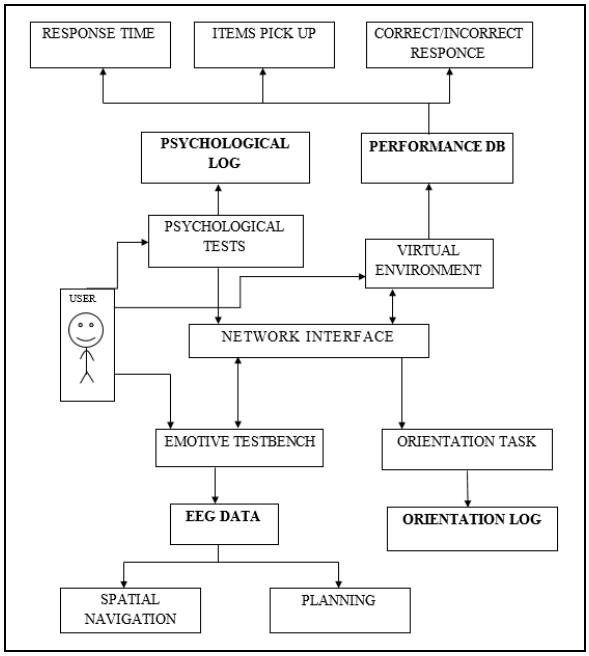

Fig. 2 Proposed System Model

VI. RESULTS

A Virtual Environment named "Square Plaza" is created with the help of 3DS Max, Blender, Unity Game Engine and MS Paint.

A. *Blueprint of Square plaza*

The basic blueprint of the Square Plaza is made in Paint software. It is also used as *"map of square plaza"* in the environment later.

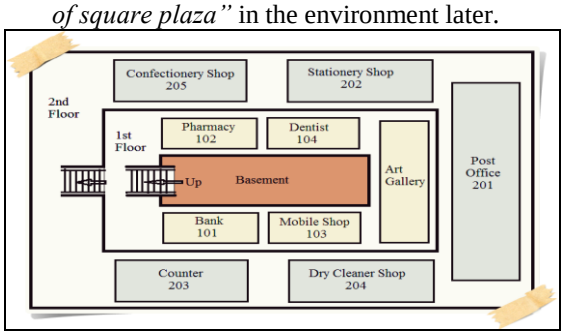

Fig. 3 Blueprint of Square Plaza

B. *Shops Designed in Square Plaza*

Taking the reference from the blueprint, all the shops (as stated in the requirement section with the shop numbers) are designed with the complete mall structure. Snapshots of some of the shops are shown below:

Fig. 4 Stairs leading to the first floor of Square Plaza

These stairs were first designed in 3ds Max and then imported in unity3D to give a look like you can see here in the figure above.

Fig. 5 Bank in Square Plaza

Fig. 6 Mobile Shop in Square Plaza

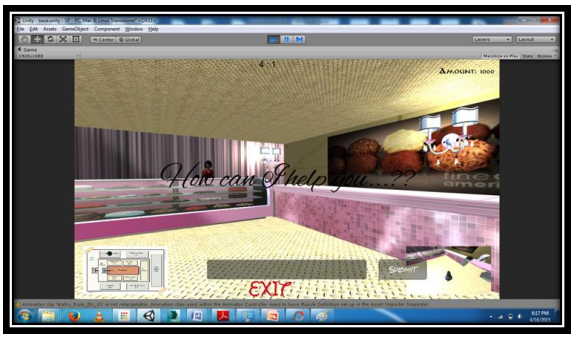

Fig.8 Confectionery Shop in Square Plaza

Below, the figure shows the main menu of the Square Plaza

C. *Storing Player's Information*

The information of the player i.e. total time taken in navigating, performing the tasks in the environment and the track of task completed is stored in a text file. When the new player enters the environment then his information is simply appended to the previous player's information.

The performance log is maintained though the virtual environment. The information of the player is recorded with the response time i.e. the time taken by the subject in navigating and completing the task is recorded. Also, the item pickup data is maintained in this log.

It is seen that the person with no TD or good navigation skills was able to navigate in the virtual environment in the shorter time interval than the

ones who suffered from TD. Also, they remembered and picked up almost all the items in comparison to the ones with TD persons.

Below, the data maintained from the Square plaza in the text file named ***SPdatabase.txt*** is shown.

--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--

Name : Aakarsh
Age : 21
Gender : Male
Profession : student
Item 1 : 2 file folders
Item 2 : 1t car plug
Item 3 : srawberry pastery
Item 4 : NOTICE : Paper 'X' will be launched by 15.01.2016
Time Taken - 10 : 1

--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--*--

Name : Raghav
Age : 22
Gender : Male
Profession : Student
Item 1 :
Item 2 : car plug
Item 3 :
Item 4 : NOTICE : Paper 'X' will be launched by 15.01.2016
Item 5 :
Item 6 : NOTICE : Doctor is not present. Please come next time...
Time Taken - 13 : 1

VII. CONCLUSIONS

Visually guided and verbally guided passive navigation process in VR enhances the general spatial cognition in neurological patients with spatial disorientation and is useful in rehabilitation of spatial impairment associated with TD.

Creating a virtual environment of a public place like a mall is best suited to the needs in assessing the subjects. The subject comes across with various tasks in the environment which is to be completed by him in the minimum time period. Meanwhile, the performance of the subject is also getting stored and his brain signals are been captured for further analysis of his cognitive abilities. The significant level of the recorded results of subjects gives the validation point of virtual environment to various psychological tests.

In VR the spatial way finding training may provide a valid ecological rehabilitation method of spatial impairments.

VIII. FUTURE ENHANCEMENT

The application of VR to neurocognitive assessment is considered by a growing body of researchers to be distinctively important because it represents the potential for more than a simple linear extension of existing computer technology for human use.

We can further capture EEG brain signals via emotive Testbench or any other device and use these signals to locate the active part of brain when the subject is navigating or performing some other task in the environment.

This virtual environment is currently used for assessing the subjects. It can be taken one step further and can be used for training the subjects who shows signs of TD in enhancing their spatial disorientation.

Many different real time simulated environments of different places other than mall can be created to train the individuals with Topographical disorientation.

Virtual Reality is still rapidly growing and generating great expectations. This research can be used further to estimate the best approach between allocentric and egocentric approaches and train the brains of the military people accordingly.

With few modifications in the environment, this project can be used to treat different neurocognitive problem.

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