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Design of a Virtual Reality Navigational (VRN) Experiment for Assessment of Egocentric Spatial Cognition*

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Abstract— **Virtual reality (VR) experiments are commonly used to assess human brain functions. We orient ourselves in an environment by computing precise self-to-object spatial relations (egocentric orientation) as well as object-to-object spatial relations (allocentric orientation). Egocentric orientation involves cues that depend on the position of the observer (i.e. left-right, front-behind), whereas allocentric orientation is maintained through the use of environmental features such as landmarks. As such, allocentric orientation involves short-term memory, whereas egocentric orientation does not. This paper presents a Virtual Reality Navigational (VRN) experiment specifically designed to assess egocentric spatial cognition. The design aimed to minimize the effect of spatial cues or landmarks for human navigation in a naturalistic VR environment. The VRN experiment designed for this study, called the *Virtual House,* is a symmetric three story cubic building, with 3 windows on each side on every floor, and one entrance on each side of the building. In each trial, a window is marked by a pseudo-random sequence as the objective. The marked window is shown to the participant from an outdoor view. The task is to reach the objective window using the shortest path through the building. The experiment entails 2 sets of 8 trials to cover all possibilities. The participants' performance error is measured by the difference between their traversed distance trajectory and the shortest natural distance (calculated using the VR engine), normalized by the shortest distance, in each trial. Fifty-two cognitively healthy adults participated in the study. The results show no learning effect during the 16 trails, implying that the experiment does not rely on short-term memory. Furthermore, the subjects' normalized performance error showed an almost linear increase with age, implying that egocentric spatial cognition ability declines with age.**

I. Introduction

Over the past decade, due to the advancement in computing power, Virtual Reality Navigational (VRN) experiments simulating aspects of the real world have gained more popularity. One of the areas of interest for researchers is to employ VRN experiments to assess the brain's functionality and cognition [1].

Virtual Reality (VR) offers repeatability, accuracy and flexibility to modify the testing environment. In contrast, modifying natural environment platforms for studying cognition and brain functions is costly, time consuming and in some cases not feasible. A VR environment also allows for repetitive testing that may not be feasible in a natural environment. Moreover, monitoring movement parameters, such as positioning and trajectory, for a participant in the natural world is fairly sophisticated, while in a VR environment it is considerably easier. In this paper, we report on a novel VRN experiment designed for spatial cognition assessment.

Spatial cognition is the perception of space, distance, depth, etc. Generally, it is perceived through visual and somatosensory information. Visual observation delivers the person a view of the world, which contains egocentric and allocentric spatial representation. In egocentric spatial representation one's localization is based on self-centric observation, as well as cues that depend on one's position (i.e., left-right, front-back). In contrast, allocentric spatial representation is constructed through the use of ambient landmarks, distances, and the relation between objects [1]. In natural world navigation, in addition to visual observation, other sensory perceptions such as auditory and vestibular (inertial based), sustain the egocentric spatial representation [2]. One normally uses both types of spatial cognition to navigate. However, it has been shown that in the lack (or perturbation) of landmarks or cues, one has to rely more on egocentric orientation [3]. Furthermore, it has been shown that spatial cognition ability declines with age [1].

Recently, our team showed that egocentric orientation capability changes significantly with age [4]; the psychophysical experiment used in that study was a 2D game with 4 rotating destinations. In this study we designed a novel 3D VRN that mimics human navigation in the natural world.

The navigational VRN experiment used in this project is a first person view simulation of an observer who enters a three story building, called the *Virtual House*; it is designed with minimum landmarks (or perturbed landmarks) such that the participant's navigation is mostly reliant on egocentric orientation ability. Our goal has been to design a naturalistic VRN experiment to assess human navigational performance, in particular the egocentric orientation capability. We tested the Virtual House design by evaluating the performance of people in different age groups. We also investigated whether or not there was a learning effect as a result of repetitive navigational tasks (different trials). Since egocentric orientation does not rely on short term memory, ideally, the navigation performance in the designed Virtual House should not be affected by repetition.

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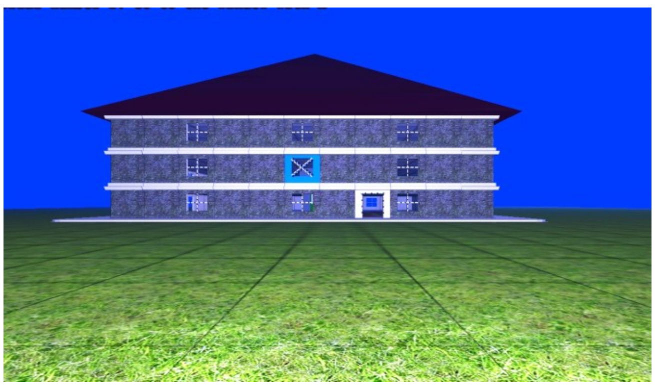
II. Method

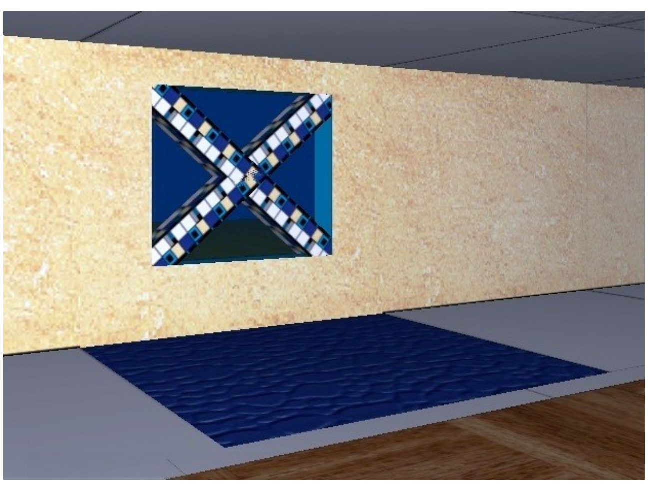
A. VRN Experiment design

The VRN experiment designed for this study is a custom made simulation of a three story house (cubic building), called the *Virtual House*. The design of the house is symmetric from all the four sides. Each side of the house has an entrance and 3 windows on each floor. Each of the windows on the 2nd and 3rd floors can be selected as an objective window by the VR engine of the experiment.

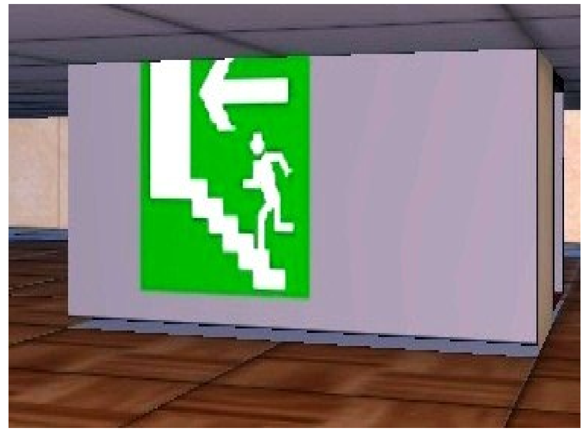
Out of the 24 windows (4 sides, with 3 windows on each side of the 2nd and 3rd floors), one window is selected as the "objective window" by a pseudo-random sequence. The selected objective window is randomly marked with either a triangle, a cross or a circle. Inside the house there are two staircases leading to the higher floors. The participant will be guided to the staircase by the sign shown on the side wall of the staircase. Figure 1, shows three views of the Virtual House.



(a)



(b)



(c)

Figure 1. a) Outdoor view of the Virtual House
b) An example of an objective window
c) Staircase sign, guiding the participant

The development of the Virtual House was performed under Microsoft® Visual Studio by using C++ and OpenGL capabilities. The simulation wraps the environment using textures which are obtained from real world photos. Moreover, Nvidia's PhysX Engine was employed to mimic gravity, friction and other realistic physical effects. All these elements are employed to provide a naturalistic environment for the participant.

While the simulator is running, a log file collects the parameters of the environment at a 1 kHz sampling rate. The environment parameters contain the elapsed time, navigation course (heading angle), position and traversed distance. In addition, the minimum required distance in order to reach the objective window is calculated and stored for each trial. The traversed distance for each participant is obtained by integrating the displacement of the participant in the virtual reality. Figure 2 shows a trajectory of the displacement for one trial obtained from one of the participants. The trajectory shows the locations visited by the participant in the VRN experiment from the starting point toward the objective window.

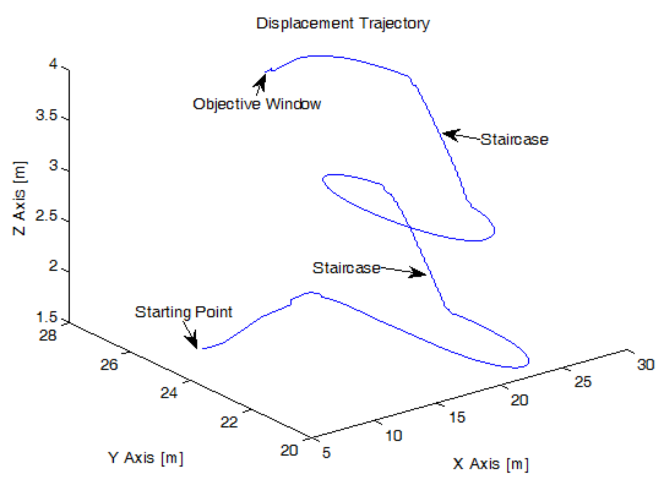


Figure 2: Displacement trajectory

The VRN experiment is executed multiple times using a batch file. There is also a command line of execution parameters that allows setting the position of the objective windows. This allows for the implementation of the pseudo-random sequence for the objective window in the designed VRN experiment.

Using a cordless joystick (Logitech Freedom 2.4 GHz), the participant is asked to enter the Virtual House, and to find the shortest path to the objective window. The window is specified at the top left corner of the screen in each trial; this info remains visible to the subject during the entire course of the trial.

B. Study Subjects

The designed Virtual House was tested on 52 cognitively healthy individuals (25 females) with an age range of 19-82 years. The VRN experiment was performed at the Virtual Reality Centre of the Industrial Technology Center (Winnipeg, Manitoba, Canada). The study was approved by the Biomedical Ethics Board of the University of Manitoba prior to the experiments. All subjects signed a consent form prior to the experiment. The cognitive level of the subjects was tested through the standard Montreal Cognitive Assessment (MOCA) questionnaire [5], in which a score of greater than 26 out of 30 is considered to be normal; all participants were within the normal cognitive range.

B. Protocol

Before performing the test, the participants were allowed to practice moving around the Virtual House. After becoming familiar with moving in and out of the Virtual House, each participant performed the experiment (reaching an assigned objective window) in 16 different trials. The only instruction given to participants was to approach the objective window using the shortest path that they perceived.

Before participants started, the objective window was shown to them by rotating the Virtual House, such that they were able to see the location of the objective window from outside the house. After the first 8 set of trials, the participants were allowed to rest for about 10 minutes before starting the second set of trials (trials 9 to 16). Each set of the 8 trials covered the eight different possibilities of the objective window location (2 floors, each with 4 sides). It should be noted that the two sets of 8 trials were identical in terms of assignment of the objective window; for example, in each pair of trials, such as 1&9, 2&10, 3&11, etc., the objective window was on the same side of the house and on the same floor.

The participant's performance error was measured by calculating the difference between the participant's traversed distance and the minimum distance required to reach the objective window, which was calculated by the designed VR engine. This difference was called the traversed distance error, and was normalized by the minimum desired distance in each trial.It should be noted that the minimum desired distance is not the Euclidean distance between the starting point and the objective window, rather it is calculated from a naturalistic trajectory that undergoes all the terrains, doors and staircases in the Virtual House. This was computed by segmenting each part of the Virtual House, calculating the minimum possible traversed distance, and adding the minimum distance of different desired traversed distances for each running trial. Finally, the error was normalized with respect to the maximum desired traversed distance and the median of the 16 trials was chosen as the indicator for the spatial cognition performance of the subject.

III. Results

Figure 3 shows the normalized performance error of the subjects sorted by their age, which reveals almost a linear trend between performance error and age. Figure 4 shows the normalized traversed distance error averaged between the participants in three different age groups (<40 y, 40 <age< 60 and 60+y) in each trial. This plot helps to see if there was any learning as a result of repetition of the experiment. Note that the starting point and the objective window of trials 1&9, 2&10, 3&11, etc., are the same. As can be seen, there is no learning effect, and therefore, no effect of short-term memory in this VRN experiment.

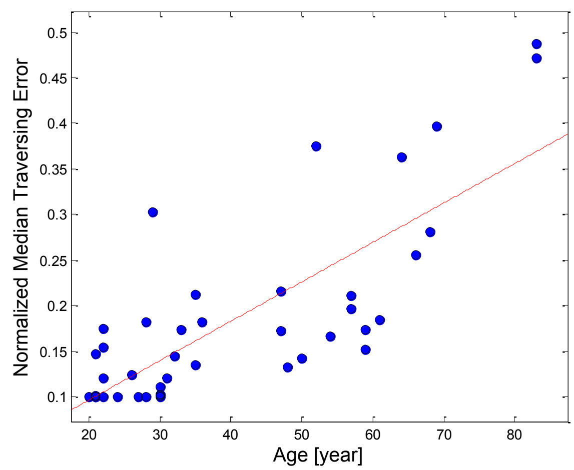


Figure 3: Median value of the normalized performance error (over the 16 trials) of the subjects versus their age.

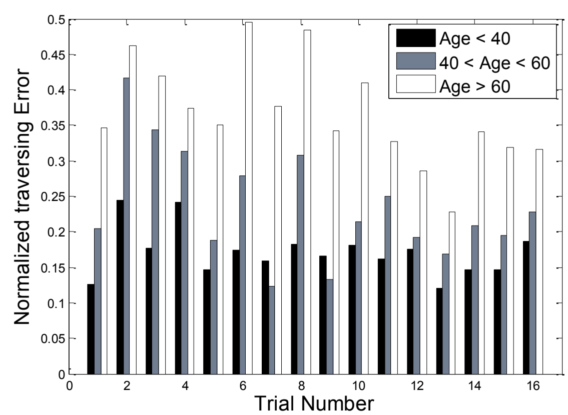


Figure 4. Normalized traversed error of the 16 trials averaged between the subjects in the three different age groups.

IV. DISCUSSION

This work shows that virtual reality can be used to evaluate human's spatial cognition, particularly the egocentric orientation using a naturalistic simulation. It has been hypothesized that the egocentric spatial representation declines with age [4]. Therefore, our VRN experiment, the Virtual House, was designed mainly to measure egocentric orientation performance.

Our designed Virtual House is a symmetric cubic house with minimal landmarks. It is impossible to design a test with absolutely no landmarks; for example the staircase can be considered a landmark. However, we designed two staircases placed in the middle of each floor to reduce their effect as landmarks, and thus perturb the allocentric orientation. Furthermore, the number of windows on each side of the house and on the two floors is exactly the same.

In the beginning of each trial, the objective window is shown to the participants from outside of the house by rotating the house 360 degrees (i.e., the house with the objective window will be rotated in front of the observer). The subject is expected to remember where the target window is located, and subsequently enter the house and reach the target window. The objective window is marked by a geometrical shape like a triangle or circle. The name of the objective window is written on the top of the screen during the trial. This is done so that the subject does not have to rely on memory in order to remember which window to reach, they need only orient themselves correctly in terms of the location of the window to reach it with minimum distance. Therefore, we claim that the trajectory of the subjects' movement in the Virtual House represents their egocentric orientation capability.

If a participant begins to wander about the Virtual House to find the objective window, the traversed distance will increase. For this reason, the difference between the traversed distance and the minimum required distance was selected to measure the performance error. The result in Fig. 3 clearly shows that the performance error increases with age almost linearly. This is congruent with previous studies [1], where 86% percent of younger participants were shown to be able to reach the target while only 24% of the elderly subjects were able to succeed [1].

In order to investigate whether there was a learning effect as a result of repetitive trials, we calculated the performance error of the subjects for every trial. As can be seen in Fig. 4, there is no trend of learning throughout the trials. This was desired, as we aimed to design the experiment for only egocentric orientation. If there were any landmarks, the learning effect would be expected.

Overall, the results are very encouraging, and hold promise to be investigated for use as a diagnostic tool to assess the brain's spatial cognition in healthy individuals and those at the onset of dementia.

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